INNOVATIONS IN SOLAR PHOTOVOLTAIC (SPV) TECHNOLOGY IN INDIA: THE MODE 2 KNOWLEDGE PRODUCTION PERSPECTIVE

A Thesis submitted to the University of Hyderabad in partial fulfilment of requirement for the award of the Degree of

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IN

SOCIOLOGY

BY

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DECLARATION

I hereby declare that the research embodied in this thesis titled: ***'Innovations in Solar Photovoltaic (SPV) Technology in India: The Mode 2 Knowledge Production Perspective'***, is an original work carried out by me under the supervision of Professor, E. Haribabu, Department of Sociology, University of Hyderabad, for the award of degree of Doctor of Philosophy in Sociology.

I declare to the best of my knowledge that no part of this thesis was earlier submitted for the award of a research degree or diploma in any other University.

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CERTIFICATE

This is to certify that the thesis titled: ***'Innovations in Solar Photovoltaic (SPV) Technology in India: The Mode 2 Knowledge Production Perspective'***, submitted by **Mr. DEVARAJ. P**, for the award of the degree of Doctor of Philosophy in Sociology, is a record of bonafide and independent work carried out by him under my supervision and guidance.

This dissertation has not been submitted either in part or in full to any other university or institution of learning for the award of any other degree.

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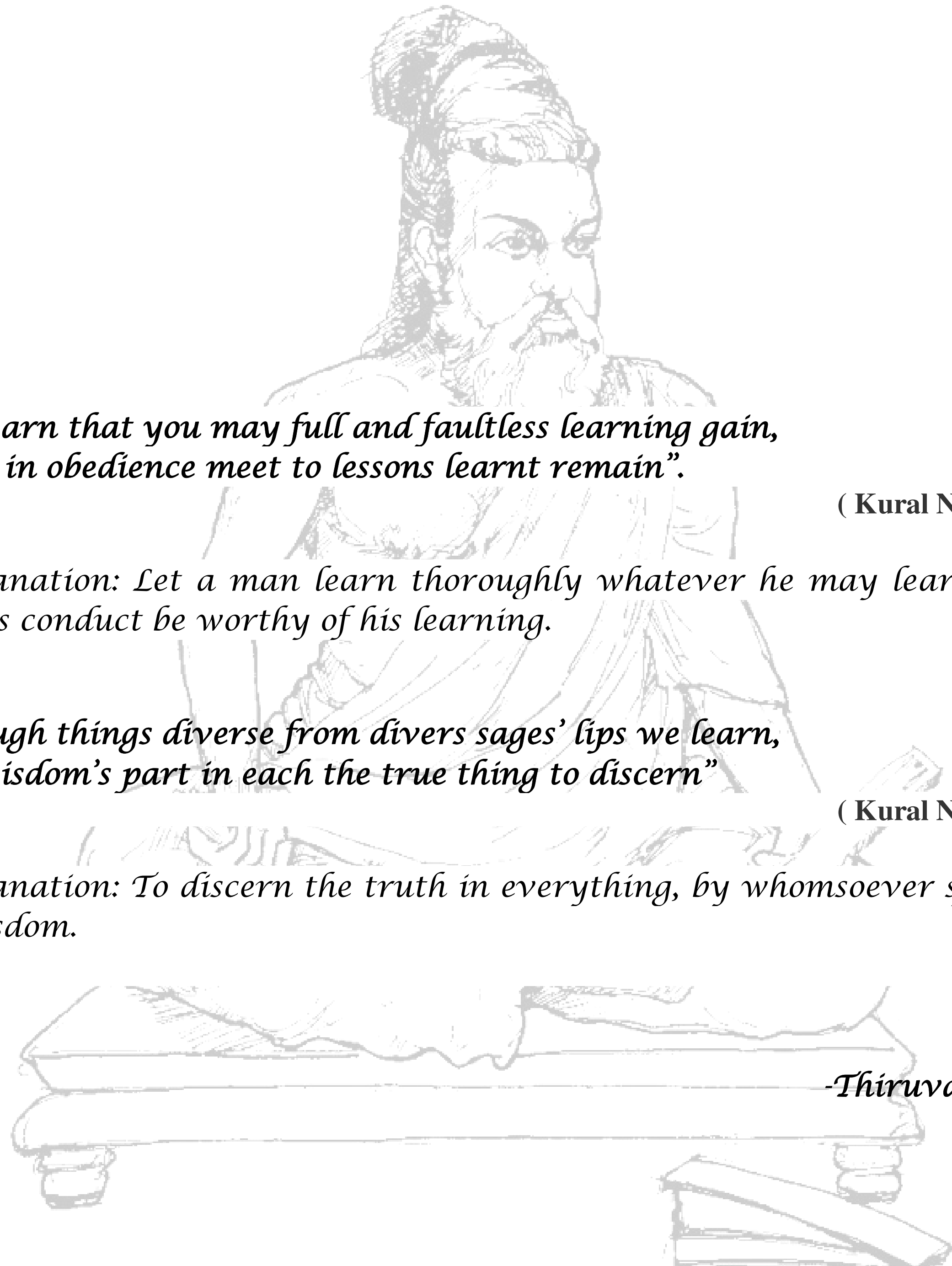

"So learn that you may full and faultless learning gain,
Then in obedience meet to lessons learnt remain".

(Kural No : 391)

Explanation: Let a man learn thoroughly whatever he may learn, and let his conduct be worthy of his learning.

"Though things diverse from divers sages' lips we learn,
Tis wisdom's part in each the true thing to discern"

(Kural No : 423)

Explanation: To discern the truth in everything, by whomsoever spoken, is wisdom.

-Thiruvalluvar

CONTENT

Acknowledgement

From my childhood days, I have never thought and dreamt of research and teaching as my career. Either I was afraid of it or it was not my liking. I always wanted to be a sportsman (especially a good cricketer and an athlete). Neither of my dreams was fulfilled. Often, we don't know what our real abilities are or we don't even realize our strength and weakness. Within this we don't even understand ourselves. However, there are certain situations or even life conditions which make us to rethink who we are and what the goals of our life are. That is the moment, which takes energy out of our body and rejuvenates with a new metamorphosis of energy into our mind and thought. Here, our ***spirit regains power****. In the same way, the thought and dream, about research and teaching, have been in an unconscious mind until I joined my M. A. programme in Sociology. This structure has nothing to do with any kind of inspiration to work, at the level of research and teaching, the social space provided me to rethink what I am and what my goals are all about. My inspiration to teach and research might have originated at the primary schooling level. I just recollected my memories of those days with my school headmistress Shanti Miss whom I have been admiring from my childhood days for her teaching, care and puzzle solving work. Despite considering me like her son, she probably might have influenced me to become a teacher one day (for me teacher is a philosopher, not only teaches but also guides life into the paths of enlightenment). When I think about teaching and teacher, the first person comes to my mind is Shanti Miss. Today, I came up to the Ph. D level, it is only because of my childhood experience of what education means and how it needs to be imparted. Though intentionally I did not select research cum teaching as my career, I think it is a* ***decided destiny****. So, I would like to take this acknowledgement as an opportunity to thank Shanti Miss and tell about those wonderful experiences of my childhood days, which made me to realize that research and teaching are my life. However, in this context, not only just as a supervisor but beyond that like my beloved teacher, who showed me the path and meaning of life, Prof. E. Haribabu, whom I respect as equally as Shanti Miss in My life. Without his guidance, not just my thesis but also my life would have been in a great trouble. There are no words to say thanks to both of them like how I cannot say just thanks to my parents.*

Until I came to University of Hyderabad, the goals of my life were blurred. In this regard, every teacher's contribution is highly responsible for such reorientation towards my goal. I am not sure that I have become a good sociologist (only time will speak) but, for sure, I have become a sensible person (a sufficient condition to become an eminent sociologist and a philosopher like Thiruvalluvar). In this respect, I would like to take this opportunity to thank my M. A. Class teachers such as Dr. Aparna Kumar. M. V. S., Prof. Aparna Rayaprol, Dr. Ajailieu Niumai, Dr. V. Janardhan, Prof. K. Laxmi Narayana (Head of the Department), Prof. Purendra Prasad, Prof. Sasheej Hegde, and Prof. Vinod K. Jairath. Likewise, various teachers' traits influenced my thoughts and approach towards academic teaching practice. There are specific approaches for teaching and students which made me to think that I should, one day, follow those approaches and carry them forward. In such cases, Prof. Shanmugam, the former Head of the Department of Commerce, from Mannar College, Madurai; Prof. Martin David, Department of Commerce, The American College, Madurai, and 12th standard tuition teachers' (Saravanan Anna and Visu Anna) teaching approach enhanced my teaching ability. However, it was my graduate friends Mr. Deepak Rajagopal (Manager, Genpact) and Mr. Mathan (Businessman) who enormously influenced and inspired me with their practice of teaching. Both are capable to teach any complex theory in a simple language which can reach anyone easily.

Doctoral student's life has become like the person who walks on a rope; we do not know when we are going to fall down. The moment we think of outsiders as reference group, our research ends and life begins under the capitalist regime or we become a capitalist. Either of the two things would have happened in my life. It takes a fraction of second to decide the life conditions but the consequences will be unbearable. In such conditions, the helping hands from Prof. Prajit.K. Basu (Department of Philosophy, UoH) and Dr. G. Nagaraju (Department of Sociology, UoH) were immense and even sometimes they have even saved me from dismal situation. I would like to take this opportunity to thank those helping hands as my savior of life. I especially thank Prof. S. G. Kulkarni (Department of Philosophy, UoH) and Dr. M. N. Rajesh (Department of History, UoH) for their care and concern.

When it comes to the selection of a research topic for my doctoral thesis, I am grateful to my friends from Chemistry Department like, Dr. Prakash Prabhu (Department of Biotechnology, UoH), Dr. Balaram (National Chemical Laboratory, Pune), Dr. Selva Ganeshan, Dr. Vairam Prakash, and Dr. Viji for their encouragement to pursue research in sociology of science in solar energy. In fact, the idea of pursuing research in the area of solar energy genesis in my mind, when I visited Dr. Vairam Prakash and Dr. Selva Ganeshan's Lab in the Department of Chemistry where the poster on innovations in solar photovoltaic was posted. Both provided me the basic materials on solar photovoltaic technology. This urged me to pursue research on solar energy in later days, but not in PhD as, I was stuck with the idea of "Corporate Governance and Innovation" with reference to "economic crisis and capitalism" in the very beginning of my doctoral study. In this regard, my doctoral committee members such as Dr. Janardhan and Prof. Vinod. K. Jairath supported my idea of solar energy rather than the latter. Really, both the respected teachers laid the solid foundation of my thesis (& also future research). However, Dr. Muralidharan, Assistant Professor, in the Department of Chemistry, played a vital role in explaining the basics of solar photovoltaic in my earlier stage of doctoral research. From the very beginning, this provided me an ample opportunity to understand the science behind solar photovoltaic technology from sociology of science point of view. Though I had the idea of looking at solar energy technologies such as photovoltaic and thermal, it was Dr. Raghav Reddy who persuaded me to do a study on Solar Photovoltaic specifically. In this regard, I am indebted to all the teachers who backed my idea and encouraged me to explore the area which was undone in the Indian context from sociology of science, technology and innovation point of view.

The inner urge to search for knowledge is a process but such process requires self conscious efforts to look at the procedure from the beginning of our thesis. The methodological forum, organized by Prof. Sasheej Hegde, was enormously created and recreated the conscious efforts to look at what procedure do I follow in the study so that my knowledge claims would equally be recognized as valid and reliable in front of the scientific community. This forum provided me an opportunity to deconstruct with what I previously learned at the M.A. Levels. In the sense, it reconstructed and also reoriented my consciousness towards the goals of research. I am

obliged to Prof. Sasheej Hegde for taking pain to organize, for providing basic materials and moreover come a long way to discuss and debate various issues on methodology. Though my contribution towards lively discussion was little, but I am sure that I am benefitted out of this forum.

With regard to data collection, it was a wonderful experience to travel around different places and institutions where I gained a lot of field exposures in collecting data and also experienced how the culture of knowledge production exist in different institutions. This provided me an opportunity to relate the field experience with the literature I reviewed. Further, I also met various eminent scholars from different institutions who helped me to gain access to my respondents and also gave immense inputs for my study. I thank Dr. P.V. S. Kumar, Dr. Dinesh K. Abrol, and Dr. Gauhar Raza from NISTADS, and Prof. Kushal Deb and Dr. Ramesh Bairy T. S., from Indian Institute of Technology, Bombay and Dr. Ahamer Raza and Dr. O. S. Sastry from MNRE. Likewise, I thank all the respondents who actively participated in the lively conversation and discussion on various issues of solar energy in India. Without their cooperation, this study would not have been possible. At the same time, academic writing is a skill and art. Majority of scholars like me literally lack how to convert an idea into a structured paper or a book. This art or skill has to be nurtured from the very beginning of our college days, but it is so pathetic that our academic system just follows what we do in our school days. This system makes us to reproduce what others have said, but not how to ground and articulate once own idea. In this regard, I have learnt a little on this aspect in working with or getting ideas and suggestions from other scholars for my thesis. I take this opportunity to thank Dr. Vigneshwara Illavarasan (IIT, Delhi), Prof. Rowena Robinson (IIT, Bombay), Dr. Itty Abraham (National University of Singapore), and Dr. Haripriya (IIT, Hyderabad).

A successful accomplishment of a thesis depends on funding. Unlike earlier, these days one way or the other scholars get fellowship for their doctoral studies, so the amount of work expected from every scholar has substantially increased. Meeting this requirement is not only accountability but also a responsibility. I thank UGC-JRF fellowship and SET-DEV project for reducing my financial burden. Likewise, I thank Indira Gandhi Memorial Library (IGML), Centre for Science Policy Studies Library, MNRE Library and various other free e-book websites for

immediate source for my work. Likewise, my friends and family members provided me a source of energy throughout my Ph.D. I thank all my M. A. batch mates especially Tapu, Illika, Suman, Baswati, Harinath, Satish, Shilpa, and Deepika, etc., for their kindness and support since my M. A. days. I thank all my family members such as Amma, Appa, Mamu, Suga, Siva, Nanna, Bou, and Sonu for their unconditional love and care. A special thanks to Mr. Anthony Raj for being within me, like a younger brother, in hard and good times. I also thank my juniors, Rachit and Tanish Siddharth Dev, for making me a proud Appa. I also thank my childhood friends such as Satish. R. (Project Manager, HAL), Prathap Kumar (Manager, Reliance), Vijaya Balan (Accountant, Government Office), NTS, Sivarama Alva (Senior Manager, IT), and Karthikeyan, (Team Lead, HCL).

*At last, every end is a beginning of something. Likewise, my Ph.D thesis is not an end, but a beginning of my research life. Thomas Alva Edison took 999 research experiments to arrive at how to invent a bulb. In a similar way, I took one thesis to learn, how not to do a research. So the beginning indicates the academic reforms that create the new era of knowledge production- a dream, a thought and a goal. When I wrote this statement I laughed sarcastically at myself once. An imperfect person to be within academic system and not a hard working boy who couldn't publish even a single paper in his entire period of his doctoral research aspires to reform Indian academics system. What a joke! However, the inner spirit inspired me that why not an imperfect can become a perfect since only an imperfect knows better what the real problem of our academic system is. This gave me the confidence to write about my dream, thought and goal in my acknowledgement. I do not know whether I can achieve it or not, but a thought in high spirit is a thought to be remembered and cherished. This is just a beginning in search of "**excellence decided by time and space**".*

Yours

Pandimuthu Meenakumari[1] Devaraj

[1] Here, I have added my mother's name and she was very happy to see her name in my thesis. Like her, many mothers' feelings are unrecognized in the patriarchal Indian society which gives importance to father compared to mother. The equality denied is equal to the loss of self respect, freedom and exclusion of woman.

List of Abbreviations

AEA: Atomic Energy Act
AEC: Atomic Energy Commission
AGM: Assistant General Manager
APEX: Advancing the Efficiency and Production Potential of Excitonic Solar Cells
APIIC: Andhra Pradesh Industrial Investment Corporation
APVG: Advanced Photovoltaic Generation
a-Si: Amorphous Silicon
ASTRA: Application of Science and Technology for Rural Applications
BARC: Bhabha Atomic Research Centre
BEL: Bharat Electrical Limited
BHEL: Bharat Heavy Electrical Limited
BITS: Birla Institute of Technology and Science
BoS: Balance of System
CASE: Commission for Additional Source of Energy
CAZRI: Central Arid Zone Research Institute
CBRI: Central Building Research Institute
CCEA: Cabinet committee on Economic Affairs
CCEA: Cabinet Committee on Economic Affairs
Cdte: Cadmium Telluride
CECRI: Central ElectroChemical Research Institute
CEL: Central Electrical Limited
CERC: Central Electricity Regulatory Commission
CGCRI: Central Glass and Ceramic Research Institute
CGIS: Copper Indium Gallium Selenide
CO_2 : Carbon-di-Oxide
COG: Central University of Gujarat
C-Si: Crystalline Silicon
CSIR: Council of Scientific and Industrial Research
CSMCRI: Central Salt and Marine Chemical Research Institute
CSP: Concentrating Solar Power
CWPC: Central Water and Power Commission
DAE: Department of Atomic Energy
DNCE: Department of Non-Conventional Energy
DRDO: Defense Research and Development Organisation
DSSC: Dye Sensitized Solar Cells
DST: Department of Science and Technology
DU: Delhi University
ECIL: Electronic Corporation of India
EFL: Electricity Fed in Law

EPTRI: Environment Protection Training and Research Institute
ESI: Energy Statistics of India
FDI: Foreign Direct Investment
FICCI: Federation of Indian Chambers of Commerce and Industry
FIT: Feed-in-Tariff
GBIS: Generation Based Incentive Schemes
GOI: Government of India
HHVC: Hind High Vacuum Company
HLS: Home Lighting System
IACS: Indian Advanced Cultivation of Science
ICRA: Integrated Credit Rating Agency
IDA: International Development Agency
IEA: International Energy Agency
IEP: Integrated Energy Policy
IES-UPM: Institute of Energy Solar, University of Polytechnique, Madrid
IICT: Indian Institute of Chemical Technology
IIT: Indian Institute of Technology
IPR: Intellectual Property Rights
IREDA: Indian Renewable Energy Development Authority
IRS: Indian Remote Sensing Satellite
ISA: Indian Semiconductor Association
ISRO: Indian Space and Research Organisation
ISRO: Indian Space Research Organisation
IT: Information Technology
JNNSM: Jawaharlal Nehru National Solar Mission Plan
JNU: Jawaharlal Nehru University
KSSP: Kerala Sasthra Sahitya Parishath
LDC: Least Developed Countries
MNES: Ministry of Non-Conventional Energy Source
MNRE: Ministry of New Renewable and Energy
MoM: Ministry of Mines
MoP: Ministry of Power
MPC: Ministry of Petrol and Chemicals
Mteo: Million Tonnes of Oil Equivalent
NAPCC: National Action Panel on Climate Change
NCL: National Chemical Laboratory
NCPRE: National Centre for Photovoltaic Research and Education
NCST: National Council of Science and Technology
NDRC: National Research Development Corporation

NEDCAP: Non Conventional Energy Development Corporation of Andhra Pradesh
NEDO: National Energy Development Organization
NGO: Non Government Organisation
NIIST: National Institute of Inter-Disciplinary Science and Technology
NIMS: National Institute of Material Science
NISE: National Institute of Solar Energy
NISTADS: National Institute of Science, Technology and Development Studies
NM: Net Metering
NMEEE: National Mission for Enhanced Energy Efficiency
NMGI: National Mission for a Green India
NMSA: National Mission for Sustainable Agriculture
NMSHE: National Mission for Sustaining the Himalayan Ecosystem
NMSKCC: National Mission on Strategic Knowledge for Climate Change
NPCIL: Nuclear Power Corporation of India Limited
NPL: National Physical Laboratory
NRDC: National Research Development Council
NREL: National Renewable Energy Laboratory
NREP: National Rural Electricification Policy
NSI: National System of Innovation
NSPED: National Solar Photovoltaic Experimental Demonstration
NSTEDB: National Science and Technology Entrepreneurship Development Board
NTP: National Tariff Policy
NTPC: National Thermal Power Corporation
NVVN: National Vidyut Vyapar Nigam Limited
OAPEC: Organisation of Arab Petroleum Exporting Countries
OECD: Organisation for Economic Co-operation and Development
ONGC: Oil and Natural Gas Corporation
PEC: Photoelectric Chemical
PRL: Public Research Laboratory
PSU: Public Sector Unit
PV: Photovoltaic
RCA: Radio Corporation of America
RGGV: Rajiv Gandhi Grameen Vidyutikaran
SAP: Structural Adjustment Programme
SEB: State Electricity Board
SEC: Solar Energy Centre
SECI: Solar Energy Corporation of India

SERI: Solar Energy Research Initiatives
SET-DEV: Science, Ethics and Technological Responsibility in Developing and Emerging Economies
SEZ: Special Economic Zone
SLECO: Solar Electric Light Company
SNA: State Nodal Agency
SPV: Solar Photovoltaic
SSP: Solid State of Physics
SSST: Social Studies of Science and Technology
STE: Solar Thermal Electricity
STI: Science, Technology and Innovation
TDB: Technology Development Board.
TERI: The Energy Research Institute
TIFAC: Technology Information, Forecasting and Assessment Council
TOT: Technology Transfer Model
UNEP: United Nation Environment Programme
UoH: University of Hyderabad
VVNL: Vidyut Vyapar Nigam Ltd
ZSW: Centre for Solar Energy

The Mode 2 Knowledge Production Perspective: Exploring the Literature

Introduction:

At present, solar energy is considered as an important source of renewable energy in the era of depleting fossil fuels and climate change. India has long been dependent on non-renewable source of energy such as petroleum, coal, natural gas and imports 70 percent of oil from abroad. As the energy needs of India have been increasing, especially in the last two decades, because of rapid economic development and population growth, solar energy technology would be an appropriate technology: a) due to increasing costs of imports of fossil fuels; and b) as a measure to mitigate the consequences of climate change. Without this consideration, attempts to understand innovations in solar photovoltaic (here after, SPV) technology have little meaning. The study explores the conditions of techno-scientific knowledge production in relating to SPV, Indian SPV industry and associated policy environment in India. Thus, it is an attempt to understand the interactions among different social actors such as the academia, industry and government in innovations of SPV technology. For which, the study adopts the Mode 2 Knowledge Production perspective to explore the issues regarding new knowledge production and subsequent transfer of knowledge to industry. This approach focuses not only on the nature and character of knowledge production, but also on how particular social and historical contexts nurture the culture of science and technology. Though originated in the experience of Western (especially European) science and technology development, Mode 2 Knowledge Production framework is helpful to explore the issues of innovations in SPV technology in India. With the implementation of Science, Technology and Innovation (STI) policy of 2013, India attempts to construct a new paradigm of inclusive innovation.

This paradigm posits S&T as a driver of innovation and development. It has become a (new) paradigm of development in which participation of different actors becomes an important criterion. So, it is necessary to understand how Indian S&T enterprise functions in fostering technological innovations.

Three important factors contribute to the selection of Mode 2 Knowledge Production as a conceptual framework. Firstly, the framework attempts to look at the context in which scientific and technological initiatives are taken up by different countries. In this regard, the framework helps to explore the socio-economic and political reasons behind the emergence of technological initiatives such as solar energy initiatives and how such initiatives bring distinct social actors into techno-scientific knowledge production process in India. Subsequently, it focuses on the open system of knowledge production. Secondly, the Mode 2 Knowledge Production framework is located at the intersection of science studies and science policy studies (Harding, 2008: 76). However, by considering the fact that India's major scientific and technological inventions, which have been produced at the laboratory level, are not transferred to the industry, since the transfer of knowledge from laboratory to industry is a complex process. The aim of STI policy 2013 in India is to take science to public, but how and why such efforts do not fructify in India. This study shows what lessons could one draw from understanding technological innovations in SPV. Thirdly, what is the relevance of Mode 2 Knowledge Production framework in understanding science-society relationship in India? These questions help us to identify the lacunae of Indian S&T system by providing solid empirical evidence to contribute to the new STI policy, and thus, strengthening the arguments for Mode 2 knowledge production in developing countries.

At the outset, this form of an exploration has to be attempted from three different vantage points. Firstly, the study explores the context in which we talk about solar energy and what made/makes us to adopt solar energy technologies (thermal and photovoltaic) as the most suitable option for the Indian society. For this purpose, the study attempts to show the different contexts in which technological initiatives in SPV have emerged and introduced. Secondly, the study makes a sincere attempt to understand the problems of Indian S&T system in relation to academia-industry interaction in techno-scientific knowledge production and subsequent transfer of technology to industry. This is to show what factors inhibit or promote technological innovations in India. Thirdly, the trajectory of technology development in SPV is traced and different phases are identified to understand how and why technology development in SPV did not reach the market. This structure of understanding exposes a certain kind of social contract that exists among the science, state and development in India. In the light of this, SPV technology, which has been ignored by the sociologists of science, technology and Innovation (STI) in India, becomes the subject matter of sociology.

Focus of the Chapter:

This chapter offers a critical review of the existing literature on social studies of energy in India. The review exposes the various actors in the field, such as scientific community, business and professional groups, sociologists, civil society and policy makers and their contributions towards a critical understanding of the question of energy at large in India. It reveals how different actors engage with the question of energy from the sociology of science and technology perspective and throws light on the relationship between the culture of science and technology and energy in general. The study actually attempts to understand the social practice of techno-scientific knowledge production and the various problems in relation to transfers and innovations in SPV. For this purpose, the study adopts Mode 2 Knowledge Production framework which links science and industry. This chapter also explores how elements of Mode 2 Knowledge Production exist in the Indian context; and what are the issues associated with industry-academia interactions, market-industry relations and policy. It aims to show, how, unlike in the Western countries, there is a longstanding gap in academia and industry interactions.

Sociology of Energy in India: Social Studies of Science and Technology Perspective

Social Studies of Science and Technology in India: Is Energy Technology Studies Misplaced?

Though considerable scholarly attention has been paid on the issues of S&T within the area of Social Studies of Science and Technology (SSST), the academic research, in India, lags behind in sociological studies of science and technology[1]. There are two reasons one could articulate for this. Firstly, the issues that are directly associated with the Indian life experiences push Indian scholars to engage with specific areas such as gender, caste, urban studies, subaltern studies, sociology of education, tribal studies, and development studies. Our life experience is not missing from the way we relate to science and technology but accounting for such practices and experiences is relatively recent in the Indian academic social studies of science and technology. In this respect, we have become passive consumers of science rather than active citizens who reflexively engage on the same. Even though the history on S&T development in India unfolds certain intermittent social

[1] In the Indian context, according to Shiv Visvanathan (2011: 290-312), sociology of science (and technology) is yet to achieve its body of knowledge. He articulates three reasons for the underdevelopment of sociology of science in India: one, the larger discipline of sociology in India mainly focused on certain issues such as development, modernization and state; two, the practice of sociology of science is limited to the Transfer of Technology (TOT) model; and three, the number of scholars engaging in STS is highly fragmented in nature. The articulation ignored its epistemological and ontological questions about the way science has been practiced. The questions on energy, ecology and environment are untouched by the Indian sociologists of science and technology.

movements against the atrocities that resulted from the practice of S&T, various issues of S&T still need rigorous articulation and orientation from/within academic disciplines[2]. For instance, within the larger gamut of social ecology studies, Guha (1994) points out that the two factors which contribute to the neglect of ecological studies in which the focus of energy is also undermined. One factor is the notion that science as a knowledge control nature, by which it contributes to the survival of human species. The other factor is that more the emphasis has been put on economic prosperity, by emulating the West, which is seen as the model of development. Subsequently, the possibility of considering social ecology within planning has been ignored. As a result, the rampant exploitation of natural resources led to the depletion of non-renewable energy resources. The practice of social sciences[3] in general neglected the question of energy, environment and ecology by taking development as prime goal of transforming the Indian society. However, Indian sociologists of science and technology articulate and address the issues of energy by focusing on the consequences of modernity and development in which the concern for nature and culture clearly takes an important position. In fact, this engagement of Indian sociologist of science and technology is itself a limitation, since such engagement located only at the level of critique that questioned the existing practice of science and technology. Within this social location, the alternative science and technology such as solar energy did

[2] This argument partially reflects Shiv Visvanathan's (1997: 1-20) academic reflection on the practice of S&T in India. He articulates that the sociology of science and technology studies in Indian academic structure is still weak and most of the re-orientation of academic studies of Indian S&T comes from the civil society's social movements against the atrocities of science in India. This pushed Indian sociologists of science and technology scholars to address the role of science, state and development in understanding the discourse of modernity and development in India.

[3]For instance, Guha (1994) argues that none of the economic theoretical frameworks (neo-classical, Marxism and Keynesian) attempts to incorporate the notion of ecology within the social construction of economic theory that led to the ignorance of nature in the process of economic development.

not get due intellectual and academic recognition. To the some extent, this is clearly witnessed in the content analysis of social studies of solar energy in India[4].

One could perhaps ground the second reason in the academic practice of sociology in general and STS in particular. Holleman (2012) traces the two factors which acted as barriers in grounding the phenomenon of energy within the larger construct of sociological studies. Firstly, the 'social' aspect has been inadequately articulated in the interdisciplinary energy studies and analysis in particular and in social science in general. He describes that majority of the energy studies focused on the technical-economic and engineering problems, thus resulting in a situation that interdisciplinary energy studies focused only on the technical and economic aspects of energy technologies. What is evident from his critique is that the approach of socio-technical aspects of energy is clearly ignored as well as underexplored. Further, he argues that the unease of sociology with technology and the physical and natural world and the insular tendencies to other disciplines have significantly contributed to the decline of sociology of energy. Consequently, a distinct sub area of sociology of energy could not emerge in the previous decades. In fact, the present work on sociology of energy comes from the sub areas of sociology such as environmental sociology, sociological work on climate change, critical sociology on energy, and ecological modernization. What is witnessed from this is that the sociology of science and technology perspective on energy is yet to ground its position on energy science and

4 An extensive content analysis was conducted to locate the social studies of energy in India by providing the key words of sociology of energy, solar photovoltaic, energy policy, science and technology studies of solar photovoltaic, etc., in various international and national journals. Such search provided large amount of study from technical (and economic) aspects of energy and solar photovoltaic rather than social aspects in India. I did this exercise to know what kind of study which exists in solar photovoltaic and how it is located within the larger gamut of sociology of science and technology. This unfolds that there are very few sociological studies focused on solar photovoltaic in particular and solar energy in general. This evidence is also proved by other studies like Holleman (2012).

technology. This is equally true about both the Western and Indian contexts. For instance, though the social studies of science is quite well established in few universities such as Jawaharlal Nehru University (JNU), University of Hyderabad (UoH), Indian Institute of Technology (IITs) and newly emerged Centres in Central University of Gujarat (COG) but still the spread of the discipline in Indian academics is quite sparse. Though it has produced enormous understanding on the way the practice of S&T happens in India by understanding the different sciences, industries, state and actors but the academic research has largely sidelined the social studies of science and technology related to the energy sectors and its policy related issues such as environment and technologies, nature, science and culture. For instance, JNU, Delhi University (DU) and UoH have the long standing history in contextualizing science and technology practice but none of the institutions provided the opportunity to incorporate S&T studies in energy. Though JNU[5] has a separate institutional arrangement for S&T policy studies, social studies of S&T were very little concerned about energy sector in general and solar energy in particular in the past three decades. The social studies of S&T, in UoH[6], have been groomed by group of eminent scholars' such as Prof. E. Haribabu, (Dept. of Sociology), Prof. K. G. Kulkarani, and Prof. Prajit. K. Basu (Dept. of Philosophy), Prof. Manahor Rao (Dept. of Economics), and Prof. Rekha Pande (Dept of History). Except for the first three scholars, the interactions among the others have been relatively minimum. Although symposiums,

[5] This position came after checking the database of Centre for Science Policy Studies which reveals a very few studies focused on the issues of energy. Likewise, the Department of Sociology in UoH has focused very little to the issues of energy studies within the larger discipline of sociology in general and sociology of science and technology in particular.

[6] This reflection comes from my personal experience, as a student and research scholar, in the Department of Sociology, School of Social Sciences, University of Hyderabad. As a student, I have been trained in sociology of science and technology and to some extent in philosophy of science. However, the latter was completely eroded from the mindset when I started researching in sociology of science and technology. This is how the contested structure influences the thoughts of the individual who is trained by something and later leaves the rest when the researcher becomes part of something else.

seminars and workshops provide common ground for these scholars to interact, such debates and discussions have highly been situated within the mainstream science and technological issues such as information and communication technology, Biotechnology, pharmaceuticals, agriculture, etc. The issues of energy sector and its social problems have remained untouched, or even marginalized within this social setting. Consequently, the lack of discourse (debate or discussion) has affected the knowledge production at various levels from theoretical orientation to empirical evidence and, thus limited the critical reflections on science and technology that dominate our history of life. This has become the black box in sociology of science and technology studies in India. It becomes a real lacuna in understanding the ground reality and the issues related to techno-scientific knowledge production in renewable energy technologies such as solar energy, biomass, and wind. This also shows that the pedagogical culture and practice of sociology of science and technology in India is largely influenced by global issues which are impinging the Indian society. At present, solar energy has become a hot topic, with the advent of climate change and resource constraint. One can see that in recent time there are quite a number of conferences, projects, etc., which attempt to address the issues of renewable energy in particular and energy in general. For instance, at UoH, the European Commission Project on Science, Ethics and Technological Responsibility in Emerging and Developing countries (SET-DEV) provided scope for addressing the problems of energy under the larger framework of climate change and resources scarcity.

Sociology of Energy in India: Social Studies of Science and Technology Perspective

The scholarship on energy by the Indian sociologists of science and technology unfolds three important facets of the culture of modern science. First, from the post-colonial studies of science and technology, various scholars attempt to engage at the interface of science, state and society in which the focus is to understanding how science plays a vital role in development; second, how public engagement of science is suppressed and weakened; and third, the emergence of new epistemic communities and activism encourage renewable energy as the best option for development and also provide various policy suggestions to National Solar Mission (NSM) Plan.

Energy as a Technocratic Project:

Sociologists of post-colonial science examine the relationship among science, state and society in which they extensively deal with the idea of energy in India. Various scholars such as Shiv Visvanathan, Ashis Nandy, J.P.S. Uberoi, Itty Abraham, Amita Baviskar[7] provide a sociological critique of modern science and technology in India that exposes how technoscience and technocratic project control the society in the name of development and economic growth. It accounts for the critique of modernity and development based on technoscience (s) that institutionalize violence as part of the development process. This reflection exposes how society is used as a laboratory to experiment its technocratic

[7] Unlike other scholars' studies, Amita Baviskar's work (1995) largely categorized under environment and development. However, her work focused on the relations among state development project, ideology of the state and consequences created by the same. In this context, she articulates her view point on development of energy as a national interest which ruins the life of tribal people. Thus it creates gap between state and society. Various other foreign scholars such as Winner (1986), Hughes (1999b), Byrne *et al.*, (2006), Byrne and Hoffaman (1988), Scheer (1994 and 2004), and Laird (2001) discuss about the idea of energy which interface with science, state and society.

projects. This is called as vivisectionism[8] which describes how live subjects are used as objects in the laboratory. For instance, in the name of progress and electricity, Visvananthan (1997) argues, that how the culture of risk is introduced through the state-driven projects such as the Narmada dam, the implementation of nuclear reactor[9] for energy production and Bhopal disaster. In a workshop conducted by the University of Hyderabad in collaboration with civil society, Shiv Visvanathan (2007) reflects that the tragedy of the 21st century is the tragedy of electricity and the tragedy of oil. Our Indian society is a biomass society in which upscaling the project of democracy of electricity and democracy of oil would lead to genocide. Here, he puts forth the argument that since the development, as a technocratic project, is taken as an experiment, thus it creates a large gap between science and democracy. This experiment, according to Visvanathan (2002), rests on the three metaphors of energy: 1) grid of discipline + 2) means of energy + 3) time energy = development of the state. However, Visvanathan's solid argument doesn't provide room to elaborate a section on how the metaphors of energy are socially constructed in India. Rather, it is my assumption that derived from the readings of Visvanathan as follows. The grid of discipline refers to control of energy – subject (citizens and physical resources) of the state and centralized energy production and distribution; 2) means of energy indicates instrument of development – human resources, technology and nature; and 3) time energy points out urgency - to implement the process

[8] Uberoi (2002: 82-92) employs the concept of Vivisection to describe the Manhattan project in which military-industry-scientific organisations came together to prove a scientific theory of critical mass rather than winning a war against Japan. In this regard, the society has taken the position of laboratory in which common citizens became the victim of scientific experiment. Further, he criticizes that the Western civilization – science, politics, economics and rationality create mass destruction to the non-Western world by implanting the same European modernity.

[9] For a comprehensive socio-political critique of the emergence of nuclear energy science, and its consequences see Shiv Visvananthan's Carnival for Science 1997, pp. 146-201. Though Visvananthan's narrative is derived from the works of Robert Jungk, the former's sociological imagination on the latter's writing would reveal how science-politics nexus is structured in career of nuclear physics.

and project of development. This structure of development is actually constructed within the larger ideological frame of state apparatus in post-colonial India in which science and technology takes an apparent position of a developmental tool. It is legitimized under the ideology of nation-building. For instance, the massive industrialisation made heavy investments in fossil fuel based energy resources rather than on renewable energy technologies. This is because majority of the renewable energy technologies such as biomass, solar, and wind are considered as unviable option for mass production of capital and consumer goods in terms of cost and the quantum of energy production. This un-viability of renewable energy rests on the laws of thermodynamics – low rate of energy conversion and low energy efficiency in terms of input-output ratio (refer, fourth chapter for the factors that undermine the SPV knowledge production). This provided an opportunity to look at solar (and renewable) energy as unviable technological option for the mass production and distribution of energy. In this regard, C. V. Seshadri argued that the laws of thermodynamics were not only ethnocentric but also oriented to a capitalist idea of work and organisation (quoted in Visvanathan, 2006: 168). Thus, science of energy played a vital role in articulation and formulation of science and energy policies in India[10]. According to Abraham (1997), 'this is how the project of Nuclear reactors as technico-economic system was introduced into the Indian system of science and technology to produce energy for civilian purpose in which, the post-colonial modalities of urgency and secrecy played a vital role'. By incorporating energy into the language of development, we look energy as a life giving object without which life becomes energy less. So, it is the state's responsibility to ensure continuous supply of energy for various purposes' such as the industry, commercial centres and household usages. However, meeting such

[10] Refer, the fourth chapter for the factors affected the inclusion of solar energy in energy policies.

responsibility creates insecurity and risk rather than security and freedom. This dissent against the practice of technoscience and technocratic project created a strong social resistance, which made the subjects of the state to react against such atrocities. In simple, understanding the Indian scholars' engagement on science and development reveals how energy as a "life giving subject" becomes a "life taking object" in the post-colonial era.

Public Engagement of Science: Emergence of New Energy Movements and their Suppression

Within the above context, sociologists of science and technology play a crucial role in examining the deeper relations between social movements and technological innovation (Hess, 2007). Examining the relations between the two provides greater insights into public engagement of S&T in which the dynamics of science, state and civil society organisations are understood. Specifically, one can understand the relations among energy, technology, and society; state action against civil society movements; and the different ideological and institutional ways in which various groups respond to state action. The above issues are theorized under people science movements[11] in India, which expose how Indian society responds to different kinds of risk and uncertainties generated by techno-scientific innovations. By understanding people science movements, Varma (2001) differentiates the public engagement of science into two cultures of science: one is opposing science and technology; and the other one is taking science and technology to the

[11] People Science Movements (PSM) denotes peoples' reaction and resistance against the development of modern science and technology by organizing a collective effort to achieve the desired ends. It deals with how people engage with science to change the experience of life conditions by opposing science when it hampers life and also bringing science into development discourse to provide alternative livelihoods and lifestyle. Refer various studies on People science movements to know the origin, objectives and ideology to understand the discourse on science movements in India (Krishna Kumar (1977); Vaidyanathan *et al.,* (1979); Jeffery *et al*., (1983); Guha (1988); Bandyopadhyay and Shiva (1988); Jain (2002); and Shiva (2009)).

public. Engaging with the two cultures of science unfolds how the political culture of science exists in India. With the above analytical construct of two cultures of science, the new energy movement focuses on the issues of energy, technology and development. The energy movements articulate and foreground their socio-political critique on energy and development in the following ways: 1) they criticize the state for maintaining secrecy about the implementation of nuclear power plants; 2) they argue that the need based approach provides importance to the industrial requirements, and neglects the needs of the common citizens; and 3) they emphasize safe and secure energy must be the government's priority; 4) that there is a violation of individual right to live a life because power project creates threat, insecurity, danger and risk; and 5) nuclear power plants are economically unviable technological projects such as Nuclear reactors of Jaitipur, Maharashtra. To simply put, the socially distributed knowledge opposes the way the energy securitization programmes occur in India. In a way, it criticizes the technological system or an artifact which creates massive destruction to human life.

In the Indian context, looking at the participation of people at the grassroot level reveals the kind of political culture of science that prevails in India. This political culture of science unfolds the repressive state actions in suppressing the collective knowledge and choices taken by the energy movements in various parts of India. For instance, one needs to look at the various actions and responses taken by the state to stop such movements. In the case of Kundankulam Nuclear Power Project, the most severe form of repressive strategies, such as firing, filing FIR, demoralizing the movements by character assassination, etc. have been employed to control and suppress the mass mobilization (Bidwai *et al*, 2012; Senthalir, 2012). Apart from this, the frequent power cuts in various parts of Tamil Nadu have been used as a tool by the government to demoralize the people from agitating against the state development projects. For instance, the power cuts make the citizens to suffer as if the life is gone, since electricity becomes a part of cultural products. This makes to stop the agitating against the state development projects[12]. This kind of new forms of repression is added to the coercive elements of the state.

According to Agamben (2005), it is the state of norm which governs the present modern world in which life as threat and death appears with the sovereignty of power – a state of emergency always exists – it is called naked life. The life, which we live, is turned to be the question of death when we attempt to take the course of action. The manner in which we participate in the process of production and consumption makes us to question the way we live in the society. Though we realize this form (s) of life existence, but unfortunately we are powerless to take action against the sovereign power which controls us. This is how energy and development politics takes the turn of bio-politics in India. With the regime of nuclear energy, Abraham (2012) claims we have entered the stage of bio-politics in India. Here, he refers bio-politics as a collective action to save life in the midst of external threat. So the social problems of contemporary society are increasing less about unequal material distribution than about the knowledge of technology in which development occurs (Lefebvre, 2009) and Habermas talks about decomposition of collectivism in front of the powerful political and administrative system (Rasmussen, 1989). The loss of individual power and social democracy to shape the historical progress is clearly witnessed from the

[12] This thought came when I went to my native place in Tamilnadu, where I experienced frequent power cuts which made every citizens of the state to talk about opening of Kudankulam Power Plant Project. The public discourse on energy revealed that the state government use power cut as medium to show that there is a huge energy scarcity in the state. So, it is necessary to open new power projects. At the same time, frequent power cuts have become a means of attracting capital investments in new consumer products such as solar lantern, solar home lighting system, battery backs (UPS), etc.

suppression of movements and agitation against the state action. Thus, Nandy (1990) argues that the culture of modern science in India has begun to produce new forms of secrecy, centralization, disinformation and authoritarian organisational structure.

Public Engagement of Science: The Question of Appropriate Technology

The other side of the public engagement of science is concerned with appropriate technology movement[13], which focuses on how an energy stratified society is being created and also provides the critique of Westernization process in India. Majority of the scholars attempted to show the social conditions which contribute to the inaccessibility to energy and inequality in consumption of energy. This is to know, how inaccessibility and inequality are intrinsically linked to the creation of energy stratified society. One of the pioneers of this approach is Dr. Amulya K. N. Reddy who not only discusses about the issues of energy but also suggests various ways to bring equality in terms of energy consumption and improving standard of living through energy technologies. Dr. Amulya K. N. Reddy, according to Visvanathan (1997), is not only a chemist but also a sociologist who extensively articulated the interface between energy and society. As a sociologist, his holistic approach on energy and society attempts to understand the nature of development that happens in India. In this context, he criticized the imitation of Western model of development and also revealed how such model of development creates energy injustice.

[13] In a larger context, the concept of appropriate technology was defined by Mahatma Gandhi to criticize the development based on westernization and modernization in India. His philosophy of development is circulated within the boundaries of village self-sufficiency, production by mass but not mass production, increasing employment opportunity by developing appropriate technology which provides employment opportunity and stops dependency. Gandhi's alternative approach to development inspired other major proponents such as E. F. Schumacher work on "Small is Beautiful" – intermediate technology, J. C. Kumarappa works on village self-sufficiency, C.V. Seshadri on what is good science (1993) – focus on relations among time, energy and thermodynamics, Amulya Kumar Reddy focused on Application of Science and Technology for Rural Applications (ASTRA) now changed to Centre for Sustainable Technologies, Indian Institute of Science – Bangalore, Sunil Sahasrabudhey (2002), etc.

For instance, Reddy and Reddy (1983) narrate that how income and energy consumption are directly related to the formation of energy stratification in which social inequalities are inherently nurtured. This is one of the major reasons for the degradation of forest resources in India. Vidyarthi (1994) argues that the depletion of forest resources, along with changing agricultural practices and mechanization, leads to energy crisis in rural areas. To provide alternative solutions to development (& energy) crisis, the articulation of appropriate technology has emerged and conceptualized in India.

As a forerunner of this movement, A. K. N. Reddy, in his work on Technology, Development and Environment (1994), attempts to provide a conceptual clarity on what is the appropriate technology for developing countries. In this work, he foregrounds a four dimensional view of an appropriate technology which not only includes economic, but also social, political and environmental dimensions. His criticism on Western paths of development, based on four criteria, makes two points: one, the Western paths of development based on modern technologies would bring mass destruction to rural livelihoods and create social inequalities in the Indian society; and two, the way the Western countries articulate the need for an appropriate technology is only focused on enhancing economic and environmental goals, which ignores how such technology contributes to the social goals of poverty eradication and building of an egalitarian society. Because of these, the Western notion of appropriate technology becomes inappropriate to the Indian (and Third world) context. Following the similar line of argument, A. K. N. Reddy (1999) criticized that the Western notion of sustainability is originated from the consciousness of limits to growth and not with that of consciousness of environment. Consequently, the emergence of appropriate technology becomes the politics of sustainable development. Meeting rural energy needs such as cooking and electricity is a must for development. So, like R. M. Lohia[14], A. K. N. Reddy also encourages that such needs should be met with an appropriate technology, which reduces the burden of women, concern about woman health and also contributes to pleasant end use activities. In that case, developing biomass technology for cooking and electricity generation is encouraged as an appropriate technology rather than importing costly SPV technology to meet village electrification programme. Subsequently, SPV technology failed to get social and political recognition in Indian context (Barabara *et al*, 2009). For instance, Nandy (1978) argues that alternative ideology of science provides new legitimacy for the traditional techno-systems and their cultural environment. Such legitimacy recognizes the values of man-nature and man-man relationship and a deeper understanding of the politics of technology. The ideology encourages a techno-system that provides importance to man-in-nature and not man-over nature technique. In this context, he criticizes solar energy as an alternative modern technology and not of dominant traditional technology. One can understand the Nandy's logic and articulation of appropriate technology as embedded in life styles and cultural practice of masses. In this light, solar photovoltaic is not considered as appropriate technology, since it establishes market relations and control of technology rest with industrialist. In the sense, it could go against the concept of 'intermediate technology' which considers the role of readily available resources and materials to produce a technology for solving community problems. Subsequently, SPV is less considered as appropriate technology in India. In short, Banuri (1990) emphasizes that the attempts of

[14] This position derives from Amit Basole's (2010) article on The Technological Questions in Lohia in which he describes R. M. Lohia's critical reflection on what is the appropriate technology for the Indian context. He believes that an appropriate technology reduces drudgery and provides economic activities for all. For which, socially dispersed knowledge is important for the decentralized form of development.

A.K.N Reddy and group claim a technology is appropriate when it is under the direct control of the people who are affected by it or directly involved in the life of the people who are affected by it. Thus, Guha (1987) claims, this communitarian approach focuses on the decentralized forms of energy options, which oppose hierarchy. This is how one can reduce the social problems of Indian society in which technological solutions play a vital role. Visvanathan (2006) understands the practices of alternative science in which he talks about the knowledge determines the possibilities of politics through which one can provide an insight into an alternative-life world to alternative livelihood, lifestyle and life cycles.

As part of the above process, nurturing a technological culture at the grass root level is assumed as a strategy to meet the rural energy needs. However, India follows fuel option instead of technological option in addressing the energy demands. So nurturing the technological culture at the grass root level fails to take off. Subsequently, with the increase in population, import of oil as a source of development makes India a dependent country and also contributes to the increase in external debt and internal losses. In this context, Reddy *et al*, (1991) understand the relations between energy-debt in the Indian context. They argue that the failure of effective policy mechanism to incorporate a right choice of technological options combined with energy efficient technologies results in huge debt in the Indian energy sector. In a way A. K. N. Reddy and others encourage decentralized energy production and consumption in India. However, he provides broader insights on why the decentralized energy option could not emerge in India. Reddy (1991) argues that the Indian energy policy is based on need oriented approach which neglects the notion of people centred approach. In this context, he talks about the concept of DEFENDUS (Development should be based on end use electricity strategies) versus

CONSENSUS (need oriented electricity strategies). The former hails from the voices of civil society which enforces that Indian electricity reforms should incorporate opportunities for employment generation and also for electricity for all. This could be possible when there is an effective policy at the grass root level. But what is happening at present is that the various players such as the corporate, presence of strong public sectors undertakings, international players, etc. control the Indian electricity sector (Sree Kumar, 2007). Ultimately, it encourages the paths of deregulations in energy sector along with effective state control in energy production and distribution in India. Under this consideration, Reddy (2001) draws critical insights from California energy crisis to provide thought provoking policy insights into power sector reforms in India. He states that the California's government approach to regulate the paths of deregulation resulted in market failure. This ultimately led to massive energy crisis in California, since the market–driven reforms ignored to look at public benefits in the name of private profits. In this context, he (2000) draws suggestions towards the power sector reforms in India by not following the paths of Westernization and Top Down World Bank approach, since the Indian electricity boards suffer from series of crisis such as capital, equity/distribution/access, environment and performance. However, India followed Western approach to Indian energy sector. With this political intervention, we entered into a locked in position and became path dependent. Coming out of this dependence is itself very difficult. This strongly resists the penetration of renewable and solar energy and subsequently, majority of the renewable energy programmes failed to get social acceptance in India.

Emergence of Epistemic Community and Activism:

Unlike the earlier decades, at present, majority of the scholars and practitioners from different disciplines attempt to show how solar (and other renewable) energy is important to the Indian context. This group of experts, in Hass (1992) terms, functions as an epistemic community. At present this community attaches shared positive meanings towards solar energy. Bijker (1995) calls this as interpretative flexibility which means different groups attach different meanings to technology. At the same time, groups' meanings may change with the context, time and scientific and technology development. For instance, in late 1980s, the solar energy technologies (thermal and photovoltaic) were considered as non-viable to Indian society whereas at present majority of the scholars perceive solar energy technologies as developmental tool to achieve environmental, economic and social goals which focus on energy securitization and mitigation of climate change. Consequently, the epistemic community takes the position of activism in recommending and fostering suitable institutional and incentive structure for developing countries to stimulate the growth of renewable energy technologies. For instance, the epistemic community employs techno-economic approach to understand the best technological option to mitigate climate change and also to meet India's present energy demand. This articulation is emerged from the social categories of scientists and social scientists who belong to various academic and scientific institutions such as IITs, Universities, Public research laboratories, research institutions, management organizations, etc. With the increasing demand for renewable energy technologies, the techno-economic approach forecasts the cost-benefit analysis in implementing various solar energy technologies such as solar thermal, SPV and CSP in India. This approach critically examines two stand points: one, selecting appropriate technology for mitigating climate change by comparing one technology with other technologies in solar and renewable energy in general; and also examines technological options in comparison with fossil fuel energy options in India. Under this larger framework, various scholars attempt to show how solar energy is one of the appropriate technological options not only to mitigate climate change but also contribute to energy securitization in India. For instance, scientific community argues that solar thermal electricity (STE) also known as Concentrating Solar Power (CSP) is an emerging renewable energy technology and can be developed as a future potential option for electricity in India (Sharma et al, 2012; and Ummadisingu and Soni, 2011). Other studies estimate the CO_2 mitigation potentials of solar energy technologies such as solar water heating (Purohit and Michaelowa, 2008) and solar home lighting system (Purohit, 2009) under the Clean Development Mechanism. At the same time, hybrid (biomass and solar) energy option is suitable to present conditions with the decrease in solar cost and increase in fossil fuel prices (Nixon *et al*, 2012). Some studies focus on the opportunities and challenges for solar energy technologies in India (Veeraboina and Ratnam, 2012; and Raman *et al*, 2012). These studies emphasize the need for reducing the constraints such as political, education, legislative, technological and financial in diffusion of solar (and renewable) energy technologies. For that, the need for new institutional framework is encouraged and envisaged. In this context, Shrimali and Rohra (2012) critically review the National Solar Mission Plan and put forward various recommendations for policy adjustments.

Like the epistemic community, industry associations and other organisations have been coming up with various reports and suggestions on how to stimulate the growth of Indian solar energy industry. Unlike the epistemic community, these groups function as interest groups to influence government to introduce various laws, policies in favouring solar energy industry. Majority of reports (India Semiconductor Association, 2008; India Semiconductor Association, 2010; Energy Alternatives India, 2011) are located at four intersecting points. One, is the understanding of SPV technology and its successive generations; the second is about the global scenario of SPV technology and comparison of different countries production capacities and technological capabilities in the SPV value chain; the third, critically reflects on the Indian SPV industry production capacities and technological capabilities in SPV value chain; and the fourth points out various suggestions to improve industry standards by providing critical insights into policy recommendations. For instance, Energy Alternatives India report (2011) suggests that there are two conditions inevitable for the survival of the PV manufactures. Maintaining cost competitive by increasing the scaling of operation and production; and vertical integration of PV firms is a must so that the cost of the PV technology will remain stable in the midst of price fluctuation. For which, effective policy mechanism is a must to stimulate the growth from silicon processing to module production. At the same time, R&D investments in building infrastructure facilities, technological capabilities and nurturing human resources are immediate concerns for the development of the Indian PV industry.

From the review of energy studies in India, the study concludes that the works on solar photovoltaic is minimal in the social studies of science and technology in India. The main focus of the study is to explore the various issues of techno-scientific knowledge production, transfer and innovations in SPV technology. Keeping these structural organisations in mind, this study carefully selected the Mode 2 Knowledge Production as a conceptual framework to address the issues associated with the technological innovation in solar photovoltaic in India. The review of literature attempts to show two standpoints of technological innovation. The first enquires into the nature of problems which exist around the issues of technological innovation; and the second deals with the location of Indian industry and technoscience research in India. The review attempts to unravel the various socio-economic and political issues which influence the development of technological innovation. This would reveal how solar energy science and technology development is largely mediated by the context like any other science and technology in India.

New Sociology of Science and Technology Perspective: Understanding the Changing Context of New Knowledge Production

In this present study, the new sociology of science and technology perspective is employed as a theoretical background that focuses on the changing context of science-society relations. Understanding science-society relations, according to Hackett *et al.*, (2008), largely fall under three categories: 1) science, as social action and activity (set of institutional arrangements and practices), produces knowledge, meaning and impact; 2) S&T as integrated actions (sciences not science, publics not public, reciprocal causality not linear causality); and 3) S&T emerges in the context of history and social space (institutional structure and change) and influences the process of knowledge production. Based on the above themes, social studies of science and technology is divided into two areas. The first area focuses on the emergent phenomena such as machine intelligence, emergence of technoscience\industrial science, economics of technology, globalisation of technology and innovation, and internationalisation of R&D. In this sense, the new sociology of S&T attempts to incorporate the factors that are internal and external to S&T that influence the knowledge production in techno-scientific research and technological innovation in the present context of globalised world. The second area addresses on the public participation and understanding of science, public controversies, politics of science and technology. It attempts to expose the consequences of development and commercialisation of scientific and technological knowledge in the contemporary society. For instance, the environmental degradation and climate change have not only led to the emergence of various protests and movements but also reshaped nature-social relations by forcing the government to initiate various technological initiatives on renewable energy technologies. Thus, sociology of S&T plays a vital role in understanding the relationship between scientific practices, and technological innovation, and also criticizes the policy framework by exposing and addressing various issues of scientific and technological practices. Subsequently, in recent years, Social Studies of Science and Technology (SSTS) functions as social activism in integrating social and natural sciences through discursive practices. Sheila Jansanoff (2004) calls this process as co-production and Nowotony *et al*, (2001) conceptualize it as co-evolution. It means how science and society are mutually influencing and shaping each other. According to Nowotony *et al*, this is called Mode 2 Society which focuses on two aspects of the society: knowledge (information) society, and risk society. Thus, Mode 2 Society refers to the context of post-modernity and talks about how knowledge capitalism plays an important role in establishing a social order. This is, according to Graham (2003), marked by the shift from one phase to another phase: 1) from Mode 1 Linearity to Mode 2 Complexity; 2) from Disciplinarity to Transdisciplinarity; and 3) from Mode 1 to Mode 2 Knowledge Production.

Mode 2 Knowledge Production Perspective: A Conceptual Framework

Subsequently, the contemporary dominant mode of analysis in Social Studies of Science and Technology (SSST) deals with the interactive and reciprocal relations of science and technology rather than science and technology as socially isolated phenomena [15](Latour, 1987; 1998; and Law, 1991). This kind of theoretical framework in STS reflects in the recent attempts made by several scholars' engagements with new knowledge production such as Mode 2 Knowledge Production (Gibbons & Wittrock, 1985; Gibbons *et al*. 1994; Ziman, 1996 & 1996; Nowotony *et al.,* 2001). Mode 2 Knowledge Production as a techno-scientific innovation approach (Hasen, 2009) understands how various social actors participate in the social production of scientific and technological knowledge. As a techno-scientific innovation approach, it emphasizes on the participation of heterogeneous actors[16]

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[15] The interactive approach claims that technology and society mutually influence each other and not discrete entities. It criticizes the theory of technological determinism of society which conceptualizes technology and its development as a force that is independent of society. The social theory misses the theorization of non-humans into the analysis of human consequently social theory becomes anthropogenic in nature.

[16] In this regard, the Mode 2 knowledge framework merges with the systems of innovation perspective – a social engineering by itself. Various theories of economic innovation or systems of innovation perspectives (Feinson, 2003; Lundvall, 2004;) such as National Innovation System (NSI), Regional Innovation System (RIS), Triple Helix and Sectoral Systems of Innovation (SSI) recognize the participatory form of scientific and technological knowledge production for the economic and social transformation. Systems of Innovation perspectives have become a concept/framework/perspective to address/create social interaction among various actors such as the industry, academia, research laboratory and government to stimulate economic growth and development. As a social engineering project, this framework focuses on the model of economic development by encouraging collectivity as source of innovation. This is much oriented towards Durkheim theory of social cohesiveness nurtures social things (Swedberg, 2006). This social formation brings scientific output, patents and publications, in turn, assure technological prosperity in a country. Thus, the social participation of institutions (set of rules and regulations) and economic structure (organizations of industry and research institutions) shape the rate and direction of technological change in the society. It functions as institutional ideologies which provide rules and roles, values, and functionality of the group and thus reconfigures the institutional networks among various actors such as the academia, industry, government and civil society. It is an important source of economic and political means that helps to achieve the desired ends. In general, innovation system perspective has become the model for economic development and a global phenomenon. Callon (1991) argues that the general focus of the economic analysis is the product such as output, patents, publications, economic development, etc. It gives importance to the intermediaries which connect the institutions. Unlike Economics, Sociology provides importance to the agency attached to the institution and its relationship, which connects the actors in the network. These social relations bring actors together within the specified field (This is in Bourdieu sense). However, this study does not differentiate theoretical and methodological orientation between innovation studies and sociology of science and technology. Rather, the study adopts both to understand the statement of the problem.

such as academia (university and public research laboratories), in-house R&D (public and private firms), government and NGO (occasionally incorporated into the framework) in knowledge production within a specific context[17]. In short, the approach links science with innovation (Nowotony *et al.*, 2003). To elaborate this position, the social participation attempts to solve problems that have their origins in the concerns of particular individuals, groups or organisations, or even society as a whole (Nowotony *et al*. 2001: 106). This is to develop, produce, and diffuse methods for generating goods and services (Callon, 1991: 133). In this sense, the applications of knowledge are socially defined for specific purposes such as industrial, commercial, and larger socio-political goals. It involves three poles: first is the scientific pole that produces certified knowledge; second, the technical pole that conceives of, develops and transfers artifacts such as products, models, pilot projects, prototypes, tests and trials, patents, norms and technical rules, etc. Third, refers to users or consumers who more or less explicitly generate, express, or seek to satisfy demands or needs (Ibid, 1991). Gibbons *et al*., (1994) describe that the Mode 2 Knowledge Production provides importance to the social context of application as a frame of reference for the production of knowledge. It indicates the socially embedded nature of application-oriented knowledge production.

With the influence of the context-based knowledge production, Nowotony *et al*., (2001) argue that the way knowledge was being produced that has been changed with the model of integration. It differs from other models of knowledge production in which social actors

[17] The major proponents describe NSI as: the networks of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies (Freeman, 1982); the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge and are either located within or rooted inside the borders of a nation state (Lundvall, 1992); a set of institution whose interactions determine the innovative performance of national firms (Nelson, 1993); national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country" (Quoted in Feinson, 2003: 17).

are segregated from other social realms. That is, the Mode 2 Knowledge Production approach differs in terms of disciplinary, cognitive, actors' participation, social hierarchy and social goals. Thus, Gibbons *et al*., (1994) assume that Mode 1 Knowledge Production[18] is being transcended by Mode 2 Knowledge Production. There are nine criteria through which one can infer the changes in the process of knowledge production: a) interest of knowledge production; b) space of knowledge production; c) actors participation; d) social hierarchy; e) creativity; f) quality control; g) social norms; h) reflexivity; and i) rigidity of norms.

Table No: 1.1 shows the differences between Mode 1 and Mode 2 Knowledge Productions

Criteria	Mode 1	Mode 2
Interest of Knowledge production	Problems are set and solved in the context governed by the largely academic, interest of specific community.	Problems are set in the context of application which has wider social, political and economic interests.
Space of knowledge production	Disciplinary	Transdisciplinary
Actors	Homogeneity	Heterogeneity
Social hierarchy	Hierarchical and tends to preserve its form	More hierarchical and transient
Reflexivity	Socially accountable within the particular social context	Socially accountable and reflexive to wider actors.
Social norms	Cognitive and Social Norms are adjusted to produce one	Norms are emerged in the context of applications.

[18] Mode 1 Knowledge Production refers to Mertonian science (1973) articulates how the institutional environment (norms & cultural values) fosters development and growth of science. It is based on three social processes: (1) ethos of science (cultural values & norms) guides scientific knowledge, (2) internal social structure of various disciplines (training, communication, information flow & evaluation) nurtures the development of the same; and (3) incentive system (reward system) guides to publish the results. The institutional values function as a constraint and enable the scientist in new knowledge production and its claims. Any scientific controversies on discoveries and inventions are dealt within these structures of norms. Consequently, the originality of science is assumed as the major institutional goal and values of modern science. Kuhn (1962) states that ideological formation / scientific belief stimulates new knowledge production and lead to scientific specialties. However, such a formation is based on the social upheaval within the scientific community. According to Bloor (1976) and Barnes (1977), scientific belief fosters interest of the scientific community leads to the development of science. It creates conflict in construction of facts and interactions (material and non-material elements) in scientific conduct contribute to the process of knowledge production. Since, it produces scientific authority (prestige, esteem) and hence the scientific knowledge production is always a power relation (Bourdieu 1975). In this regard, the objectivists such as Barnes, Bloor, and Merton and subjectivists such as Latour, Centina, Mulkay, Pickering notion of science also exist in a parallel mode.

	another and produce disciplinary knowledge.	
Creativity	Individual creativity the driving force of development.	Collective creativity the driving force of development. It is group phenomenon.
Quality control	Disciplinary structure acts as a constraint and enables the individual	The context of application forms the structure, which act as a constraint and enables the individual. For instance, configuration of human resources in a flexible, essentially transient form of organisation.
Rigidity of the norms	Highly rigid in terms of social conduct in scientific practices and knowledge production	Flexible disciplinary norms, loyalty and institutional control

Author's Compilation from different Sources: Gibbons *et al.*, (1994); Nowotony, (2000); Nowotony *et al.*, (2001); Nowotony *et al.*, (2003) and Nowotony *et al.*, (2005).

With the heterogeneity of actors in knowledge production, two kinds of experiences emerge. Firstly, under the conditions of modernity, there is a lack of a clear boundary and transgressive nature of relationship that exist among different institutions such as science, industry, state and market (Nowotony *et al.*, 2001: 166: and Nowotony *et al.*, 2005)[19]. The Mode 2 Knowledge Production attempts to look at the changing role of state in academic research system and industry participation in R&D activities. For instance, university as factory (emergence of entrepreneurial science and university, Etkowitz (1998) and Etkowitz *et al.*, (2000)) and factory as university (basic and applied research in commercial settings) – brought new waves in social participation of actors in knowledge production[20]. Kleinman and Vallas (2001) call these phenomena as the "industrialisation" of the academy and the "collegialisation" of industrial research. It emerged with the notion of

[19] Various scholars have criticized this claim. They argue that the transgression or end of differentiation is still at the theoretical level (for further reading, Hasen, 2009) and without critical examination, it is borrowed from reflexive modernization theory.
[20] This is called the second academic revolution in which university not only performs research and teaching but also highly focuses on economic and social development. Here, the research groups functions as quasi firms. This is called University's Third Mission (Etzkowitz and Leydesdorff. 1998).

capitalization of knowledge such as commercialization of knowhow (entrepreneurial science), emergence of new culture of scientist-entrepreneur in university, consultation services offered by scientist to industry, etc. These factors brought science-industry interaction closer in recent times, which created new ways in organizing science[21]. For which, the state formulates policy to develop industrial knowledge base (training human resources, developing S&T capabilities, and technology development) and to contribute to the economic development[22]. This framework is called 'Triple Helix Model of Science'. This model of organizing science becomes a part and parcel of the modern day practice of science and technology. Therefore, we are in the age of participatory form of scientific and technological development which encourages different actors to participate in the social process of technological innovation. It makes a social contract between the knowledge producers (scientists / engineers / users) and knowledge users (industry / government / consumers) in an open system of scientific practice. Thus, Mode 2 Knowledge Production permeates each other's realms and professional identities and institutional boundaries are relaxed within this mode of knowledge production (Nowonty, 2000)[23].

Secondly, with the heterogeneity of actors' participation, Mode 2 Knowledge Production shows how the social context of science is changed according to the realms of application

[21] Refer the chapter, "Techno-Scientific Revolution", in Braverman's (1974: 107-117) Monopoly and Capital, for a deeper understanding of the history of science-industry interactions in techno-scientific innovation. Likewise, refer the chapter Incorporation of Science, in Rose and Rose (1976) The Political Economy of Science: the ideology of/in the Natural Science, to know more about the relations among the state, science and capitalism.

[22] Hilpert (1991) in his study on State Policies and Techno-industrial Innovation points out the role played by the state in fostering techno-industrial innovation: a) to ensure the needs of innovation, state organizes academic research structure and its techno-scientific progress; b) organization of markets for science based products encourages the creation of new and innovative industries; c) creating appropriate environment such as incentives, policy, that makes firms to engage in newly emerged markets.

[23] The dispersed areas of scientific research have led to the formation of multi-disciplinary based research programmes and hybrid communities. The new interfaces between scientific communities have emerged. For instance, energy and environment has created an interface between social science and sciences. This is what is called Techno-Economic Networks by Callon, M. The new social movements based on scientific and technological responsibilities have been influencing the social institution of science.

of knowledge. Consequently, the scientific and technological knowledge has a pluralist orientation that defies the old orderly picture of functional differentiation such as the pure and applied sciences, technology development and transfers. The actors now become more interactive and reciprocal rather than following the linear model of create, develop and transfer to industry. It socially embeds other social realms such as the pure and applied sciences, technology development and transfer since the context of application brings the various actors together in scientific knowledge and technological productions. With the advent of Mode 2 Knowledge Production, the two social categories of knowledge production in science - pure science as basic or fundamental research and applied science as an extension of industrial application- become more coherent to develop science and technology for specific applications. This is called as co-constitutive of science and technology for the purpose of industrial applications[24]. Likewise, Latour's (1987) work on 'Science in Action' describes about the science (Scientist) - technology (engineer) interface in knowledge production and how the knowledge production is materialized with such interactions in which the concept of techno-science is socially embedded. Here, it refers to employing scientific ideas to invent a device to explore the properties of a phenomenon. Such exploration results in new understanding of science, subsequently, it contributes to further application of knowledge in a variety of fields. Nordmann *et al.*, (2011) describe technoscience as production of knowledge that often employs scientific representations (such as theories, models and diagrams) to make things work. In Shiv Visvananthan's words (1985) it is a form of research that unites the culture of university

[24] Such form of research has been undertaken in various social settings such as university, in-house R&D in firms, and public sector laboratory. However, one should not limit that the context of knowledge application happens within these social settings but also the non-governmental organisation actively takes part in the application of scientific knowledge.

and the culture of factory under the techno-scientific research, which focuses on converting an invention into a viable economic product. It covers issues ranging from knowhow to technological innovation for particular economic purpose or application of scientific knowledge. Technological innovation indicates the social production of techno-scientific knowledge; and on the other hand, it focuses on the transfer of such knowledge from the laboratory to the industry. The industry as a social agent translates knowledge production into viable economic product or a process. Schumpeter (1934) recognizes that the industrialists, manufacturers or entrepreneurs are required to convert R&D into a viable economic product. Flichy (2007) describes that the 'Schumpeterian' entrepreneur mediates between the industrial R&D and commercial (market) domain, through which new technical system will be established.

Carlsson (1991:14) describes innovation as a social process. This social process requires association of individuals within a system. He mentions four criteria to look at innovation as a social process. One, innovation is not an act of an individual but rather a collective activity in which the inventor constantly interacts with various groups of people. Two, inventors join their artifacts with social organization that is, linking invention with business structure. Three, innovation process includes market strategy as a major component. It describes why individuals would want to buy a particular product. It creates and attaches social meanings to their products. Four, innovation as a social process concerns the knowledge base. A body of ideas, skills and values (scientific beliefs, community structure, and knowledge) certainly influence professionals' knowledge production and transfer of knowledge into viable commercial products. Institutional structure and financial means should work as a coherent system for converting an idea into an innovation with an eye on returns on investments (Machlup 1972; Hughes 1999a; Swedberg, 2000, 2006). The techno-scientific research and technology development come to the state of rest, if these two do not meet the above mentioned criteria.

Interactions and Collaborations: Factors Influencing Academia-Industry Interactions, Inter-firm Collaborations, and Technological Innovations

In the present context, there are two factors that contribute to the increased academia-industry interactions. First, is the increase in new specialization and diversification of knowledge; and the second, is the increase in the global competition and recognition that S&T is both a commodity and a resource (Reddy P, 1997; 2000). In simple, technological innovation is followed as a strategy by the firms in the globalised production and innovation. First, Mode 2 Knowledge Production indicates that the organizational landscape of knowledge production has changed with the increase in specialization and diversification of knowledge as evident from the increase in new theories of sciences and their applications in a variety of fields (Vessuri, 2000). The transdisciplinary mode of knowledge production forms a part of it. Graham (2003) puts forth three interconnected concepts to define transdisciplinary mode of knowledge production: contextualization, transgressiveness and hyper rationality. In this mode, the experts from each discipline come together and contribute to the knowledge production. These factors increase the density of communication and multiplicity of the participation of the individuals\actors in knowledge production. Such scientific communication disperses the knowledge and contributes to the growth of heterogeneous knowledge development. This also reconfigures the group formation (hybrid community/new networks/collaboration research) based on the belief they share, which contribute to the reemergence of components in the process or it provides interest for further knowledge development. It creates a common culture and a common language within the scientific specialties and forms new sub-culture within the structure of scientific knowledge production. This group formation is a potential source for the emergence of multi-disciplinary and trans-disciplinary research programmes. Within this network of relations, there are no sharp boundaries that exist among sciences. These distinct cultures are bound by inter-languages[25]. At present, what makes the knowledge domain complex is the involvement of various actors such as the industry, military, experimental and instrumental and theoretical practices. Most of the actual practices of science draw insights from heterogeneous grouping of theoretical knowledge, disciplinary and sub-disciplinary cultures, machines, business strategy, materials and practices. These are the important criteria for the development of new science, discipline and continuity of science without which there will be rupture and discontinuities and consequently, it will make the science stagnant. Ziman (1996a) calls this larger transformation of culture of science as Post-Academic Science. Ziman claims that Mode 2 Knowledge Production is essentially a post-industrial hybrid of the academic and industrial research (quoted in Nowotony, 2006).

Second, with the advent of post-Fordist model of production, the need for technological innovations has increased with the increase in number of firms and global competition. Technological innovation becomes a strategy to counteract two factors: low wages and favourable capital structure. The increased investments in new technology are the main source of economies of scale and at the root of successive economic gains, which could eliminate the two factors. The scientific and technological knowledge becomes the part and

[25] Inter languages refer to the transdisciplinary forms of knowledge production which breaks the disciplinary epistemic structure and practices. With the advent of Mode 2 Knowledge Production, the interface among various sciences is increased and subsequently, cross-cultural practices are evidenced and practiced to develop knowledge and technology.

parcel of production since the structural changes in the economy and industry alters the way industry functions. The network of relations, R&D alliances and enterprises of webs become the trend in the present context to decrease the cost of production and diffuses the cost across the inter-firm relations, so as to enable the firm to survive easily within the present economies of scale. The interrelatedness and interdependency between inter-firms alliances and R&D relations are to avoid the cut-throat competition and for mutual benefit out of technology generation. There are two ways of looking at the inter-firm relations and R&D alliance among scientific laboratories, academic institutions and industry. One is associated with the generation of new technological innovation and the other is associated with the transfer and diffusion of technological innovation. These activities are predominantly theorized under the framework of globalisation of innovation. The taxonomy of globalisation of innovation involves three main categories; (1) international exploitation of technology produced on a national basis; (2) the global generation of innovation; and (3) global technological collaborations (Archibugi and Michie, 1995; Archibugi and Iammarino, 1999; and 2002)[26]. The group selections, in technology generation and innovative activities, will be based on the resources and competence such as knowledge, skills, ideas, capital structure and equipments, etc. In this context, Archibugi and Michie (1997) argue that the flows of innovation related information are multifarious

[26] The three main categories of globalisation of innovation are described as follows: First, international exploitation of technology produced on a national basis indicates the export of innovative goods, cession of licenses and patents and foreign production of innovative goods internally designed and developed by firms or individuals. They are mainly profit seeking firms and individuals involved in the process of commercializing the technological innovation at the global scale. Second, global generation indicates that R&D and innovative activities are being conducted at the national level and also the host countries. These activities are mainly carried out by multinational firms. Third, global techno-scientific collaborations deal with two aspects: first, joint scientific projects, scientific exchange, sabbatical years and international flow of students which are mainly involved by universities and public research centres; and second, joint-ventures for specific innovative projects and productive agreements with exchange of technical information and or equipments, which are mainly carried out by national and multinational firms.

in nature. (1) It involves the transfer of technology and knowledge in both market and non-market transactions. For instance, individuals imitate and learn; and know how is often exchanged informally and voluntarily. (2) It takes the form of either tangible or intangible assets. For instance, a piece of machinery and a scientific paper may be an important source for innovation. (3) It is not only limited to firms but also public institutions such as universities, research centres and other government agencies play a crucial role in fostering technological advances. However, Gibbons *et al*., (1994) argue that the globalisation of innovation and information flows destroy the local cultures and organisation activities on innovation. Thus, it brings inequalities to the development in science and technology in developing countries and creates dependency. On the other hand, Archibugi and Pitrobelli, (2003) suggest various policy measures for developing countries to reduce the technological dependency and gaps in knowledge production to reduce the negative effects of globalisation of technology in the present context.

Closed Social Contract of Science: Scientist as Labour and the Accountability of the Scientist

The new organisation of science redefines the goals of the institution of science as commodity and as a consequence, the role of scientific community also changes. This is what Elzinga calls “epistemic drift” (cited in Sardana and Krishna, 2006). The institutional character of science as conceptualized by Merton is lost in the paradigm of commercialization of scientific knowledge. This paved the way to the shift from disinterestedness to interestedness in capitalization of knowledge production. Many scholars (Gibbons *et al*., 1994; Gibbons and Wittrock, 1996; Ziman, 1996b; Krishna *et al*., 2000; Pestre, 2000; Vessuri, 2000; Nowotony, 2000a; Frickel and Moore, 2006; & Kleinman and Vallas, 2006) outlined the reasons responsible for the shift from public to private modes of knowledge production and its consequences. First, scientist as entrepreneur has emerged with the concept of entrepreneurial university which led to the formation of new organisational structure to exploit the knowledge production. Second, the professional competition and commercial pressure constraint scientists not only to hide information and not to publish his / her work but also stop further knowledge production. The first and second reasons are subsumed with the emergence of market capitalism in which law of demand and supply determines the production of new knowledge.

To elaborate further, science is perceived as socio-economic activities and focuses more on the aspects of commodification of scientific knowledge that are produced in the scientific laboratory. In short, science as a social activity is shaped by the law of profit through commodification (Gibbons *et al.*, 1994; Gibbons and Wittrock, 1985). The effective control of market mechanism determines the supply and the demand since economic aspects of science govern the knowledge production with the eye on return on investments[27]. The market mechanism plays a predominant role in bringing science under the marketisation, commercialization and privatization (Baskaran and Boden, 2004). In this regard, social relations and networks are framed and constructed within the pragmatic point of market. It is the process of ideological orientation that hegemonies innovation as socially institutionalized in the capitalist economic development (Habermas, 1962). This has been guided by the capitalist values of new. The innovation is the larger capitalist construct that makes the world as more and more exploitable. It ruptures the values of science as public goods and shifts science from public mobilization to science for private

[27] Economic factors indicate not just means and ends related or profit oriented capitalist investments that determine the knowledge production. It is about a new type of economic rationality which acts as a principle in selecting, constraining, and coping with the ever increasing flow of new uncertainties and options that determines the knowledge production. Thus, the first order of economic rationality is conjoined by the second order of new economic rationality dominated by investments and calculations of profit and derivative economic logic of material objects and scientific results (For further readings, refer Nowotony *et al*., 2001: 37-38). This functions itself an ideology that connects science and policy together in the process of decision making.

utilization. Further, the above process sideline science as intrinsically valuable universalistic cultural activities. This reflects the changed context of knowledge production from social to market interest of science and technology. As a result, science and society relations are largely shaped by the market relations.

This is one of the main reasons for the decrease in public funding on R&D and forces the scientist to depend on private investment. One can see the consequences in terms of decline of open publications, shift in technical and scientific manpower to private corporate sectors. Kleinman and Vallas (2006) argue that the asymmetrical convergence (university and industry interaction) is responsible for the contradiction in practice of science and knowledge production. Rule and Shamoo (1997) observe that globalisation of R&D has reduced the public funding to pharmaceutical industry which makes academia more dependent on industry funding. Consequently, scientists' identity and scientific practice are called into question in the era of changing academic knowledge production. The social commitment of the scientist is lost in the regime of market-governed research practice. Scientific research programmes and scientists' commitment to the society and values have always been in the focus of social science research. In this context, the scientists autonomy over their knowledge production is questioned. The freedom of science and scientists is lost with the mission-oriented research since every scientist is compelled to do what is assigned to him/her. Gibbons and Wittrock (1985) argue that the scientist is conceptualized as a labourer under the capitalist hegemony. The scientist's autonomy and the elite status enjoyed by the scientific community come under the scrutiny in terms of economic efficiency, the language of accountability and return on investments.

Subsequently, according to Ravtez (2003), the priorities of research are not set by scientific community, but by the external interest that supply funds. Thus, the economic factors play predetermined roles in new knowledge production that creates close relation between science and policy. Science which does not fit into the category of market mechanism (such as uncertain and risk, low level of returns in terms of economies of scale and scope and relevance of human values) will be excluded within the gamut of policy consideration. This phenomenon is called as post-normal science (Funtowicz and Ravtez, 2003). Frickel and Moore (2006) explore how the relationship among institution, network and power influence the idea of commercialisation of scientific knowledge. In which, they understand the interactions of rules and routines, meanings, interest, organisation and resource distribution in knowledge production. They specifically focus on various questions such as who benefits from new knowledge production, what knowledge gets produced, who gains access to knowledge, what kind of knowledge is left undone and who takes the decisions about the research agenda. These questions throw light on the power relations involved in the new knowledge production. This is what largely called as the politics of science[28] (Ibid, 2006). For instance, Jacobsson and Lauber (2006) narrate the relations between policy and politics in diffusion of renewable energy technologies in Germany in which they explore the socio-political condition led to the recommendation and formulation of new renewable energy laws in favour of solar and wind energy technologies[29]. Consequently, it exposes the 'politics of policy' in determining research priorities and the choice of technological

[28] The 'politics of science' deals with three important aspects of science: 1) accessibility and controllability of science like decision making in setting priorities of research and allocation of funds, specific interest in new knowledge production; 2) consequences of science such as commodification of science, rupture of university values, etc; and 3) maintaining secrecy in knowledge production (for further reading, refer, Dickson, 1988).

[29] For further reading on history of support for solar photovoltaic technology (refer, Teske and Hoffmann, 2006).

selection as per the changes in wider social and political interest. These are all part of the institutional arrangements and practices which guide the professional practices in the changed era of knowledge production. This change could be called as "epistemic drift in epistemic culture[30]". However, despite the changes in knowledge production, some of the studies point out that university maintains the institutional norms of science and governs the knowledge production practices (Pestre, 2000; and Nowotony, 2000a). In the larger sense, the Mode 1 Knowledge Production based on Mertonian and Kuhn Paradigm of science and scientific practice prevails with the same rigidity of norms. So, the autonomy of science still exists though there are other realms which influence the production and contextualization of science such as culture, economy and politics.

To sum up, Mode 2 Knowledge Production approach is important to understand the different dimensions of techno-scientific innovation in the area of Solar Photovoltaic technology. This is because of the practice of innovation brings different actors into the process of knowledge production and transfer of knowledge to the industry. It helps to understand the various issues associated with the context of knowledge production, actors and intermediaries, and also the politics of knowledge production. This particular framework exposes the economic, social and political aspects of knowledge production in Solar Photovoltaic technology since the knowledge production and transfer are always curtailed in the name of cost economics. So the investments in new knowledge production have been questioned in the realm of demand controlled market regime. The study, with the help of Mode 2 Knowledge Production approach, attempts to highlight the problems

[30] Cetina (2007: 364) describes epistemic culture as set of practices, arrangements and mechanisms bound together by necessity, affinity and historical coincidence which, in a given area of professional expertise, make up how we know what we know. Epistemic cultures are cultures of creating and warranting knowledge. Here the epistemic drift in epistemic culture refers to the change in set of practices, arrangement and mechanism of knowledge production.

faced by different actors in the social process of knowledge production in SPV techno-scientific research and technological innovation.

Mode 2 Knowledge Production in India: Understanding Technological Innovations in the Indian System of S&T

An exploration of the notion of technological innovation in the Indian system of S&T exposes two aspects. The first aspect is that there are certain changes occurring within the Indian system of S&T that influence the process of technological innovation; and the second aspect is that the Indian system of S&T has its own constructed problems in fostering technological innovation, despite the changes. Historically, there has been minimal interaction among the various social actors in the process of technological innovation. Nowotony *et al*., (2001: 69) claim that 'innovation is shaped by history and institutions and nurtured (or the reverse) by a wide range of societal, cultural, political and economic arrangements'. NISTADS Report (2011: 8-9) on "*Understanding Innovations: The Indian Context*" suggests how to approach innovation in India. It attempts to understand the concept of innovation as different from the point of view of developed countries. The articulation provides importance to "Context Specificity". It means there are organisational and cultural differences in nurturing innovation that prevails from one context to the other. Hence, one needs to have an alternative approach to understand innovation in developing and less developed economies. This approach falls largely under three categories. First, unlike developed economies, the weak market forces and inadequate development of market act as disincentives to innovations in the Indian context. Understanding the factors that contribute to the weak market forces would reveal the aspects undermining innovation. Second, the focus should highlight the weak-links of network among technology generation system, user system, production and financial systems. Third, the institutional mechanism or arrangements that fosters innovation through tax benefits, nurturing selected sectors by assigning priorities, nurturing human resources, specific R&D policies, etc. need to be understood and addressed. In short, one needs to understand the historical and socio-political context in which innovations are nurtured in the Indian context.

Various studies show the emergence of a new pattern of innovation in India (Ghosh, 2011; and Desai, 2011). It highlights that India is emerging as an "Innovation Hub" for various sectors that contribute to the increase in new knowledge production. For instance, India's global publication share is 12 percent and India stands at the 12^{th} position among the top 20 countries in science and technology. To prove this point further, the recent trends in output publication and patent reveal that there is an increase in the number of publications and patents in India. Majority of the contributions come from priority areas such as medicine, chemistry, physics, agriculture and biological sciences, engineering, biochemistry, genetics and molecular biology and materials sciences. In this regard, the general universities, state agriculture universities and medical collages contribute around 70 percent of the total publications in the above mentioned areas. An increase in patent activities is witnessed in various institutions such as universities, public research laboratories, industry (public and private), etc. However, these patents activities are predominately located in chemistry, chemical technology and related areas, and drugs and pharmaceuticals. Further, the newer areas such as food products and technology, micro-organism and genetic engineering, information and communication technologies are also added to the strong patent activities. Various studies bring out the reasons for the increase in the science and technology output in India. Firstly, one of the major reasons for the increase in publication and patents is the increase in collaboration and interactions with foreign institutions, firms and scientific laboratories. Secondly, private sector participation in industrial R&D has marked a twofold increase. Thirdly, India is emerging as a preferred destination for the off-shore knowledge production activities. Krishna *et al.*, (2012) put forth that the Indian knowledge production has moved from one way technology transfer (adaptive R&D) to two way knowledge transfer (creative R&D). India has emerged as an important destination for about 471 TNCs with 649 R&D units. However, the predominant knowledge production and technology development are located in the six main industries such as pharmaceuticals, automotive, electrical, electronic, chemicals and defense R&D in India. These facts show that new knowledge production and technological innovation are happening but limited only to certain areas. Thus, the Indian innovation system is dominated by sectoral system of innovation rather than a national innovation system. This pushes the present study to understand the other side of the coin which focuses on the problems in knowledge production, transfer of technology and technological innovations.

Social Interactions and collaborations: Problems in Knowledge Production, transfer of technology and technological innovation

It is difficult to adopt Mode 2 Knowledge Production in the Indian context (Krishna *et al*, 2000; Sardana and Krishna, 2006) as a conceptual framework, it is derived from the Western experience and consequently, its application in the Indian context explores little on what happens in the various spheres such as knowledge production, transfer and technological innovation[31]. This criticism suggests that Mode 2 theoretical framework is

[31] Note: In this regard, Mode 2 Knowledge Production as a theoretical framework generalizes the way knowledge is being produced now. It talks about the general context in which the organization of science happens for techno-scientific innovation. In the larger context, it neglects to examine how these changes operate in different settings, thus devoting insufficient attention to the potential comparative research (Hansen, 2009); it is difficult to adopt Mode 2 Knowledge Production in different context in which knowledge production happens (Hessels and Lente, 2009); the concept of social robustness is yet to take

inadequate to understand the Indian experience of science and technology development. There are two factors that underscore this phenomenon: Firstly, unlike the developed countries, in India, contribution of indigenous science and technology to industrial and economic development has been very low. There are various studies from different sectors such as IT, Pharmaceuticals, Biotechnology, Telecommunication, etc., which articulate the reasons for weak social participation and institutional linkages between various actors such as industry, government, academia and consumers in knowledge production and transfer of technologies to industry. These studies reveal that the industry, government, academia and civil society in the Indian context are perceived as distinct entities which rarely come together or as interacting occasionally when there is a need-based knowledge production. Secondly, various studies show that science and technology as a resource and a commodity influence and confine the practice of Indian science and technology within the Western paradigm of S&T. This highlights how the Indian knowledge production and industry are in a locked-in position and path-dependence, which curtails the technological needs of the country. Despite the sectoral differences, the above two factors reveal the general problems of the Indian S&T system and the factors which undermine interactions and collaborations between various actors in knowledge productions, transfer of technologies and technological innovation.

Organisation of Science for Industry in India: A Critical Outlook

Linear Model of Science and Technology in India: A Disjunction between Policy and Practice

Each social actor has a different set of problems, which culminates the interactions between knowledge production and transfer of knowledge and technology to industry.

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shape in science-society interactions (Rip, 2009); Mode 2 Knowledge Production should be considered as a tool box and a sensitizing concept rather than a sociological theory of Mode 2 Society and Mode 2 Science (Wehling, 2009).

Jairath (1984: 111) puts forth some fundamental questions on why the ultimate aim of S&T policy in transferring science to industry fails in India. He outlines two prominent reasons for this: science has developed inadequately (insignificant contributions to the body of knowledge, and not transforming scientific knowledge into technology) and inappropriately (the technological aspect has been ignored in understanding and contributing to the body of scientific knowledge). This affects the transfer of knowledge and technology to industry. Shiva and Bandypadhyay (1980: 592) claim that the gap between science and its application is the gap between science studies and science policy in India. The meeting point of science and policy occurs when science is taken to the public via technological development, but the social actors are in divergent positions which create unavoidable problems and a tension between the two social spheres - politics and science. Krishna (1994) points out the reasons for the social tension in S&T policies in India that creates a disjunction between theory and practice: 1) technology priorities are left to implementing sectors and agencies; 2) absence of mechanism through which knowledge generation transfers into knowledge applications; 3) tension between context of legitimation (National socio-economic goals as articulated in S&T policies) and context of research; and 4) institutional weakness in bringing skilled human resources and entrepreneurial talents in new knowledge production. In short, the weak institutional structure and incoherent framework discourage wide actors participation in the social process of innovation. Thus, Kathuria (2010) argues that science policies in developing countries create unfavourable conditions to transfer of knowledge and technology from academia to industry. Siddhartha (1991) points out that an integrated policy framework in terms of bringing science, technology, and industry development under one roof would provide a coherent approach to national development, but this approach is missing in Indian science policies. Several studies attempt to understand the interrelated phenomena such as inappropriate incentive structure, lack of policies for commercialization of indigenous technologies and weak policy measures on improving S&T capabilities and infrastructure facilities which affects the development of science and technology. For instance, inappropriate R&D incentive structure affects R&D institution and firm collaborations in purchasing indigenous technology license and development (Ray, 2004). Lack of institutional mechanism in promoting patent and technology transfer hampers the diffusion of knowledge from academia to industry (Sardana and Krishna, 2006). Weak inter-linkages between R&D institutions and potential users in India (Mehta and Sarma, 2001; and Krishna, 2001); ineffective policy mechanism such as tax incentive, financial assistance, and low entrepreneurial efforts affect the process of technological innovation in Briquetting industry in India (Clancy, 2001).

Several studies attempt to understand the transfer of knowledge and technology at the level of public research R&D and academia in India (Hyndman *et al*, 2005; Krishna and Chandra, 2009; Chandra, 2010; Kathuria, 2010; Arumugam and Jain, 2012; and Nandagopal, 2013). These studies attempt to look at the corporatization of academic culture and science in India. Such studies are located at two junctures: one, it points out the prevalent Acts and practices followed in developed countries such as Bayh-Dole Act, National Co-operative Research Act, technopreneur, technology park, Technology Transfer Office (TTOs), etc that contributed to the effective transfer of technologies to industry; and two, it attempts to understand the existing practice in different academic and R&D institutions in India. These two levels of understanding made the scholars to reflect on the practice that exist in India regarding transfer of technology and the industry-academia partnership. For instance, emerging new institutional mechanism, in IITs, fosters different modalities in transfer of knowledge and technology: 1) licensing of technologies and patents; 2) industrial consultancy; 3) mobility of faculty to industry and vice versa; 4) incubation and joint IIT-industry centres; 5) strategic research coalitions; and 6) research / technology parks. However, out of the above modalities, sponsored research and industrial consultation, bring government, industry and academia interactions. Such coalitions and sponsored research prevail in the frontier areas of research such as computer science, information and communication technology, etc. At the same time, IITs play an insignificant role in transfer of technology licensing to industry and handle a low level of patent applications compared to foreign universities. Likewise, not every technology developed in laboratories is transferred to industry. The new alternate model of commericalisation is required to facilitate those technologies which are highly prone to market failures. To avoid such failures, the concept of de-risking technology development is required through external supporting mechanism to sustain the longer period of time in developing and commercialization. Along with effective mechanism, new start-ups and entrepreneurial ventures could easily take off. For this purpose, formation of course work as per the industry needs has to be incorporated. Likewise, the joint projects in the form of industry sponsoring students' research at the level of M. Tech and PhD have to be materialized to ensure effective participation of industry in academic knowledge production. Facilitating the culture of entrepreneurship is encouraged within academic and Indian public funded laboratories to ensure effective transfer of technology and academia-industry interaction. Scholars also believe that academia-industry interaction could be enhanced along with other institutional mechanisms such as National Research Development Corporation (NRDC), National Science and Technology Entrepreneurship Development Board (NSTEBD), Technology Information, Forecasting and Assessment Council (TIFAC), Technology Development Board (TDB), Home Grown Technology Programme, National Innovation Council and 'Innovation Act 2008' and declared 2010-2020 as the Decade of Innovation. In the midst of these initiatives, one can say that the corporatization of academic culture and scientist-entrepreneur relationship are less prevalent in the Indian context.

Linear Model of Science and Technology in India: Reasons for the Disjunction between Science and Technology

Katrak (1997) claims that there is a gap between the type of research carried out in research laboratory, and the type of research required for industry in developing countries like India. Other studies claim that the Indian industrial R&D lacks commercial outlook (Mani, 1990; and Ray, 2004) and problems in materializing the techniques developed in a laboratory into commercially viable products (Prasad, 2005). Subsequently, it affects the assimilation, absorption, and accommodation of technology. Gupta and Sharma (2002) argue that the professional environment and socio-cultural context shape the practice of science. So, one need to understand various facets, which dampen the practice of science, transfer of knowledge and technology to industry.

Conflict between Academic Science and Industrial Science:

One of the main reasons for the lack of transfer of technology is that the Indian academic system is largely focused on publications rather than on patents and technology development (Mehta and Sarma, 2001; Sardana and Krishna, 2006). Kathuria's (2010) study unfolds that style and the nature of functioning between academia and industry create disjunctive position. The generic nature and cultural embeddedness of universities affect the university-industry interactions (Joseph and Abraham, 2009: 492). Thus, we can find a strong conflict between academic science and industrial science in the Indian context[32]. Basically, this structure of conflict emerged in the colonial era that gave importance to basic science (Jairath, 1984; and Krishna, 1997). Colonial science as a social practice and ideology introduced the distinction between result-oriented science and curiosity oriented science, which made science a commercial activity (Kumar, 1995). Subsequently, paper-patent conflict always exists even within industrial laboratories, since majority of the scientists were trained and socialized under the ethos of values[33] (Visvanathan, 1985). Krishna (1991: 104) argues that ethos of values includes cultural as well as economic, but in reality, there is little connection between science and economic growth, thus technological progress is affected. Visvanathan (1985) points out the disjunctive link between fundamental and applied science in understanding the core problems of industrial application of science and thus, affects technological development. He articulates further that India followed the linear model of innovation – which provides importance to science push and demand pull. Actually, it is a social product of colonized minds in response to Western science and development. This model of innovation accentuated knowledge excellence as an intellectual pursuit. This created conflict,

[32] For further readings on role of S&T in development, and ideological conflict that leads to disunity between pure (science) and applied science (technology) in colonial India refer (Kumar, 2009; Abrol, 1995; and Krishna, 1995).

[33] Visvanathan (2009) explains the historical conditions in which industrial research was established and institutionalized in India. By tracing the trajectory of industrial research, his narratives show the broader picture of how industrial science finds its resistance to institutionalize science for economic (& cultural) development. The conflict is not about the negation of science for development, but technological development should precede science education, for which nurturing the culture of science has been given prime importance. This exposes how Indian industrial science is trapped within the linear model of science and technology without considering the economic fact of market. In spite of this, academia-industry collaboration has been existing in India since 19th century onwards.

contradiction and disjunctive positions (science and technology) by creating hierarchy in knowledge production that acted as a constraint for the emergence of entrepreneurial science[34] in the post independence era. However, Abrol (1995) claims that populist interpretation in innovation theory distorted the discourse envisaged by a group of experts such as Saha and his associates, who influenced the ethos of science culture in India. In reality, the group attempted to nurture a culture of science that facilitates technology for industrial production by giving importance to fundamental research. Though the group makes a clear distinction between science and technology, they consider both as a single knowledge system. Thus, they were referring to the practice of technoscience in the Indian context. Further, he claims that division of labour in knowledge production brings science and technology together rather than creating hierarchy. The goal of this group attempted to foster network based R&D system through which adopting technologies and improving them for local context got prime importance along with concern for national goals of economic development. Krishna's (1995) articulation on colonial science constructs more light on the nature of research practice that was encouraged to be followed in the post-independence period. Basically, it was an ideological conflict between Saha and Bhatnagar in enforcing the organisational ideals of scientific practices. The former encouraged an equal role to pure and applied sciences whereas the latter argued for clear institutional differences and objectives between the two. According to Bhatnagar, university is the ground for pure science and public funded R&D should focus on applied research. But,

[34] Visvanathan's (1985) seminal work "*Organising for Science: The Making of an Industrial Research Laboratory*" attempts to understand the social process of organizing science for industry and its problems in National Physical Laboratory, India. Various issues are examined to understand the factors that contribute to innovations in India: 1) intellectual debates on nurturing industrial science in colonial and post-colonial context; 2) science-politics nexus in deciding laboratory locations and research priorities; 3) paper-patent conflict; 4) factors impeding invention-innovation (transfer of knowledge and technology to industry); 5) bureaucratisation of science; 6) reasons for the lack of synergy among pure and applied science and technology; and 7) centre-periphery model in understanding the collapse of the local market.

Saha encouraged autonomy of science by exempting scientist and scientific practice from the bureaucratization process whereas the latter emphasized on the control and regulation of R&D institutions that brought scientists under the notion of accountability and autonomy of science in the hands of government control. In short, these dialogues reflect the two different Models of organisation of science that were encouraged since colonial era.

Habermas (1991) argues that the social practice of science is historically nurtured by an ideology of purposive rationality of the state. In the Indian context, the purposive rationality of scientific practice varies from public research R&D to academic system. The university culture grooms scientists on fundamental research compared to public funded R&D rested on applied science. In general, the discourse on what kind of a scientific practice one should follow determines the nature and character of knowledge production in Indian scientific laboratories. Abrol (1995: 278) adds another dimension to the above condition. The 'science and culture' group in colonial context provided much importance to incremental innovation rather than radical innovation. This introduced the notion that India should adopt technologies from West and improve it in the local context. It focused on developing generic scientific and technological knowledge rather than attempting to develop end to end products and services. Such activities are partly driven by the influence of Western technology and science. Thus Big Science Model provides importance to science and technology, which are highly influential at the global frontiers. In this regard, science (scientific elites) -politics (political leaders) nexus plays a major role in the decision-making process from the practice of science to setting research priorities and allocation of funds. It indicates the process of bureaucratization and politicization of science that happens in India. Krishna (2001) argues that political-bureaucratic culture was based on the science-political alliance initiated in the Nehruvian era. It changed the trajectory of science by introducing the phase of policy for science. However, this culture of science under the control of bureaucracy and political system became the model of organizing science in the post-colonial era in which academic science was neglected at the cost of industrial science. Consequently, the contribution of academic science to national innovation system was relatively low and nurtured little linkage among different actors and killed the culture of innovation. Thus, India follows Top-Down approach in facilitating research and development (Krishna, 2001: Abrol, 2006). Jairath (1984: 124) claims that top-down approach is a feudal practice in which bureaucratic-hierarchical arrangements decide the nature and character of science that is to be practiced. Majority of the science projects followed 'Big science' model or mission oriented approach to generate technology. Banerjee (2010) describes the conditions in which the 'Mega Science' or 'Mission-Oriented Science' fails to take off in India. He provides three reasons: 1) weak political will; 2) low funding and accountability; 3) research in multi-party multiple locations project with micro research strategies by participants underscore mega innovations. This model of science follows a marginalized approach in terms of policy, funding, infrastructure development and resources to sciences which do not fit into the culture of modern science. Subsequently, Krishna (2001) argues that the academic science in Indian context is at the stage of declining trends. To some extent, Kothari (2004) points out the decline of science disciplines are affected by political and bureaucratic control. These reflections one can see in the scientific performance and low infrastructural facilities in the Indian academic system.

Weak Infrastructure Facilities[35] and Performance of Scientists:

The low level of scientific manpower, performance and technological capabilities hamper the interaction between academia – industry and government and their participation in knowledge production. Some studies show the factors that constrain scientific productivity and performance of scientists in the Indian context. Pattnaik's (2003) study shows the direct relations among reward structure, infrastructure facilities and role performance of scientist in various universities and research institutions. The scientific productivity declines with the lower infrastructure facilities and reward system. However, the former IIT Director K.L. Chopra accepts that weak infrastructure facilities lead to low quality of knowledge production but he also emphasizes on the need for an effective peer review system and social audit (Chopra, 2004). However, in Indian context there is no effective peer review system (Haribabu, 1991) due to decline in the number of academic scientists (Krishna, 2001). Pattnaik and Chaudary (2006) study reaffirms that absences of appropriate reward structure, funding and work environment affect scientific practice and knowledge production. Altabach (2005: 66) argues that the weak infrastructural facilities in terms of laboratory, library and journals in developing countries hamper research and locate research institutes and universities only at the level of teaching. Chatterjee and Moulik (2006) discuss about the social conditions of research environment and how it leads to decline of science studies in India. They point out the lacunae in the Indian research system such as low resources, facilities, and opportunities. Gupta (2010) argues that this system of S&T creates academic dependency even in premier institutions like IITs. Gulhati (2007) summarizes the existing conditions of IITs at present ''Its autonomy

[35] Scholars who employed Innovation system perspective to explore the issues associated with innovation in India claimed that the weak infrastructure facilities and bureaucratic hurdles pose a major challenge to the emergence of quality research (Refer, Herstatt *et al*., 2007).

is seriously eroded; its infrastructure is wearing thin; laboratories are getting outdated; faculty is depleting; and the competition for admission is pushing aspirants into an unhealthy grind" (quoted in Jayaram, 2011). Finally, the culture of academic system produces a low level of skilled personnel and leads to low quality of knowledge productions (Narashimarao, 2009) thus calls for immediate investments in advanced equipments and laboratory facilities to facilitate the intake of students in science and technical education (Reddy, 1997). Likewise, Varghese (2006) argues that pure science is drastically declining and also leading to the shortage of R&D personnel in certain specific fields such as physics, chemistry and mathematics. Garg and Gupta (2003) study unfolds that the weak career mobility in science makes science studies less attractive among children and parents in India. This stimulates the brain drain in the Indian context.

Influence of Western Science in India: Social Interest of Knowledge Production

There are a set of studies in Indian S&T, which attempt to expose the centre-periphery model[36] in understanding the power relations and why the Indian knowledge production is unable to solve the social and economic problems of India. One needs to have a deeper understanding of the influence of Western science in India. Chakrabarti (2004) argues that Western science as a hegemonising device influences the Indian knowledge production and thus, hegemonies the practice of science and technology. Various scholarly works, on social studies of science and technology, criticize that the Indian S&T system is highly integrated into the Western paradigm. As it articulates, though the national structure affects the technological direction but from the third world perspective – the national system of

[36] Note: Certain scholars opposed the idea of employing the model of centre-periphery as they consider it as coherent system to understand the local practices in connection with the global interactions in techno-scientific knowledge production. Scholars claim that the boundaries are transcended and became more deterritorial with the movement of people and knowledge, thus the reconfiguration happens through reterritorialism, that is, via technology (Refer, Anderson, 2002).

science and technology is always influenced by the networks of relations and power (Prasad, 2006). It shows how the power structure is incorporated into the Western modes of knowledge production and also reveals the way social participation occurs in the real context of development of S&T. The development of S&T within this paradigm that involves the state, industry and academia in developing technoscience is largely questioned in India (Abraham, 2006). Thus, Anderson (2002) describes the new configuration of technoscience that consists of interaction between local and global, technologies, practices, mobility of people and knowledge and contestation over intellectual property. Understanding such elements reveals the context in which science and technology in periphery is stuck in the Western paradigm of theories and method. Nandy (1980) argues that the mode of knowledge production exposes the nature of subjugated knowledge and the identities of science and scientists in India. For instance, Nandy argues that Western values of science created a social tension within the minds of Indian scientists such as JC Bose[37] and Ramanujan. Subsequently, it curtails scientific creativity and annihilates the scientist and knowledge production[38]. Thus, Indian science and scientists are located at a socially unequal position to the Western forms of knowledge production in which publishing a paper is a power relations (Abraham, 2006). This unequal position, Shiv and Bandyopadhyay (1980) argue, is the result of locating oneself within Western science by

[37] Dasgupta (2009: 334) shows the birth of technoscience in J.C. Bose's work on radio wave transmission. His earlier work is the combination of instrumentation and experimentation. First, Bose devised an instrument for laboratory experiments in solid-state physics to produce an artifact for the application of telegraphy that is technically viable.

[38] Note: Nandy's (1980) study is focused on the psychological aspects of two Indian scientists, namely J.C. Bose and Ramanujam, to understand the nature of science practiced in Third World. Nandy consciously avoided science as social process which leads to technology generation and applied knowledge by considering the fact that it may sideline his purpose of the study. He focused his study to understand the scientist's scientific creativity and how such creativity affected the individual minds in the realms of Western science. Thus, he describes Western science as oppressive in nature. Here, I reviewed Nandy's work to mention how Western science affects the creative process of scientists in India.

selecting a research topic which is ongoing in the Western journals and publications. Such scientific practices not only affect the creative process of the scientist, but also the scientist's commitment to social and economic problems gets sidelined. Hence, they describe the Indian scientific community as fragile in nature.

A major part of the critique points out that research carried out by scientists is of little use to the social and economic problems of our country (Siddhartha, 1991; and Balaram, 1994) and is rarely driven by technological compulsion (Rajan *et al*., 1997). In this context, Balaram (2011) quotes the citation of the former directors of IITs P. V. Indiresan and N. C. Nigam to criticize the way premier institutions like IITs function:

"[It is] critically important for the faculty and staff to develop a pride in the Institute as an Indian Institute of Technology, not as an imitation of some foreign technological institute. This entails an orientation towards problems confronting India and a realization that the development of an Indian technology for dealing with Indian problems can be both interesting and exciting."

The reflection indicates the nature of scientific practice and the functioning of our academic institutions would have been highly influential in terms of contribution to national development, if it would focus its target on what is the social and economic problem of our country. However, Bourdieu (1999) points out two important factors that guide scientific practice: one, is about attaining scientific authority and other, talks about profit. The former emphasises on prestige, recognition, fame, etc whereas the latter provides importance to investments that focus on average chances of profit (specified in terms of capital). The interest is intrinsically related to the scientific activity and also formulates the strategies to achieve such interest. In the Indian context, scientific practices are shaped either by the reward structure that facilitates values of knowledge production or by commercial interest. For instance, publishing paper in journals (especially international) provides recognition and promotion to Indian scientists (Haribabu, 1991; and Pattnaik, 2004). In this case, Dasgupta (2009) provides reasons as to why J. C. Bose's theory on physiology was unacceptable as scientific knowledge among his peers of his time. Within the colonial strategy, Bose's theory of science was considered impractical ideas for economic activities. His theory was socially accepted as pure, simple and as a dogma of life rather than as science. Though publishing a paper or contributing to existing knowledge is considered as prime means, one also needs to look at the economic benefits of practicing science. Thus, the scientific and social determination of practice is largely shaped by social recognition and economic benefits of science in Indian context. Subsequently, Bourdieu (1999) claims that these phenomena influence the present day struggle between different specialists for research grants and facilities. However, this struggle is not only about gaining political power, but also epistemological in nature.

In simple, the trap has been constructed in the form of Western science and Western laws of economic production which govern the local knowledge production (Kumarappa, 1951; and Seshadri, 1993). Subsequently, it is the double trap which functions as the mode of knowledge production, and also shapes the trajectory of knowledge and innovation in the local context. It legitimizes mass destruction and consumption of energy as a part of the social progress; hence science is an integral element in the process of development (Viswanathan, 1997). It discouraged the science which did not fit into the colonial strategies, for instance, Malaria research was one of the neglected sciences and other sciences such as botany, geology, and geographical science got importance since it had commercial value (Kumar, 1995). This is how a particular social organisation of science (institutional as well as epistemic) structure creates a particular mode of politics (Prasad, 2006).

Commodification of Science and its Consequences in India:

Another set of studies expose the new organisation of science and its consequence in India. At present, as we have discussed earlier, the new organisation of science is organised within the idea of commercialization or commodification of science ruins the welfare state of development. Thus, Pestre (2000) criticizes that Mode 2 Knowledge Production is backed by the neo-liberal ideology in which market demand and competition for a product determine the nature of knowledge production. It enforces new social and political order, that of economic neo liberalism. Moving away from the goals of socio-cultural requirements of knowledge hampers knowledge as social goods (Cowan, 2005; and Krishna *et al.*, 2000). For instance, economic investments happen if economic viability of the product exists or else, it excludes the science which is considered non-economic and unprofitable. This is called Unsound Science. It has constructed the notion that scientific knowledge is a valuable commercial product and the knowledge that is less in terms of commercial value is considered detrimental to the national economy. The science as a public good is always neglected in the practice of science as market oriented practice. Market forces determine the scientific research and thus influences national innovation systems (Bhagavan 1995; and Rana, 1995). It exposes that the knowledge production towards market oriented goals creates negative impact on the Mode 2 Knowledge Production. For instance, in the Indian pharmaceutical industry, most of the large scale firms, such as Ranbaxy, Dr. Reddy, etc., focus on the market oriented innovation and especially focus on western market needs rather than on Indian markets. At this juncture, the knowledge production in welfare oriented science and technologies such as health, medicine (& Ayurveda) that satisfy the needs of the people are commercially excluded and thus socially excluded too. Most of the innovations are of little relevance to the technological needs of the country.

In this context, the projects of social engineering such as systems of innovation are severely criticized since the created innovations are not pro-poor. Globalised knowledge production process benefits the rich countries and affects the development of pro poor technologies. For instance, neglected diseases such as TB, Malaria are considered as low profit areas since the foreign countries are less affected by these diseases. Abrol (2004) claims that Indian pharma firms believe that investing in neglected diseases would be a financial burden, which may result in low economic gain. With the institutionalization of modern science, Sujatha, V. (2011) argues that the practice of innovation at the level of traditional knowledge is socially excluded as unscientific language with the western practice of modern medicine in India. It curtails further knowledge production in traditional sectors. Likewise, many studies criticized that the market oriented laws neglected the need for R&D and knowledge production in non-conventional energy technologies which affected rural electrification programmes and created more energy problems in India (Chandrasekar, 1995; Reddy, A.K.N, 1999; and 2001). This reflects that it is not the market that determines the law of production but mediated by government by which it failed to recognize problems of society and the concept of welfare state. Swedberg (1994) argues that the market is a social structure not only controlled by law of demand and supply but also that the government puts a constraint on price mechanism in the form of public policy to ensure the concept of welfare state. This may be in the form of various instruments such as subsidy, tax evasion, etc. This is clearly reflected in various energy policies in India which neglect the massive investments needed for decentralized source of power production and technology development in renewable energy (Sagar, 2004). Likewise, NISTADS Report (2008) reveals that the public science and energy science are the least priority areas of sciences in terms of research publications, output and international collaborations in India. It is not only limited to science studies but also the sociology of science and technology on energy (especially renewable energy) studies are also little focused in the Indian context (Made argument in the beginning of this chapter).

Indian In-House R&D and Industry in the Era of Globalised Production and Innovation:

With the advent of globalisation and liberalisation, there is a relocation of work and production taking place from the developed to emerging economies and developing countries, since 1990s. Several studies (Beck, 2000; and Sennett, 2006) throw light on the emergence of new forms of network as an economic activity to meet the demand structure or competitive pressure of the world economy. The new system of economic production fosters networks of relations between economic and scientific organizations since innovation becomes the institutionalized means to survive in the global competition. As a part of this development process, globalisation of innovation and internationalisation of R&D led to the search for new resources such as scientific labour, S&T infrastructure and flexible structure of patent laws. Reddy (1997) claims that global technology development is stimulated by two factors: one, the gap in technology development; and two, the demand for S&T infrastructure, rise in high skilled manpower and resources.

First, the gap in technological development makes the local firms to depend on technology from foreign firms. For instance, Ray and Saha (2009) trace the technological backwardness and low technological progress in the manufacturing industry in India. Such an attempt reveals that the protectionist strategies in terms of technological self reliance and import substitution hampered the acquiring and upgrading of technologies and technological capabilities. Consequently, India was unable to keep pace with the global technology frontiers in the post liberation period. In this regard, Kumar, N (1997) claims that India's import of technology has increased in post 1990s and such dependence will make India as a technological obsolescence.

Secondly, the demand for S&T infrastructure, rise in the cost of high skilled manpower and resource scarcity brought synergies, collaborations, joint ventures and technological tie ups since the firms are embedded within the structure of global production and innovation. This has two implications in the Indian context: one, it pushes Indian firms into a technologically locked-in position in terms of knowledge production and innovation; and two, creates the culture of import which destroys indigenous knowledge production and technology development. Various scholars expose the neo-liberal ends of globalizing economy (Dasgupta and David, 1994) as exploitative in character, which destroys the existing practices of S&T at the local level and creates dependency and a locked-in position. Osborne (1999) argues that the institutionalization of Western technoscience by underdeveloped nations benefits the First World countries. It injects various changes into the direction of nurturing science and scientific communities in India. Banerjee (2010:319) argues that ideological stance on deregulation ruined the research practice within Indian R&D institutions and subsequently, industry interaction increased social accountability and audit. On the other hand, many studies, in India, explain how the low innovation trajectory prevails in various sectors due to path dependence. For instance, in the Indian IT sector, which mainly arose out of the IT sector's dependence on the export of service to one single market (especially, the U.S.A.) led to lesser investments in R&D in the Indian IT industry (Parthasarthi and Joseph, 2002; D' Coaste, 2002; Krishnan and Prabhu, 2002; and Ilavarasan, 2006). Likewise, the trends and nature of R&D investments in various sectors such as IT industry and pharmaceuticals show that the MNC controlled in R&D centres dominate Indian knowledge production (Devaraj and Vigneshwara, 2011). However, MNC centres play a predominant role in new knowledge production and hold a larger number of patents compared to Indian firms. The sector of Information Technology is the best example of it (Mani, 2009); it led to the attraction of local scientific manpower and resulted in internal brain drain (Kumar, N. 2001).

However, various other studies point out that the import of technology led to a decrease in the in-house R&D efforts in Indian public enterprises (Ghosh, S. 2011). To a great extent, our outward policies encouraged the TNC and the MNC to capture the Indian market and reduced the profitability of Indian public and private firms. It eroded our technological efforts in the era of globalization of technology. Kumar and Aggarwal (2005) argue that there is a decline in technology licensing and an increase in importing technologies from abroad after the liberalisation. For instance, the C-DAC and ISRO Insat Satellite series (Chandra, 1993) and C-DOT (Saha, 2004) are some of the best examples of this phenomenon. In short, the globalisation of technology and FDI investments in technological intensive sectors affect developing countries' effort on technology development for which the IPR regime, WTO, Dunkel Draft, etc become an instrument in enforcing their agenda on marketisation of technology. At the same time, there is another set of studies, which shows that the low end jobs are predominantly relocated to India (Arora *et al*. 2000). For instance, the IT sector, automobile, electronic industry and the growth of pharmaceuticals utilize the low cost human resources in India. As a result, it demands work relations to be deregulated and flexibilised in nature, which increases the insecurity or job risk. The incoming of jobs does not mean that the first world countries' labour reserve army of labour is unable to meet demand structure of work or in other words, the economy is over employed. The search for extra labour reserve army is to reduce the cost of work to maximize the profit nature of capitalism (Patnaik, 2008).

To Summarize:

From the above theoretical reviews, two aspects of knowledge production and technological innovation are evident: first, the factors undermining the technological innovation which need to be looked at from within the Indian context such as institutional mechanism, problems with academic and scientific institutions, in-house R&D knowledge production, industry and government on technological innovation; and second, the factors undermining the technological innovation which are need to be looked from outside the Indian context such as globalisation of innovation and internationalisation of R&D which influence local knowledge production and technological innovation. These two reveal that there are certain problems which exist within the Indian innovation system at various levels such as knowledge production, transfer and technological innovation. On the other hand, despite these constraints, India is emerging as an important destination for new knowledge production in restricted areas such as pharmaceuticals, biotechnology, ICT, automotive, etc. The other areas such as neglected diseases like as TB, Malaria, and Cholera, public health, renewable energy science and technology etc, are ignored in the market controlled paradigm of knowledge production. This is not only limited to the sciences but also social sciences. The sociology of energy studies and sociology of science and technology studies on energy technologies are ignored by the modern day practitioners of sociology of science and technology. Visvananthan (2011) argues that the sociology of science and technology is a democratic necessity and one should have democratic imagination to explore the problems of our contemporary Indian society. However, in reality democratic imagination has been limited to the issues which are chiefly experienced in the process of development such as ICT, Biotechnology, and Pharmaceuticals. Sociologists have looked at the developmental and modernization context of India in which energy studies are misplaced; so the real reflection of imagination (reflexivity) is also misplaced. However, with climate change and resources constraint, sociologists of science and technology in India attempted to explore various issues underlying the energy sector in India. This thesis is a part of a larger context which we discussed earlier, and it explores the factors constraining SPV technological innovation in India by focusing on the knowledge production in techno-scientific research and the industry development in India.

Structure of the Thesis:

The dissertation consists of eight chapters including the introduction and the onclusion. The review of literature, in the first chapter, foregrounds and articulates various issues associated with the development of STI in India. It critically looks at the factors which, according to extant literature, are responsible for the impediments of technological innovation in India. The second chapter describes the design and the content of PV technology, structure of PV industry, and critically examines the position of Indian PV industry to find the core issues of PV technology development in India. This chapter also describes the methodological procedures, tools and techniques that are followed to collect the data from various actors such as Indian Institutes of Technology, Public Research

Laboratories, Government Officies and Indian SPV firms. The third chapter contextualizes solar energy in India by examining the contexts in which solar energy technology initiatives have emerged and articulated and how it has undermined the regime of state controlled energy production. The fourth chapter looks at the political economy of SPV technology in India to understand the historical context of the emergence of PV industrial R&D and industry development to know the factors, which hampered R&D and industry development. The fifth chapter reveals the factors, which curtailed the industrial R&D at various scientific and academic institutions and in-house R&D in SPV technology. The sixth chapter illuminates the present conditions of industrial R&D at various scientific and academic institutions and in-house R&D in PV technology. The seventh chapter deals with the nature and structure of Indian PV industry and throws light on various issues affecting Indian PV industry in association with technological innovations. The final chapter provides the summary of findings, draws some conclusion on the basis of findings and future trends in social studies of SPV science and technology.

Understanding SPV Technology and SPV Industry: Locating the Problem and Methodology

Introduction:

This chapter describes SPV technology, successive generations of SPV technologies and the emergence of new technologies in SPV. Firstly, the chapter exposes the structure of PV industry. Secondly, the study locates the Indian PV industry and examines its nature of technological and institutional dependencies. This reveals that Indian PV industry is located at the end stage of production. Furthermore, the chapter attempts to understand different issues associated with the development of SPV technology. From which, the study articulates the research problem, research questions, and its objectives. Thirdly, this chapter narrates the methodological procedures, tools and techniques that are followed to collect data from various actors.

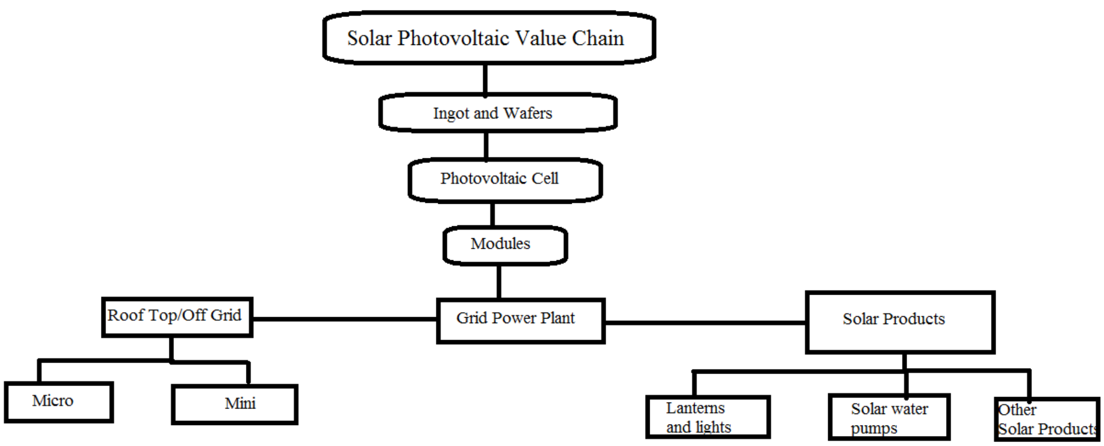
Understanding Solar Photovoltaic (SPV) Science and Technology and PV Industry: Content and Design of PV Technology and Classification of PV Industry

Content and Design of PV Technology:

The Solar PV technology converts sunlight (natural resource) into electricity through a device known as PV cells[39]. The SPV cells consist of semiconductor materials called wafers (silicon), which have the right optical properties that enable sun radiation to generate electricity. The SPV module is a number of interconnected PV cells. SPV module, a commercial component, varies in size, voltage and power ratings to constitute the building blocks of a solar PV system[40]. The PV technological system has two designs that vary as per the electrical connection: the autonomous off-grid (stand alone systems) and the grid connected systems. The former indicates that the SPV field is connected to a means of energy storage (usually electrical batteries) which helps to store the energy

[39] Refer, Markvart and Castaner (2003: 71-95) for deep understanding of science behind solar cells.
[40] Refer, The German Energy Society (2008) for further of understanding of what is SPV Modules.

produced. The stored energy can be used when the sun does not shine. The latter indicates that the power conditioning system needs to operate continuously, so it requires an inverter to convert the direct current produced by the modules into useful alternating current. The final part of the PV system is its supporting structure called "balance of systems" and includes power conditioning systems, wiring and eventual storage systems. There are two categories of systems: the mounted on-purpose-built structure (that is power plants in open fields and PV systems on flat roofs) and building integrated systems, which use part of the building structure for support. Diagram No: 2.1 shows the SPV value chain and industrial production.



Successive Generations of PV Technology:

SPV techno-science is classified into three generations based on the construction of materials, technologies and innovations. Table No: 2. 1 shows the features of successive generations of PV cell technology and materials employed in the construction of the PV module. The first generation of PV cell occupies large area, with single junction but high quality device. The silicon wafers (c-Si) technology such as mono and multi-crystalline cells dominate the process of production and market concentration. The second generation solar cells are constructed from the materials of cadium telluride (CdTe), copper indium gallium selenide (CGIS), amorphous silicon, polycrystalline silicon and micro amorphous silicon. These materials are applied in a thin film (technology) to support substance such as glass or ceramics to reduce the material mass and cost of production. Amorphous silicon (a-Si) is the leading technology in the market. The reduction of manufacturing cost of PV cell is the driving factor for the shift from first to the second generation. For instance, the transition of materials and technologies, from the first to second generation, is not purely based on the efficiency of a material and technology but rather on the reduction in the rate of energy consumption by silicon crystalline in the process of production, which stands at 4600 (MJprim/m2 module) compared to thin film the rate of consumption of energy which stands at 1600 (MJprim/m2 module). However, the viability for producing consumer products holds the main thrust of these technologies. Subsequently, the second generation technologies attract investments in R&D, in the midst of low efficient technologies compared to first generation. The innovation in the process of production of thin film not only reduces the process timing but also saves labour involved in the process of production (for a better understanding of the process of production of PV crystalline silicon, See, Alsema and Nieuwlaar, 2000). The third generation cells, at present, are just at the level of laboratory research. These are nanocrystal solar cells, tandem cells, photoelectric chemical (PEC) cells, polymer solar cells and organic solar cells, dye sensitized solar cell (DSSC) and hybrid-inorganic crystals within a polymer matrix. The cost of the production still dominates the R&D investments which mainly focus on the technological efficiencies such as electrical performance and low cost of production. However, at present these technologies at the laboratory scale. **(Table No: 2. 1)**

Table No: 2. 1 Shows the Different Generations of Photovoltaic Technologies[41]

Generations	Technology	Solar Cell	Solar (Module) Efficiency Achievement			Technological Benefits	Technological Defects
			Theoretical Limit	Laboratory Percentage	Commercial Modules Percentage		
First Generation	Silicon wafer technology	Single Crystalline silicon	30-33	24.7	13-15	Save time, Money and relative efficient	High cost of production, silicon technology fails in high radiation zone
		Polycrystalline silicon	22	116.6	8-11		
		Multicrystalline silicon	20	18.8	12-14		
Second Generation	Thin Film technology	Cadmium Telluride (Cdte)	28	16	7-10	Less Expensive compared to first generation technologies, efficient and stable cell compared to amorphous silicon	Immature manufacturing techniques, little understanding of quality, contacts, mechanisms of degradation and lifetime and toxicity of materials.
		Copper Indium Diselenide and Alloys (CIS)	23.5	18	8-11	Highest efficiency of thin film	Slow vacuum steps and immature manufacturing techniques
		Amorphous Silicon	27-28	13.5	6-9	Mature manufacturing and long time investment	Initial 20-40% efficiency loss and slow deposition rate
Third Generation	Technology based on Tandem Ideas	Nano crystal solar cells		7-11	Under Laboratory Scale	Cost-effective, cheap materials, it will be like a screen printing, produce energy anywhere concept.	Impure, low technological efficiency
		Organic solar cells		11.1			
		Dye sensitized solar cell		11.9			

[41] The projection of the information varies from one source to another, so should consider this information as a face value. The information was compiled from different sources such as Handbook of Photovoltaic, Web sources like Wikipedia, Journal articles, NREL data on efficiency achieved, etc.

PV Industry in India: Revenue, Market Implementation and Production Capacities

Solar PV industry is one of the fastest-growing manufacturing industries in the world (Balaguer and Marinova, 2006) in terms of technology development and market implementation. It is not a new industry, but in recent years has witnessed a rise in the utilization of solar-energy technologies. There are four factors which contribute to the growth of PV industry and technology development: (1) revenue; (2) market installation; (3) polysilicon and wafers production; and (4) PV cell and PV module production. First, the world solar PV industry has generated \$ 93 billion in 2011 (Chadwick, 2012)[42] compared to \$ 5. 8. billion in 2004 and 2.5 billion in 2001 respectively. With the conditions stimulated by policy, the trade prediction shows that the industry would reach \$100 billion in 2014 but any change in the policy conditions would also suppress the predictions. Second, World solar photovoltaic (PV) market installations reached a record high of 29.6 gigawatts (GW) in 2012, contributed by 81 countries, representing the growth of 139% over the record of 2009. Europe accounts for 80% of the world demand in 2011 (Renewable Energy Report, 2011), out of which 74% is contributed by the demand created in three countries namely Germany, Italy and Czech Republic (Solar Buzz, 2010) which pushed Spain to the sixth place in the market installation programme. The rest of the world accounts for just 19 per cent of the market installation programmes in SPV technology dominated by Japan (1 GW), USA (0.9 GW) and China (0.6 GW) (Renewable Energy Report, 2011: 23). Out of 29.6 GW, with the first phase of National Solar Mission (NSM) implementation, India contributes to 1000 MW or 1 GW in on grid connected energy

42 http://www.laserfocusworld.com/articles/2012/08/photovoltaic-industry-revenues-sees-strong-growth-says-epic-report.html

production (Mishra, 2012) which made India one of the emerging countries in the solar installation programmes. However, it accounts for just less than one percent of world market concentration. Overall, the average growth rate of SPV technology has increased from 30 percent in 1997-2002 (Waldu, 2002) to 60 percent in 2007 (Waldu, 2008) and finally ended with more than 40 percent decadal growth rate (Waldu, 2011). Third, the production of polysilicon was dominated by seven major players located in developed countries such as the USA, Japan and Germany. USA dominates the production of polysilicon followed by Japan and Germany. The polysilicon is employed in two industries, namely, solar industry and semiconductor industry for microelectronic applications. In 2006, due to recent demand for renewable energy based power production, there is an increase in the production of polysilicon materials and for the first time in the history, half of the production of polysilicon has gone to PV industry. This demand encouraged new firms from different countries (especially emerging and developing) such as China, Taiwan, and Korea to enter into this social space of production. Though East-Asian countries are emerging as dominant players in the production of polysilicon materials (Wikipedia, 2012)[43] but still the polysilicon production is still dominated by the First World countries. India is yet to start the production of polysilicon. In India there are only two firms such as Reliance and Titan Energy Systems have proposed to start 1000 MW and 500 MW production of polysilicon respectively. Fourth, the trade trends reveal that the global PV cell production has increased in recent times. Various countries such as Japan, China, Taiwan, Germany and the USA dominate the global cell production. Out of which, China has recently emerged as the major cell producer pushing Japanese, European

[43]http://en.wikipedia.org/wiki/List_of_photovoltaics_companies#2011_global_top_ten_polysilicon_manufacturers_by_capacity

and the USA firms to the next positions in the hierarchical order of global PV industry. For instance, from 6.85 GW in 2008, the global solar PV cell installed capacity reached 29, 600 MW (29.6 GW) in 2011. Out of the 29.6 GW production, the contribution of China and Taiwan stands at 49 percent followed by European and Japanese firms. Compared to global PV cell productions, Indian cell production capacity has increased from 4.2 MW in 2000 to 75 MW in 2008 (Pode, 2009) to 1000 MW (1 GW) in 2012 (Singh and Prasad, 2012). In the module production categories, India's installed solar PV module reached 2000 MW (2 GW) in 2012 (Singh and Prasad, 2012) from just 8.2 MW in 2001. The trade prediction assumes that Indian PV module production capacity will increase to 6 GW by 2015 and is expected to grow at the rate of 20 to 25 percent.

Technological Dependence over Resource Dependence: Undevelopment of Indian PV Industry and Scientific Knowledge Production

The above account shows that though the spatial concentration of global PV industry is predominantly located in the First World countries[44], in recent times there has been a shift in the production to emerging economies and developing countries such as China, Taiwan, and Korea. These countries have become the hotspots for production of wafers, cells and module. There are four factors that contribute to the growth of PV industry in these countries. First, policy induced growth in various segments of PV industry; second, low cost of labours; third, lower land and capital cost; and fourth, emerging market economy. However, the growth of SPV industry in East Asian Countries (especially Taiwan) is

[44] Despite the commonality in the technology development programmes such as government funded R&D laboratories and industry development has been contributing to the growth of PV industry across the world. But one could understand the different social conditions have fostered the growth of PV industry and technological innovations in various countries. First, Japan is based on the industrial development and indigenous technological innovation along with policy contributed to the development PV industry. Second, socio-political movements in Germany contributed to the enactment of various laws in renewable energy which led to the development of PV technology Third, various government programmes such as space and telecommunication long with indigenous technology development, favourable incentive structure contributed to the development of PV industry in the USA.

predominantly associated with the development of polysilicon which registered high growth with the emergence of microelectronic and semiconductor industries (Mathews *et al*. 2011). The study by Bierenbaum *et al*. (2012) unfolds that East Asian countries such as Japan, Korea, China and Taiwan, as an Innovation hub for SPV technology, account for 45 percent of the world solar energy patents. These countries are followed by the USA and Europe standing at 27 percent and rest of the world contributes to just one percent. He also argues that East Asian countries patents are effectively adopted by the European countries in the development of SPV industry.

On the other hand, an increased demand for polysilicon has witnessed been with the increased new market installation programmes on solar energy. This has increased the production and consumption of polysilicon materials which are controlled by a few large scale SPV firms located in the East-Asian countries', the USA, and Germany. This shows that the total number of players in the first stage of production is still low which means that the control over the technological production by a few prevails in the midst of high demand for polysilicon materials. For instance, though there is an increase in the supply of polysilicon by 30 percent but the inadequate supply of polysilicon has led to the increase in the cost of polysilicon. It eventually increased the cost of production in value chain and affected the overall growth of SPV industry. This has a great significance for the Indian SPV industry.

Technological and Institutional Dependencies of Indian SPV Industry:

Compared to the global standards of PV industry, the size and scale of operation in the Indian PV industry is relatively low. It shows that majority of the PV firms are socially positioned at the end stage of production such as module and system integrator. This creates technological dependency (Singh, 2012) and leads to vulnerable position in the global production of SPV technology. One can divide the technological dependencies of the Indian PV industry into two categories: first, the new market installation programmes in solar energy is witnessed with the public policies of climate change which led to the increase in demand for polysilicon and wafers in India. Subsequently, the demand for SPV technology also increased substantially in India. This position is highly critical to the Indian PV industry. Since, India is the net importer of embodied forms of technologies such as polysilicon, wafers, SPV cells, and other raw materials from international market, Indian SPV firms are vulnerable to price fluctuation and increase in cost. In short, due to lack of infrastructural facilities, the Indian SPV cell and module manufacturers depend on foreign firms for polysilicon, ingot, and wafers. The Indian PV industry will be eliminated from the international and local competition, if it cannot maintain the low cost of PV technologies. As of right now, it purely functions as an export industry rather than domestic.

To understand this point further, let's look at the National Solar Mission Plan. In the first phase of National Solar Mission (NSM) plan, the power producers who committed to provide power at the cheapest rates were selected (Paliwal, 2012). This is called reverse bidding. According to Barghava, the director of MNRE, that this method of selecting the power producers will be retained in the second phase of NSM (*ibid,* 2012). According to the Indian solar energy policies, the power producers can choose either silicon technology or thin film, but who comply with first generation of PV technology should purchase indigenous SPV cells and modules. This is mainly to encourage indigenous PV industry. However, no such clause prevails in the second generation of PV technology (Koshy, 2012). Compared to the first generation of silicon technology, thin film technology is cost effective though efficiency rate is low. Consequently, majority of the power producers opted for second generation of PV technology in the first phase of NSM (Ibid, 2012). With the favourable capital structure, Chinese firms dump the PV technologies in the Indian Market (Singh, 2012) and America employs Fast Start Finance Fund to attract Indian power producers to purchase second generation PV technology (Beetz, 2012). These issues are recently echoed in the anti-dumping policies on solar PV which suggest changes in the solar policies in India (Singh and Prasad, 2012; and Shreya, 2012). Except MoserBaer, very few firms produce second generation PV technologies. Subsequently, the production capacities of Indian SPV firms are under-utilized at present. In order to overcome this situation, most of the PV firms focus on high end services by providing quality modules and increasing the efficiency of modules by 30-40%.

The above mentioned factor takes us to the second category of dependency such as licensing agreement, purchasing patents, knowhow, and development of scientific and technological manpower. We have seen that fostering institutional innovation become an important instrument for new technology development. Several trade reports suggest that the PV firms, which lead the technological innovation in photovoltaic, will survive in the global competition. With the technological innovations and mass production, various PV corporate giants have reduced the cost of production and the increased rate of efficiency led to the decrease in the cost of PV technologies. At present, the subsidy rates are determined by the rate of PV technology. At this juncture, very few PV firms in India have in-house R&D (Barabara *et al*., 2009) except public sector units such as Central Electronic Limited, Bharat Heavy Electrical Limited, etc. It indicates that majority of the technologies are acquired either through license purchase or joint ventures. Though India is emerging as one of the top five countries in SPV patents, UNEP report (2010: 34) suggests that solar PV is the only field where India shows no effort in clean energy technologies. There is little difference in patenting rates between 1978-1987 and 1998-2007 in photovoltaic. Consequently, there is a tough competition existing to import cost-effective PV technologies so that PV firms can easily survive in the international and local markets. These two dependencies (technological and institutional) encourage the culture of import in which the Indian PV industry exists.

Understanding the Nature of Problems in Solar Energy Technology in the Indian Context:

Though few detailed studies in Indian context have attempted to understand the nature of problems faced by the Indian PV industry, there are various reports and scholarly articles that expose the reasons for the retarded development of solar energy technology in India. This articulation largely falls into the following four categories: 1) lack of technology development; 2) weak industry development; 3) failure of market development programmes; and 4) political factors and policy lacunae.

First, due to lack of R&D investments and technology development in renewable energies (Ghosh, 1991a & Ghosh, 1991b); PV technological research is still at the level of exploratory research and cost-effective technologies for commercialization is unavailable in India (Sinha, 2011); there is no proper mechanism for industry participation in SPV R&D (Ibid, 2011); low social acceptance of solar energy technologies constrained the indigenous technology development (Patel, 1978; Visvananthan, 1985; and Anderson, 2001); and investments in renewable energy technologies considered as capital risk (Ali, 1981). Second, little or no support for polysilicon and wafers production by the government of India (Swaminathan, 1995; Singh, 2012); the vertical integration is an energy intensive and requires huge capital and technical knowhow which is lacking in

India (India Semiconductor Association (ISA) Report, 2008); weak PV manufacturing base and imports of technologies from foreign firms (Srinivasan 2007; Singh, 2012); export oriented growth dominates Indian PV industry (Batacharya and Jana, 2005; Srinivasan, 2007; ISA Report, 2008); and patent protected industry forces Indian entrepreneurs to enter collaboration with foreign firms in the absence of indigenous technologies (Barton and Osborne, 2007).

Consumer inability to pay and a subsequent lack of available credit or financing hinders diffusion of renewable energy technologies; inconsistent standards for PV technology fail to ensure quality (Harish *et al*., 2011); minimal market concentration in remote areas, telecommunications (Sastry, 1997; Bharagava, 2001); the cost of solar energy which is four times higher than the cost of fossil fuels gave PV technology an elitist status (Reddy, A. K. N., 1999); Still, PV technologies are diffused through subsidy programmes (NSM, 2009); and absence of service after the sales of PV technology hinders diffusion rates (Boparai, 1998). Fourth, fossil fuel subsidy is higher than the solar energy subsidy which makes solar energy less viable market option (Harish *et al*., 2011); exclusion of renewable energies from mainstream energy framework (Reddy, A. K. N., 1991; Mitra, 1992; Visvananthan, 2002;); lack of inter-ministry dialogue (Radulovic, 2005); grid connected electricity and subsidy become political tools to capture vote bank (Pendse, 1980; Pendse, 1984; Reddy *et al*., 1992); there is no comprehensive policy for renewable (and solar energies) in India (Rangarao, 1974; Pendse, 1980); failure of institutional structure, weak co-ordination and enforcement of renewable energies affected the growth of renewable energy technologies; state did not create suitable policy framework to facilitate the research, training and education, which is one of the major drawbacks in creating the solid knowledge base in solar energy (Hansavivek, 1979; Barbara *et al*., 2011) consequently, it is a failure of an innovation system (Barabara *et al*., 2009).

Lack of Academia - Industry Interactions:

The failures in solar energy technological innovation in India that largely fall largely under two categories: one, low techno-scientific knowledge production and transfer of technology; and two, lack of industry development. The present study attempts to understand the factors undermining technological innovation by looking at the techno-scientific knowledge production relating to PV and industry development in India. One of the earliest proponents of industrial research in India, Shiv Visvanathan (1985) argues that it is not that the application of solar energy technology failed in India but the social acceptance of technology in terms of economic viability was extremely low. This affected the transfer of technology from laboratory to industry. The recent reflection of Barbara et al. (2009) suggest that the empirical studies of PV science and industry development would throw light on what actually retarded the development of PV technology in India. It shows that very few studies in India attempt to find the reasons for the undevelopment of PV technology in India. The present study is an unpretentious attempt to do the same. For which, I look at two aspects of technological innovation: first is knowledge production in techno-scientific research, and the second is the PV industry development and the third, institutional context. These are intricately related to the trajectory of SPV technology development in India.

Rationale of the Topic and Statement of the Problem:

We are living in an era of climate change, and resources constrained world which essentially requires technology to adapt and also to mitigate the consequences of climate change. SPV technology is perceived as one of the best options to mitigate not only climate change and resources constrain world but also help us to co-exist peacefully with the environment we live in. In the present context, the PV technology is less ubiquitous and its applications are less prevalent. But, it offers enormous opportunity for development and growth in the path of socially and economically sustainable and inclusive development. It has the capability to create widespread impact on all spheres of life through green energy production and consumption. To reap these enormous potentials, the investments in development, transfer and innovation (DTI) of SPV technology is required with the creation of mass market and adoption of the same. This brings together the different social actors involved in the process of technological innovation, namely industry and academia, which are mediated by the government. Visvananthan (1985) claims that to understand the problems of scientists vis-à-vis industry the enquiry has to be located in sociology of science (and technology) studies of developing society. Subsequently, through the insights gained from Indian social studies on science and technology, the study employs Mode 2 Knowledge Production perspective. Thus, the study attempts to understand the relations among various actors such as laboratory, industry, government and civil society in relations to technology development, transfer and innovation (DTI) of PV technology. It attempts to highlight the relations between science, state and society, which make a fascinating sociological exercise. This examines not only the nature of problems bundled in the realms of DTI but also how techno-scientific research and Indian SPV industry are located in the globalised process of production and innovation. So the main aim of this thesis is to know the factors that promote\curtail the development of techno-scientific research and industry development in SPV technology. It deals with empirical studies to understand the varied interest of social actors in developing and transferring solar PV technology. The study also aims to suggest policy measures to facilitate the R&D, industry and commercialization of PV technology.

Research Questions:

- How the techno-scientific knowledge relating to solar photovoltaic is socially produced and practiced in academic and scientific laboratories in India?
- How Indian SPV scientific community understands the role of government and industry in promoting techno scientific innovations– technology generation, transfer and commercial production of SPV technology?
- What is the present status of Indian SPV industry in relating to technology generation? What are the internal and external factors that promote /constrain the development of technology in Indian SPV industry?
- To what extent we can use the case of SPV technology to understand Indian system of S&T functions in relation to knowledge production, transfer and innovation? What policy interventions are required to facilitate SPV technological innovation in India?

Objectives of the Study:

- To review the literature associated with the issues of technological innovation in India to gain a comprehensive understanding and a holistic perspective of how Indian PV techno-scientific knowledge production and PV industry is embedded in the present context of globalised production and innovation.
- To examine the context in which the debates on solar energy have been taking place to know the factors stimulate scientific and technological initiatives in solar photovoltaic in India.
- To understand trajectory of SPV technology development in India by focusing on the relations among S&T policy, entrepreneurial development, SPV techno-science and adoption of SPV technology.

- To know the factors that govern the techno-scientific knowledge productions related to solar photovoltaic (SPV) technology in India in an attempt to explore how do (or did) these factors curtail/curtailed the technology development and transfer of technology from laboratory to industry.

- To understand the PV industry structure, functions and its relations to SPV technological innovation and to examine the factors curtailing the productions of PV technology.

Methodology:

From the methodological point of view, Uberoi (1978) argues that the relations between the subject and the object of the study determine the method and nature of the study. The subject of the present study is an attempt to understand the PV technology innovation in India and the objects of the study are the factors curtailing PV industrial R&D, technology transfer and PV industrial development in India. The study demands collection of primary data from two sets of social actors, namely industry and academic and scientific laboratories. However, there are other actors such as consumers, government officials and NGO activists who participated in the study by providing relevant data and their own reflections. This contributed to a comprehensive understanding of: a) what governs the practice of technological innovation - SPV industrial R&D and transfer of technology; and b) factors promoting\constraining the development of PV industry in India. These two kinds of collected data helped to achieve the objectives of the study: one deals with the scientists' point of view on the issues of industrial R&D and technology transfer to industry; and two, industry's point of view on the issues of technological innovation, the present conditions of the industry, policy environment and the problems faced by it. In the Indian context, very few studies have attempted to explore this subject of PV technological innovation and the object of the study in PV techno-scientific research and transfer technology. As a result, the study employs an exploratory cum descriptive research design.

Mapping the Universe: Selection of Scientific Laboratories, Academic Institutions and in-house R&D

Technological innovation involves two aspects. The first one is knowledge production oriented towards application (SPV industrial R&D) and the second is conversion of knowledge into technology. The application of knowledge is an important aspect of industrial R&D and transfer of technology from laboratory to industry is conceptualized as innovation. To understand various issues of SPV technological innovation, one needs to look at different actors involved in the production of knowledge and transfer of technology to industry. This prompts the study to select three different actors involved in the SPV industrial R&D in India: the first is a public research laboratory (PRL); the second is an academic institution involved in scientific knowledge production and technology development; and the third, public sector in-house R&D. Despite the recognition that SPV R&D is predominantly located in the university based research system (NISTADS, 2009) the study consciously avoided the inclusion of university by considering the fact that it focuses only on the scientific knowledge aspects of technology and training manpower (Reddy, P 2011). In this sense, it contributes to the development of knowledge base and scientific human resources but developing and transfer of technology to industry is still low in Indian universities. Based on the purpose of the study, the non-probability sampling method was employed to select the R&D institutions. In this regard, the study adopted the theoretical sampling[45] as a strategy to collect data from appropriate respondents who were willing to provide information on relevant themes of research. Subsequently, for the

[45] Theoretical Sampling strategy refers to the process of identifying organisations and individuals who have the potential to provide information and reflections relating to the objectives of the study.

present study I collected information regarding the scientific and academic institutions involved in the SPV industrial R&D and transfer of technology. The purpose of the study is to address the factors curtailing the process of technological innovation vis-à-vis the practice of SPV industrial science and transfer of technology to industry. To understand this problem, the study collected data from different scientific and academic (technical) institutions and also corporate R&D by considering two aspects. First is the history of SPV technological research in the particular scientific and academic institutions; and the second is based on new technological initiatives and programmes started in academic and scientific institutions. This is to highlight the problems of SPV industrial R&D and transfer of technology in the historical context and also to show the discontinuity of practice that exists in the process of technological innovation. It brings the old and new research practices into the limelight. Based on this structure, the study locates the scientific institutions, academic laboratories and corporate in-house R&D in SPV techno-scientific knowledge production. To elaborate this research position, the study collected data from different scientific institutions such as Indian Institute of Technology (IITs), public research laboratories and public sector R&D. In the case of public research laboratories, National Physical Laboratory (NPL), Delhi and National Chemical Laboratory (NCL), Pune, have been selected for the collection of data for the study. For instance, NPL is one of the oldest laboratories focusing on device based R&D in the areas of solar energy in India (Visvanathan, 1985). In 1980s, NPL has developed and transferred new technologies in SPV to the public sector firm Central Electronic Limited (CEL) (Crystal Report, 2008). On the other hand, with the advent of CSIR pan India programme on SPV industrial R&D has provided the scope for NCL to involve in new initiatives in PV technology. It is helpful to understand the other disciplinary contribution to the development of PV. In this regard, transdisciplinarity becomes a part of academic and scientific research practice in PV technology. I found it very difficult to get access to these institutions despite carrying formal letters mentioning that I am a researcher. At the initial stage in NPL, I had to go through long bureaucratic procedure in getting access for which my research supervisor sent formal letter to the Director of NPL regarding the nature and purpose of the study. However, in the case of NCL, the procedure was a bit relaxed compared to the former. Though I carried formal letter, the concerned project director provided the room conduct interview with all scientist who engage in solar energy research.

Regarding the selection of academic institution such as Indian Institutes of Technology, IIT Delhi laboratory is one of the oldest research laboratories in India (DST-CSRI Report, 1974) and in the process it introduced separate Centre for Energy Studies in general and solar energy in particular. In IIT Delhi, the Department of Physics has a separate laboratory for SPV thin film research. I took prior permission from the Head of the Department before conducting the interviews with respective scientists. Though IIT Bombay has a separate Department of Energy Science and Engineering studies, recently with the support from MNRE, it introduced the National Centre for Photovoltaic Research and Education (NCPRE). It focuses on developing new technologies to train manpower for SPV industrial requirements (IIT Bombay Report, 2011)[46]. These two academic institutions were selected to know the old and new research initiatives and to trace how solar energy research is historically located in India. This exposes the various problems faced in developing and

[46] However, there are other initiatives exist in the PV technology. For instance, Department of Science and Technology has IITs pan India programme on PV technology development, which was started in the year 2008 and the recently inaugurated IIT Rajasthan has separate Centre for PV technology is noteworthy to mention. At the same time, the study cannot state that I have collected all the information regarding all the places in India where SPV related research is going on.

transferring technologies from laboratory to industry. To support this point of view, public sector unit in-house R&D in Amorphous thin unit (BHEL) and also Solar Energy Centre (SEC) were selected to know the industry and testing laboratory point of view on SPV industrial R&D in Indian scientific and academic laboratories. The latter R&D institution acts as an intermediary in communicating with scientific laboratories, industry and consumer in testing and transferring of technologies to society. From the methodological point of view, this examines the similarities or / and differences in the scientists' account of doing science in different social settings. It is a kind of triangulation method employed to understand the actors' position. These different positions were counterposed to find differences and similarities in their accounts of practicing science. It is manifestly employed to find the credibility and reliability in the act of speech. Therefore, the study suggests that all the data from these R&D institutions are important to articulate the sociological reasons for the factors undermining SPV industrial R&D, transfer of technology and innovation in India.

Selection of the Respondents in Scientific laboratories, Academic Institutions and In-house R&D:

The selection of the respondents varied from scientific laboratories to academic institutions and in-house R&D. This is mainly due to the difference in the practice of science in different social settings. In the case of PRL, the mission mode research determines the practice of science. The selection of the respondents in NPL and NCL was based on the different generations of SPV technologies in which respondents practice science. A total of 18-20 and 12 scientists' work in NPL and NCL respectively in different generation of technologies. I took permission from higher authority in both the institutions and later went to the project coordinators to ensure that all the respondents provide relevant information.

However, based on the accessibility, I conducted interviews with 10 scientists in NPL and 6 in NCL, from different generations of technologies. Expect first generation group in NPL, all other scientists from both the public research laboratories are engaged in second and third generations of SPV technology. On the other hand, the academic institutions such as IIT Delhi and IIT Bombay have separate Centres for Energy Studies. In the first phase of the interview in IIT Delhi, the selection of the respondents were predominantly from within this engineering discipline but later the study also covered one respondent from the Department of Physics. The non-probability sampling was employed to select the respondents who work specifically in the area of SPV. Out of 19 scientists in IIT Delhi at Centre for Energy Studies, the study selected 4 respondents who were willing to provide relevant data on the specific topic which I have selected for my thesis. The 4 scientist are working in the second and third generations of SPV technology. However, I also interviewed one of the prominent scientists who work in the area of solar thermal to know the historical context of solar energy in general. He is one of the members in DST pan IIT programme in solar energy. On the other hand, in IIT Bombay, I collected a list of scientists, who work in the MNRE initiatives of NCPRE, from one of the social scientists who work in the area of urban research in the Department of Humanities and Social Sciences. The list contained 30 scientists belonging to different disciplines such as physics, chemistry, energy studies, electrical and electronics, social science and management. I have gone to almost all the scientists but only ten respondents were willing to participate and some declined to answer my questions by saying that they are just part of the NCPRE initiatives and their roles are minimal in the NCPRE. The remaining scientists were unavailable at the time of interviews in IIT Bombay. Here also, the majority of the scientists focused on second and third generations of technologies rather than on first generation. In PSU in-house R&D, the researcher conducted two interviews with Assistant General Manager and Deputy General Manager of Amorphous Silicon R&D (ASR&D) unit in Gurgaon. Both the scientists are alumni of IITs namely IIT Delhi and IIT Bombay. I have conducted interviews in their respective chambers. Initially, the interview was started with the deputy manager which went till the lunchtime. At the lunchtime, I met Assistant General Manager (AGM) and he voluntarily came forward to offer an interview which went on for more than two hours. Both the respondents were highly cooperative in responding each and every question I have asked. They also provided me thought provoking insights about the PSU in-house R&D conditions in the era of globalised innovation in PV technology.

I was permitted to stay in Solar Energy Centre (SEC)[47] for one week to complete my interviews. It provided me the opportunity to stay in SEC for a week. There are 10 scientists working in the Solar Energy Centre. Out of 10 scientists, 7 scientists regularly come to the Centre and rest of the 3 scientists has their office at MNRE. I interviewed 6 scientists in SEC and 1 in MNRE. Out of 7 in SEC only 4 scientists work at the level of testing and demonstration of PV technologies and rest of the 2 scientists belong to solar thermal and biomass, and 1 scientist takes care of the administration. During my stay at SEC, various interviews with scientists made me to reflect how SEC as a R&D institution is controlled by MNRE and functions at the level of implementation. This position of understanding unravels various issues faced by the Indian PV industry, which I could not come across during the interviews with industrialists. This was a completely different

[47] Various scientists such as Dr. P.V.S. Kumar, Dr. Dinesh K. Abrol, and Dr. Gauhar Raza from NISTADS helped me to get access to SEC and MNRE.

picture of how industry exists in the present context. Different interviews with scientists from different social settings gave me the opportunity to contextualise and provided a holistic perspective of the issues encountered by the scientists. Excerpts from these interviews are effectively quoted in appropriate places in the text of the thesis to substantiate the argument.

Profile of the Scientists:

Table No: 2: 3 Profile of the Respondents in Scientific Laboratories selected for the study

Institutions	No of Respondents	Gender		Age Distribution			Respondents Previous Areas of Research		
		Male	Female	31-40	41-50	51-60	Solar SPV	Indirect SPV	Non-SPV Solar
NPL	10	9	1	5	2	3	3	2	5
NCL	5	4	1	2	1	2	2		3
IIT Bombay	10	9	1	5	3	2	2	2	6
IIT Delhi	6	6	-	1	-	5	4		2
SEC	7	7	-	2	-	5	2		5
In-house R&D	2	2	-	-	-	2	2		
Total	40	37	3	15	6	19	15	4	21

Based on the nature of problems, personal information about the respondents was collected to look at the social and disciplinary background of the scientists. The social profiles such as age, sex, solar and non solar background were collected from each scientist to know the status of scientific manpower in India and also to understand the main area of research focusing on SPV technology. The table No: 2.3 shows that out of 40 scientists interviewed, only 3 scientists were woman and rest of them are all male scientists. This shows the disproportionate social category of scientists in India. Several studies explore the reasons for the lack woman scientist and their contribution to the field of science in India (Gupta and Sharma, 2002). This study also finds unequal proportion of woman scientist in the field of solar photovoltaic. Likewise, the majority of the scientists belong to the age group of 51-60 followed by larger number of scientists in the age group of 31-40 and a few scientist in the middle category of 41-50. One can interpret this age group in two ways:

one, solar energy research has become a stagnant in India that witnessed very few scientists under the middle category and large number of scientists from higher age group; and two, the study witnessed a large number of scientists in the age group of 31-40. This unfolds that the field of solar photovoltaic in particular and solar energy in general is emerging in Indian context. With the recent scientific and technological initiatives in solar energy, it attracted a number of young scientists to the field of solar photovoltaic. Perhaps one may arrive at a hypothetical statement that solar energy research might have become a continuous discontinuity in Indian context that produced a few scientists in the field of solar photovoltaic. This is witnessed through majority of scientists come non-SPV science such as Nanoscience and Nanotechnology, organic and inorganic chemistry, power and microelectronics, etc.

Mapping the Universe of Indian PV Industry: Field Site and Selection of PV Firms

To provide a holistic view of PV industry in India, the study has collected data from various social actors such as PV industry, Solar Energy Centre (SEC), Ministry of New Renewable Energy and consumers located in India. The data has been collected from various actors such as industry and government since 2010. Indian Semiconductor Association Report (2010) suggests that there are 15 firms actively engaged in solar cells and 20 companies in the manufacturing of PV modules. Likewise, Indian Semiconductor Association Report (2008) has listed total 9 solar cells manufacturers and 19 PV module manufacturers exist in India. However, these data reflect only the number of firms registered under the Indian Semi Conductor Association (ISA). The recent demand for solar technologies would have stimulated the new startups in India and subsequently, the data is unable to provide the actual number of firms that exist in India since the search through various trade websites shows that there are 21-25 PV Cell manufacturers and 45 module manufacturers in India. Out of the 45 PV module and 21 cell manufacturers in India, the highest number of 15 PV module and four cell manufacturers including public sector units like BHEL and ECIL are located in Hyderabad. Apart from this, Hyderabad is emerging as the Fab City for semiconductor production and PV industry, which is located at Maheswaram. However, except for Solar Semiconductor, very few firms have completely shifted their operation to new industrial site even though most of the interviewed firms are allotted space for production. Due to administrative problems, the operation and production of all the firms are located in the city. Consequently, in Hyderabad, the PV firms are not located in a cluster, and it was very difficult to find the firms since all the firms are spread across the city. The selection of the PV firms was based on the accessibility to conduct the study. I went to 13 PV module manufacturers but only 9 PV firms provided access to the data. Out of these 9 firms, 2 firms have recently started cell manufacturing divisions, and one of the firms told that it was yet to start productions in cell technology. In the first visit, most of the top officials rejected the request to collect data and it was difficult to proceed further. After several visits and convincing the purpose of the study, the firms agreed to provide relevant information. Similar kind of experience was also witnessed by other researchers from other industries such IT, pharmaceuticals where getting access to insider story involves power relations (Upadhya, 2007; Parvathi, 2010; and Devaraj and Illavarasan, 2011). For instance, directors of many large scale firms have checked my insights, perception about Indian PV industry before providing access to relevant data. In most of the firms, the top officials acted as gatekeepers and were also interested to have more than two interview sessions once I located myself as one among them. This made me to reexamine the information collected in the first interviews. It means, I as a researcher, shared common perspective about how the industry exists and what are required to improve the conditions of Indian PV industry in globalised production and innovation. This way of proceeding provided various thought-provoking insights into the study regarding the way firms exist since 1990s onwards and how Indian PV industry is located at the low-end production. Since very few studies exist in the area of Indian PV industry, historical insights facilitated the earlier conception of thought about Indian PV industry and its relations to technology transfer and innovation. All the interviews were conducted in natural settings and in a free-flowing conversation mode. Most of the respondents through their narratives shared their past experience about the firms' history such as when it started and how it stared. Those experiences reveal reactions, their conditions of existence from past to the present context of globalised production and innovation. There were only 3 SPV firms existing before 2000. Rest of the SPV firms started after 2005 onwards. The study recognizes that the selection of the sample seems to be rigid and limited. To avoid this rigidity, the study also incorporated the viewpoints of various other actors, such as scientific staff at the SEC (as I have already mentioned) which predominantly interlinks the industry and consumers by testing and standardization of PV technology. This reveals the other side of the coin which the industry did not explain anything about at all. It exposes the other side of Indian PV industry. Furthermore, the study also incorporated the viewpoints of other actors such as NGOs, consumers and state nodal agency NEDCAP. All the firms declined to provide information regarding the consumer using PV technological systems in urban and as well as rural settings. However, I got the indication from one of the industry respondent that RT (Pseudonym of NGO) provides PV technology water pumps to rural agricultural workers. Based on this information I travelled to Anantapur to know the field performance of Indian PV technology and collected information regarding the consumer using PV technology.

Profile of the Respondents in PV Industry:

I interviewed 12 respondents from 9 firms. All the respondents belong to the category of top officials such as Managing Directors and Vice presidents of the PV firms. All the firms rejected the request to interview the workers of the firms by saying that they are unaware of the real picture of global PV industry and technology. In the sense, most of the workers belong to the category of blue collars. On the other hand, the consumers belong to the category of marginal and small farmers, who cannot afford the cost of PV technology. The RT provides SPV technology as part of livelihood programme and sustainable agricultural programmes for famers. From the list of 165 farmers, through random sampling method, I interviewed 10 consumers who employed PV technology for agricultural practices. Furthermore, I interviewed one of the NGO activists in-charge for the sustainable development programme in RT and also another NGO activist from Prayas Energy Group to know the issues of energy in general. Apart from this, I interviewed three government respondents; one from Non-Conventional Energy Development Corporation of Andhra Pradesh (NEDCAP) – the State Nodel Agency (SNA) and two from MNRE to know the role of the state in facilitating industrial R&D and PV industry growth in India. Though it yielded little response, it provided the information that programme of distributing PV technological system was stopped in 2003 due to technological failure. The government did not take any further action to revive the programme. These kinds of information helped me to understand the quality of PV technology produced in India. This position made me to reflect why the social acceptance of solar energy is low and what kind of policy intervention is required to sustain the Indian PV industry. These insights gained from interviews are effectively employed in the chapter on Indian PV industry. Finally, the Table No: 2.3 shows the distribution of respondents from various social categories such as scientific community, industry, consumer, government officials and NGO activist in reference to solar energy.

Table No: 2: 4 Distribution of Respondents from various Social Actors

Different Actors	**No of Respondents**
Scientists	**40**
Industry	**12**
Consumer	**10**
Government Officials	**3**
NGO	**2**
Total	**67**

Methods of Data Collection: Tools and Techniques

The study employed the socio-historical method to collect the data from various actors such as industry, academia and government. The history of SPV science and technology is little explored from the perspective of sociology of science, technology and innovation. On the other hand, the empirical realities and micro level understanding of SPV scientists and industrialist accounts are unexplored in India. This kind of understanding helps to bridge the gap between the known present and the unknown past. So I employed in-depth interviews and semi-structured methods to explore the phenomena underlying the practice of the scientists and industrialists. In the process, the life histories of scientists and manufacturers were collected to know the historical background of SPV technology and SPV industry in India. Though this kind of method was specifically employed to senior scientists and the employees or manufacturers who have been in the industry since 1990s, it was less employed with junior scientist and newcomers in the industry. However, the latter also narrated the story of what might have happened in the past in various generations of PV technology. Both the kind of interviews helped me to understand the historical background of SPV technology. In the course of data collection, the study modified the interview guide and semi-structured questions as per the experience and insights gained from the interviews about the PV technology. The flexible nature of interviews yielded various responses from the different social categories of respondents such as the industry, government, consumers, civil society and scientists. This position not only shaped the outcome of the study but also reveals the subjective dispositions of the actors such as entrepreneurs and scientists in specific area. I also participated in various seminars conducted by trade association such as FICCI and NGO to know the present status of SPV technology and industry position in India. My participation provided a lot of insights relating to my research questions. Furthermore, the interview questions were framed in such a manner that they elicited perceptions, reactions, suggestions and drawbacks in various scientific and academic institutions and industry. One could notice these reflections in several conversations between the respondents and me. For instance, in a conversation with one of the scientists at the SEC, New Delhi I provoked him by saying that that there is no scientific knowledge production happens in SPV technology and little technological innovation came in our Indian scientific and academic institutions. The immediate reply of the scientist was: “you are not aware of what happened in the history of PV technology. The technological innovation happened in public research laboratories and was transferred to public sector units such as CEL. But these technologies were located only in the PSU. The bureaucratic-political structure controls the SPV technoscience as you can see the same picture is evidenced in SEC." Likewise, from industry, one of the top officials from Indian PV industry reacted to my question "whether the Indian PV industry is capable of meeting the global demands of PV technology". At the first interview the respondent tested my knowledge about the Indian PV industry in terms of policy, nature and overall production capacities of PV industry, etc. When I replied based on the past data about the capacity, the respondent immediately replied that the data is outdated and that now his firm's capacity is equal to the past industry capacity in module and cell production. We don't know what is going to happen in future but we invested huge money in technology and production."

At the initial stages of data collection, I took prior permission to record the interviews but it made the respondents to be aware of what s\he speaks which curtailed the spontaneity of the actors' speech. So, none of the interviews were recorded since the earlier stages of interviews yield less responses from the respondents. So I decided to write down all the conversation during the course of the interviews and immediately it was transcribed and typed into detailed notes in my laptop. The duration of the interviews varied from respondent to respondent and also from laboratory to industry. For instance, in industry most of the interviews with top officials lasted between one hour and two hours but it was highly intermittent since the respondent had to look after his official work such as attending phone calls, small office work, etc. In the meantime, they also offered refreshments. Likewise, most of the scientists allotted more than forty five minutes to one and half an hour depending on the interest of the scientist in the socio-political aspects of SPV technology and Indian conditions of science. Majority of the scientists responded to the questions which I posed, though very few scientists declined to answer and provide critical insights. In this sense, all the interviews were socially productive in understanding the problems of the study. On the other hand, I participated in various workshops conducted by trade association and NGOs in the area of solar energy in India. This social participation provided scope to interact with NGO activists and manufacturers who came from different parts of the country. It also further helped me to understand the nature of the problems, oppositions and reactions which the SPV technology sector faces in the present condition. This led to in-depth exploration of the reasons for the underdevelopment of solar energy in India. For the study, I also collected secondary data from various journals, MNRE, State Nodal Agency web and PV firms' websites regarding policy, description of the type of company, academic research situation, and the state policies. Apart from this, the study also made an archival search in MNRE library which helped to identify some of the valuable documents on solar energy.

Discourse Analysis:

The study employs the method of discourse analysis to explore the phenomena underlying the industrial R&D, technology transfer and technological innovation. Discourse is a set of meanings through which a group of people communicate about a particular topic. It often indicates the spoken or written language but also includes the shared ways in which people make sense of things within a given context. Discourse analysis, according to Mulkay et al., (1983), attempts to highlight similarities and dissimilarities in the process of understanding the actors' perception on the knowledge production at a given point of time. Cetina and Mulkay (1983) describe that the practical reasoning of the scientist both as a topic of analysis and as a resource in describing and accounting for scientific practice unfolds the valid meanings of the action involved in the process of constructing a particular knowledge. However, in this study, the conversations of various actors such as scientists, industrialists, consumers and government officials are analyzed to find the similarities and differences in the narratives to understand the factors curtailing industrial R&D, technology transfer and technological innovation. Since the unit of analysis is about the technological innovation which covers scientific knowledge production of technology relating to SPV technology and its transfer to industry. In the process, the study attempts to understand and explain the constructed meanings of the experiences which are faced by various actors such as scientists and manufactures in encountering the problems of PV technological innovation.

Conclusion:

In this chapter, the study attempted to define the problem of the study, located the research questions and outlined the research objectives. Further, this chapter explained the holistic perspective on the methodology that was followed in the study.

Contextualising Solar Energy in India: A Critical Understanding

Introduction:

Contextualisation, according to Nowontony *et al*., (2005: 10), embodies wide range of changes – economic, cultural, political and social - through which society invades science, but also invaded by ‘science’. In simple terms, science speaks to society and in turn, how society speaks to science. Contextualisation depends on two conditions: the first one talks about the objective conditions and also assessing the reliability of knowledge under which the objective conditions arise. The objective conditions are based on particular social problems and public outcry in which people actively involves in discussing the social issues. It deals with the public attention towards the social conditions which produce public protests. The second one deals with how a particular context influences the direction and selection of research priorities and its normative expectations, economic and political opportunities in relation to cultural, industrial or military forms of knowledge production. Based on these conditions, debates on solar energy in India arose in two different contexts at two different points in time. The first one was in the context oil crisis in the 1970s and the debate was about the emergence of scientific and technological programmes in solar energy and its execution. Further, the debate in this context explored the relationship between energy politics and economic losses of particular preference mode of energy production in which alternative technologies are socially neglected.

With the increasing industrialisation and urbanization process, the demand for energy has increased and also contributed to environmental degradation and pollution. Here comes the second context in which debate on solar energy has been revived. The context is contemporary concern over climate change and resource constraints which act as a motivating factor for restarting scientific and technological initiatives in development of solar energy technology in India. However, a closer analysis of the two contexts reveals that India took initiatives on solar energy as a compulsion imposed by external factors and internal urgency to meet the requirement of energy for developmental needs in India. Thus, understanding the context reveals that compulsion and urgency influence in setting the research priorities and shaping research goals in solar energy. This brings in the concerns of various social actors into knowledge production relating to SPV technology.

Oil Crisis, New Technology Initiatives and Energy Securitization: Focus on Solar Energy in India

Internationally two important forces influenced the emergence of solar energy technology. *First*, is the downturn with the formulae of Fordism and Keynesian theories of development[48] (Antonio and Classessado, 2000); and the second is the outburst of oil crisis in 1973. The first was primarily associated with the experience of American (and Western) economies, which faced the state of stagflation since the 1960s. The major reason for it was that by enforcing technical control over employees, the Big Business Corporation employed labour saving technologies and also reorganized social labour process to bring down the cost of production. Consequently, the Fordism as a new social method and technological innovations was introduced in the process of production. Thus, the coordinated instruments of labour reinitiated the values of efficiency (technology intensive) and cost (reducing labour and decreasing the time of production) which led to a

[48] The era is controlled by Fordist-Keynesian metaphors, which led to the sharp recession followed by the shock of oil crisis. This era has five distinguished features: 1) mass production of goods; 2) class configuration of industrial workers such as blue collars; 3) mass consumption became the norm of consumer society; 4) nation-state was the locus of economic activities and was dominated by national oligopolies; 5) securing the nation became the prior concern of state and thus, ensuring continuous supply of all resources required for development such as coal, gas and electricity play a predominant role in economic growth (Webster, 1993).

decrease in wages. These strategies mainly focused on increasing productivity by mass production of commodities through technological means. It led to the social process of degrading and deskilling of employees (Blauner, 1964; & Braverman, 1974) and created symbolic relations among energy (resources and labour), technology and employment opportunities[49]. Every capitalist investment in the form of new technology re-ensured the relative and absolute surplus values by reducing the employment of labour power and by increasing the inanimate sources of energy in production. Further, it reduced the level of income and tried to change the pattern of mass consumption and finally, caused environmental degradation. The accumulation of profit at a rate grew above the rate of growth in market demand. This situation was further intensified with the participation of new players, such as Japan, European countries and newly formed independent nation-state like India, in international production. As a result, the world economy witnessed decrease in demand and increase in supply of commodities. This is what Engels would have called systematic 'anarchy' of production which led to the phenomenon of overproduction (Clarke, 1994). These social events brought the world (especially American) market into the state of stagflation. It was further widened with the outburst of oil crisis in 1973.

The *second* instance was the oil crisis[50]. The major reason behind the oil crisis was 'oil embargo' which led to the cartelization of oil fields by Organisation of Arab Petroleum Exporting Countries (OAPEC) in 1973. This is to show the solidarity among the Arab nations against the Western countries such as Britain, France, and America, for indirectly

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[49] The symbolic relations, between technology, energy (labour and resources) and employment, refer to the process through which the power of labour is reduced with the introduction of scientific-technical instruments in the production. The complete mechanization of production has reduced the requirement of labour power, which ultimately decreased the social opportunities for labours and increased the consumption of energy. Thus, the relations between industry and science displaced skilled employees and increased the control over production. For which, the techno-scientific revolution is one of the major reasons for the accumulation of capital (For further reading refer, Barverman, 1974).

[50] Refer, Venn (2002) for a detailed history of oil crisis and politics.

supporting the newly formed nation-state Israel by providing warheads in Yom Kippur War against Palestine. This created a social tension, and oil producing countries organised a protest by enforcing control over the oil fields by monopolizing the oil price which created fictitious hike in demand in the short run. This was done as part of political tactics to pressurize the Western nations to withdraw the military support to Israel. Thus, the whole world witnessed shortage of oil and energy crisis. An increase in the price of oil pushed the state of stagflation into the state of recession. The repercussion of the cartelisation created spiral effects on the world economy, thus, resulted in uncontrollable inflation, increase in the cost of production, extreme poverty, decrease in consumption, and a state of crisis[51] at last. Eventhough this might be the real case, Frank, A. G. (1980) claims that the oil crisis was socially constructed by the Americans to restabilize their economy which was suffering from stagflation. It has to be noted that it is the politics of energy, which established the domination of America in the international politics[52]. However, the case may be, with the oil crisis, social and political dimensions of energy were clearly

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[51] Clarke (1994) emphasizes that there is a longstanding debate that exists to understand the dynamics of the phenomenon crisis. It follows two sets of arguments. The first argument is originated in the Marxist approach that describes crisis as a failure of capitalism, which led to the structural contradiction of social relations. Here the prime causes for the crisis lie at the core of capitalism. The argument concerns about the change in structural relations of a system through revolution as a solution for crisis. The second argument is based on the liberalist (and Keynesian) approach which describes crisis as a contingent phenomenon and denies that crisis not lies inherent in the social form of capitalist production. It conceptualized capitalism as a self regulating system that often disrupts existing equilibrium to set another. It enforces that the prime causes for crisis exist outside of the capitalist system. In this context, the restoration happens through market adjustment programmes (Keynes) through policy interventions as institutional strategies. The argument focuses on the change in the market practices through institutional reforms as a solution for crisis. The continuous and consistent recurrence of crisis made interventionist model of development to introduce series of institutional reforms to mitigate the crises dominated situation. It has been the logic of socio-political practice, since the 19th century.

[52] Harvey, D. (2003: 1-25) in his book on The New Imperialism exposes the history of oil politics in which he narrates how America played a predominant role in controlling the Middle East to control the global economy since the 1950s. It unfolds that US played covert and overt politics in overthrowing the democratically elected Mossadegh government in Iran, in 1950, which ultimately led to the increased control of Middle East oil reserves. Thus, controlling the Middle East has become part of the American international politics so that it can control the other nations by controlling the resources. This is largely called as international energy politics or resources politics.

evidenced: energy scarcity is considered as a social problem and energy dependency creates unstable situation to the economic development. With the Meadows *et al*. report (1975), the concern for environment was perfectly added as another relevant dimension to energy, and the consciousness of resource scarcity in the long run made Western governments to think about alternative source of energy and alternative practices of development. It came to acknowledge that the only solution is to approach science to take the development to the next step forward.

To overcome the state of crisis, the new growth strategies were laid down as a foundation to reconstruct the lost economic regime. It was based on the introduction of various new practices which largely fall into three categories. 1) Withdrawal of state action from controlling the market forces. It emphasizes the policy of deregulation, privatization and liberalization. The rise of neo-liberalism as a political and economic practice was witnessed within this context. 2) The notion of sustainability and appropriate technology were introduced as an alternative practice to economic development. It meant that the continuity of economic production needs to be based on long-lasting resources so that the accumulation of profit would be all time high and also transfer the risk-based and energy-intensive work to the Third World countries. With the implementation of neo-liberal ideology, these strategies become the legacy of the Regan and Thatcher regimes[53]. **3)** Various scientific and technological programmes were initiated as stimulus to growth and innovations. Subsequently, Structural Adjustment Programmes (SAP) were introduced and

[53] In the Jimmy Carter Regime, solar energy technology movement in USA was initiated. Later, in the regime of Ronald Regan, the movement was receded back with the state withdrawal of funding R&D for various renewable energy technologies. This forced scientific laboratories to look forward to industry to fund R&D. But, very few private firms in 1980s came forward to invest, subsequently the development of new energy technologies were thwarted with the state control over science and technology. There are two sources one could refer to this experience Laird (2004) and (Dickson, 1988: 13).

various financial institutions such as the World Bank, International Development Agency (IDA), etc. provided funding to stimulate economic growth in Least Developed Countries (LDC). Various programmes were envisaged from implementing power plant projects (Ali, 1981) to the development of hi-technology intensified areas such as information and communication technology, biotechnology, automobile, electronic industry, alternative energy technologies such as solar energy, biomass, wind etc (A. G. Frank, 1981). These scientific and technological initiatives were implemented with the motive of eliminating the crisis-dominated social conditions of the West. Thus, oil crisis is seen as an opportunity to achieve economic growth rather than distortion of economy (Nowotony *et al*., 2001).

India was highly influenced by the above geo-political events and saw those technological and industrial challenges as opportunities for economic development. Within this context, various scientific and technological commissions, programmes and policies such as New Computer Policy (1984), Biotechnology Programmes (1981), automobile industry, electronics, etc., were initiated in India. In a similar way, Solar Energy Technology Initiatives (1976) were also introduced by the Government of India. The research initiatives in SPV technology largely fall under two categories: a) through public driven R&D investments a mission mode research was initiated to develop indigenous technology (*See chapter four for a detailed history of solar photovoltaic technology and the problems faced by SPV technology development in India*); and b) in collaborations with foreign countries, various pilot projects were implemented to check the suitability and viability of solar energy technologies as an option for energy production. Such testing and evaluation of SPV technology reported that the cost of energy production is high (Sharma, 1994), and market potentials of SPV technology were weak in nature. So, SPV technology was considered as unviable idea for development. Moreover, most of these programmes were short term in nature and were initiated as a response to the energy shortage, and not to meet the long term socio-economic needs of the country.

On the other hand, due to uncertain external factors such as the Gulf War, the recurrent energy shortage, increase in oil prices and internal factors such as developmental needs of industrial growth, changing consumption pattern, etc created the social conditions for increasing energy dependency. Thus, energy securitization was perceived as the only way forward to the economic development. As a capital starved power sector, with the support of international financial institutions, it was forced to invest heavily on conventional sources of energy in various Five-Year Plans in 1980s, 1990s, and 2000s. It led to the growth of resources-intensive rather than technology-intensive sector. Reddy, A. K. N. (2000) argues that Indian power reforms were influenced by the World Bank approach on energy. To remove externalities in Indian power sector, a Top-Down approach was followed as a solution to sick Indian electricity boards. This is based on three factors: 1) institutional change (privatization); 2) financial reforms (attractive incentives, tax rebates, power purchase agreement, easy purchase of land); and 3) management measures (maintenance, repair and distribution). A.K.N. Reddy further argues that these solutions are highly irrelevant to Indian power sector since Indian problems, such as capital shortage, financial sickness, and poor quality of electricity delivered, are completely different from industrialized countries. However, the approach changed the trajectory of Indian power sector by incorporating private sector and international players in power production[54]. Thus, the public-private partnership became complex and centralized in

[54] In Indian context, according Sree Kumar (2007), the grid connected electricity system consists of many players such as the state, private, national and international organizations. These different players control the regulatory system of

nature. However, in general, Pendse (1980) argues, India has followed the paths of Western strategy in energy policy, which encourages "Power Supply Must Be Surplus Policy." This is because the "energy as security and a source for development" has been incorporated into the energy policy since 1947[55] (Abraham, 2012). This position was further continuously reviewed by each energy Act such as the Electricity Supply Act (1948), the Electricity Regulatory Commission Act (1998), the Energy Conservation Act (2001) and the Electricity Act (2003). Despite these acts, the Electricity Act (2003) gives specific importance to the rural electrification in remote areas, which are not connected by grid-based electricity. This is the first act that recognizes the need for penetration of renewable energy technologies to enter the structure of Indian technological system[56] dominated by fossil fuel based energy. As a result the market demand for solar energy was unable to emerge. Subsequently, solar energy technologies were not even considered as alternative energy producing technologies. India was dependent on fossil fuels as predominant sources of economic development. This is called locked-in position or path dependence in energy sector, which affected the political will and commitment to solar photovoltaic (Barbara *et al.*, 2009 & 2012). Therefore, SPV technology was not implemented on a massive scale and mass market could not emerge in India.

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production, distribution and consumption of electricity (and energy). Apart from this, unlike any other sector, this energy sector is heavily unionized.

[55] Itty Abraham (2012) "……..it has been a permanent assumption of Indian political economy since independence from colonial rule that energy security is vital for national development, and hence, a prime means for securing the state. This justification is written into the Atomic Energy Acts of 1948 and 1962, and has been constantly reaffirmed in numerous policy statements well into the present, including the India–US nuclear agreement of 2005 (IAEA, 2008)".

[56] The concept Technological systems as employed by Thomas Hughes (1999) denote the arrangements of institutional setup dominated by the production, distribution and consumption of electricity based on fossil fuels.

Energy Politics, Exclusion of Alternative Technologies and Consequent Economic Losses:

At the implementation level, energy question has been incorporated into the political agenda of state programmes on industrial and agricultural development. Subsequently, it acts as a tool for vote bank politics in India. For instance, to attract FDI investments in the IT sector, statist policies provided free space, capital subsidy and continuous supply of power to develop India as a global IT hub. On the other hand, the subsidized fuels such as kerosene and diesel, free electricity to rural households and agricultural production have been distributed to the rural populations. Due to transmission and distribution losses, high capital investments in the grid connected electricity and low purchasing power in rural areas, fossil fuel options such as kerosene and diesel are considered as better options than providing electricity. In fact, it is a business model that has been encouraged since the independence. Within this scheme of things, the technological option for decentralized energy production is excluded, which thereby excludes the 'social'. At the same time, despite massive investments in the power sector, India's average per capita electricity consumption stood at 566 Kwhr in 2010. This is very low, compared to other countries such as OECD 8486 Kwhr, Non-OECD Europe 3378 Kwhr, and China 2471 Kwhr (Garg, 2012). Sixty five percent of rural population consumes less than 30 percent of overall electricity production in India (Boparai, 1998). Still, 1, 05, 379 villages are not yet electrified as on 2008[57]; and those villages that have been electrified face acute energy shortage and poor quality of electricity supply in villages (Integrated Energy Policy, 2006). Lack of access to affordable energy has created inequalities which results in stratification

[57] Different data shows different projection on how many villages are electrified in India. Some of the official data show that only 18, 000 villages are unelectrified but the other reports from the Ministry of power and newspaper show that more than 80, 000 villages are unelectrified (http://www.solarplanet.in/zoom_in.htm). To come to a common conclusion, the study took other reports such as daily newspaper, publications, etc by considering the fact of number of villages in India.

based on access to energy. This is closely linked to existing social inequalities in terms of poverty and standards of living. This eventually further accentuates the marginalization of lower socio-economic groups. Several studies in the Indian context (Aggarwal, 1986; Reddy, A. K. N., 1999; Batliwala and Reddy, 2003; Mathur and Mathur, 2005) show the inter-linkages between the energy, gender and health[58]. These studies reveal that women and children suffer more than men as they are involved in fuelwood collection work. Involvement of children in home labour such as fuelwood collection leads to a high number of dropouts and low level of performance in school. Consequently, majority of the rural households depend on kerosene or primary wood as energy sources in India.

On the other side, various reports and scholarly studies suggest that Indian energy sector incurs enormous losses and acute power shortage in spite of massive investments. Majority of the economic losses arise due to the middle distillates such as kerosene, diesel and providing free electricity to rural populations and urban based industrial growth[59]. ICRA report (2012) suggests that Indian distribution companies incurred a loss of Rs. 80, 000 crore in the fiscal year 2012 with an increase of 14 per cent compared to 2011. During the period, the rate of subsidy also substantially increased to 13 percent[60]. However, the Cabinet Committee on Economic Affairs (CCEA) claims those losses of State Electricity Boards stood at 1. 9 lakh crores in March 2012, out of which 24, 000 crores account for transmission and distribution losses. These losses threaten the entire distribution network in the country (*Economic Times*, 2012; and Narashimhan, 2012). Likewise, according to

[58] Human Development Index –Energy consumption and Human development Index. The human development index is strongly associated with access to electricity and calculated from literacy rate, infant mortality rate and per capita GDP is plotted against per capita electricity (Integrated Energy Policy, 2006).

[59] This energy projection is at the level of the nation though there are considerable differences, which exist at the level of various states in India.

[60] ICRA report (2012) is based on the data collected from eleven states in India. The inability to meet the transmission losses and increasing power purchase expenses, further interest rate increase the burden of debt are some of the reasons for losses in distribution companies DISCOMs (for further details, kindly refer ICRA Report).

Shenoy (2010: 5), the government incurs a loss of 3.9 billion US dollars in the distribution of kerosene, followed by 4.9 billion dollars in the distribution of diesel every year in the form of subsidy. TERI's report (2012) suggests that there is a difference between the desired prices of fuels such as kerosene and diesel and subsidized prices of the same. While the actual market prices of kerosene and diesel stand at Rs. 42.31 per litre and Rs. 46.2 per litre respectively and the subsidized market price is Rs. 12.99 per litre and 33. 47 per litre respectively. Majority of these losses are due to: a) the need to satisfy the energy needs such as cooking and electricity of households; b) agricultural energy demand such as requirement of electricity and diesel to run pump sets; and c) low energy efficient technology results in huge transmission and distribution (T&D) losses.

Losses would have been easily averted if the state responded to the various proposals made by scholars like D. D. Kosambi, Amulya K. N. Reddy, Vidyarthi, Arun Ghosh, Pendse, in the energy sector in 1980s and 1990s. They suggested four ways to mitigate the energy problems in India: a) the complete restructuring of Indian energy sector by focusing on geographical conditions and technology based approach so that the renewable energy could easily penetrate into the remote areas of India. By limiting the social space of energy production and consumption, the energy dependencies and economic losses could have been averted after the 1990s. By considering the consequences of dependency and losses, the decentralized approach to energy was suggested for providing technologies and setting up of distributed and off-gird energy systems in households and villages; b) the introduction of various employment-oriented schemes and programmes by combining renewable energy and livelihoods; c) the consideration of environmental factors in implementing power plants for energy production should get prior importance; and d) immediate investments in R&D, scientific manpower and the development of renewable and energy efficient technologies to mitigate the energy crisis. These suggestions were provided to reduce and compensate the economic losses incurred by the mainstream energy production based on import dependency. Nonetheless, these recommendations were sidelined by the state or the central government. This is indicative of the relationship that exists between the state and civil society in energy sector. However, it is the politics of science constructed within the larger framework of politics of energy, which stops diffusion or distribution of knowledge[61].

There is no effective mechanism evolved to solve the energy problems in India. In spite of various technological initiatives and programmes in renewable energy technologies[62], the programmes created a minimal impact and attracted low community and social acceptance. Ineffective implementation and the state of underdevelopment of technologies since 1980s are the reasons for the failure of various renewable programmes (Bhattacharya and Jana, 2009). The alternative technologies were never utilized on a mass scale in energy production and as a result, the decentralized solution to the energy problems of India could not be achieved effectively by combining rural energy for rural livelihoods. However, there are recent attempts made by the Ministry of New Renewable Energy (MNRE) to enhance the rural development by combining the renewable energies through Urja Samitis or biomass, gasifiers sheds, etc. Recently, to address the problems of village electrification, the government programmes on universalisation of electrification such as Rajiv Gandhi

[61] This position has taken from Visvanathan (2011: 304), shows that the main motive of KSSP is to take science to village. In the process, it considers politics of science as a problem of distribution or diffusion of knowledge in the society. Here, I consider that the penetration of renewable energy technologies where curtailed due to the control of energy sector in India. It is the point where the politics of energy and politics of science meet together.

[62] Various technological initiatives on renewable energies are as follows: 1) National Programme on Improved Stoves (1983); National Programme for Demonstration of Gasification Technology (1987); All India Coordinated Biogas Programme (1975); Subsidy Based Solar Thermal Programme (1984); Small Hydro Projects (1887); Solar PV Development Programme (1993); and National Wind Power Programme (1983).

Vidyutikaran Yojana was launched in 2005 by the Ministry of Power to provide free electricity connections to 23.4 million rural households in which SPV technology plays vital role. However, the rural electrification has benefitted the affluent sections in villages leaving the majority of the households without access to electricity. Still, the majority of the population in India is yet to see the scope of light and lights of hope. But these activities are in the beginning stage and may take some time to catch up. Apart from wind energy, other renewable energy technologies such as biomass gasifiers, solar energy, small hydro projects and waste recycling contribute a very minimum amount of energy to the mainstream energy production. For instance, Table No: 3.1 shows that most of the energy production (2012) comes from thermal (coal) stands at 131 GW, followed by hydro 37. 5 MW, the Nuclear 4.5 GW and the rest comes from renewable energy. The contribution of renewable energy to the mainstream energy production comes around 19, 970.76 MW. Out of which, the installed capacity of wind energy production stands at 14, 155 MW in 2011 followed by small hydro power 3042, Biomass 2664 MW and waste to energy stands at 72 MW respectively (Energy Statistics, 2012). Within this larger scenario, solar energy (thermal and SPV) plays a negligible role in energy production at present.

Table No: 3:1. Installed Generating Capacity of Electricity for the Period of 2011-2012

Distribution System	**Utility**	**Production in MW**	**Total**
Grid Conventional	Thermal	131229	
	Hydro	37567	
	Nuclear	4780	
	Non-Utilities	32900	
	Total		**206526.00**
Grid Renewable	Wind	14155	
	Biomass	2664	
	Small Hydro	3047	
	Solar Power	35	
	Waste To Energy	70.54	
	Total		**19970.76**
Decentralized Energy	BioGas (Nos)	4798233	
	Water Pumps Wind Mills (Nos)	1352	
Solar Photovoltaic	SPV Pumps (Nos)	7373	
	SLS (Nos)	204523	
	HLS (Nos)	748676	
	SL (Nos)	731021	
	Power Production (kWh)	9146	
	Solar Cooker (Nos)	66350	
	Biomass Gasifier (Nos)	138053	
	Hybrid System (kWh)	1076.65	

Complied By Author from Energy Statistics 2012, Government of India

Energy Demand, Environmental Pollution and Loss of Life:

Various reports contribute to the comprehensive understanding of the factors that caused an increase in the consumption of energy in India (International Energy Agency, 2010; Energy Statistics, 2012, Integrated Energy Policy, 2006). Though these studies are directly or indirectly related to the consumption of energy in India they also reflect on how changing context of practices, modernization of lifestyles, increase in population growth and rapid economic development affect energy consumption and demand in India. This structure of development is a reflection of the reproduction of Western culture and practices in India. Such practices rest on the metaphors of Fordist-Keynesian era such as: 1) mass production; 2) mass consumption; 3) class configuration; and 4) rampant exploitation of resources. By understanding the three intersecting aspects of development, we see that the changing cultural and life practices contribute to ecological degradation and environmental pollutions in India: *First*, with the growth of hi-technology sectors, the development of new forms of urban social identities[63] as upper and neo-middle class led to the creation of new culture of consumption such as discotheque, party culture, eating out, rise in malls and multiplex, living in gated communities and high rise apartments, etc. This social change provided the room for the emergence of new commercial complexes as new middle class industry (Upadhya, 2011). Thus social identity by possession, as a class distinction, emerged with conspicuous consumption such as automobile culture, increase in the usage of electronic gadgets such as television, computer, refrigerator, washing machine, mixer grinder, etc. It not only increased the per capita energy (electricity and fuel) consumption in Indian urban households (Rao *et al*., 2009) but also led to a rise in

[63] The creation of new consumer society (Baudrillard, 2003) with higher frequency of movement (physical and virtual) of people from one place to other (Bauman, 2006) has increased with this process of development. It led to the formation of global culture (Featherstone, 1990) and imagined communities (Appadurai, 2005).

energy consumption from commercial settings in India. The per capita energy consumption in urban households stood at 288 kWh in 2009 (Wikipedia, accessed on 10-9-2012). On the other hand, by creating the new culture in consumer market, the neo-liberal agenda created unsustainable lifestyles of the West (Nayar, 1994); altered the ecological structure of urban space (Srinivastava and Mukerji, 2005); reduced the capital and labour contradictions (Sandhu, 2008) and also appropriated the excess income from newly emerged middle class. *Second*, various studies in the Indian context articulate the reasons for the increase in consumption of energy in agriculture production and unsustainable agricultural practices (Pendse, 1984; Rao, and C. H., 1988). The factors contributed to the increased consumption of energy (electricity and diesel) in agriculture production are: a) extensive use of technologies such as high yielding varieties; b) employing machines such as tractors, electrical and diesel pump sets, trashing, drying, etc., for agricultural practices and increased transportation; and c) chemicalisation of agricultural practices. These factors increased the cost of production (Vyas, 2004) and decreased the level of profit and created debt traps, with the advent of IPR regime and deregulation of market forces (Shiva, 2000). Vasavi (2009) claims that economic pauperization and de-peasantisation is the result of the above factors, which caused the individualization of peasants in India. This process of agricultural production affected the livelihoods of rural population and witnessed suicides, and the crisis led to the production and reproduction of class inequalities since majority of the population in India depend on agriculture. It aggravated the problems of social suffering and pain as part of our culture.

Third, the increase in energy-intensive manufacturing sectors such as iron and steel; cement; chemical and petrochemicals; pulp and paper; and aluminum productions consume

56 percent of commercial energy in India (International Energy Agency, 2011). Out of which, steel production consumes 30 percent of commercial energy in India (Ghosh, 1991b). Due to the present economic growth rate of industrial production, the total commercial energy consumption is expected to grow at the rate of 4. 2 per cent in India. However, the major chunk of the production has been exported to different parts of the world. Purnamita and Taneja (2010) claim that in 2007-2008, the total export of these five industrial products accounts for 17.9% of India's total exports. Out of these products, India exports majority of the production to USA, which stands at 14.7% of chemicals and 16% of steel respectively. The geographical relocations of chemical and heavy industries led to the degradation of quality of life, transferred the risk to the labourer, and environment for which the standards and regulations of environmental law and policies have always been relaxed in the Indian context (Divan and Rosencranz, 2001). The search for new resources such as nature, labour and market created new forms of exploitation and transferred risk to individual and ecology (Schuurman, 2000). For instance, like the nuclear accident in Chernobyl (Greenpeace Report), in India it was the Bhopal tragedy in which leakage of poisonous methyl isocyanate from a pesticide plant of Union Carbide (India) Limited, killed the factory workers and commons in and around the place (Bandopadhyay and Shiva, 1988; Guha, 1988). The other side of the industrialization process such as industrial affluents polluting village tank led to the deterioration of not only agricultural and allied activities, but also it put the labourer at high risk of health (Vijay, 2003). The opening up of the economy brought notorious substance– toxicated and wasteful consumer goods into the Indian market (Kothari, 1995). With the introduction of Genetically Modified (GM) crops and foods such as Bt cotton, the consumer markets are being exploited in India; and

forced land acquisition for SEZ and real estate business made "nation as real estate" (Vasavi, 2012).

New Energy and Technological Movements: Critique of Dominant Development Paradigm, Science and Energy Options

It is in the above changing context that science (nature) speaks to society in the form of environmental degradation and climate change. Members of the civil society and their organisations criticize and comment on the model of development in which science and technology plays a predominant role. The speaking is in the form of protest, public attentions, agitation and movements. Such expressions reveal that the riddle of human struggle between labour and capital seems to have been resolved but in the long run, it has failed to solve the conflict and contradiction between life and capital. The partial success of social (labour) movement against capitalism (in terms of wage and surplus value) is reified and subsequently reintroduced in the form of socio-ecological movements (struggle)[64] against the nature of capitalist development and economic growth. The participatory form of development is seen as the way to emancipation and liberation from the socio-politically trapped social life. One could see the emergence of new energy and technological movements under the larger rubric of social and ecological movements in India. First, the emergence of new energy movements such as anti-nuclear movements in Kudankulam in Tamil Nadu (Senthalir, 2012; Times of India, 2012); and also in Maharashtra (Bidwai, 2012); anti-thermal power plants in Somepeta (the Hindu, 2010) and Bhavanapadu in Andhra Pradesh (The Hindu, 2010); agitation against mining in energy

[64] In the Indian context, there are certain ideological differences that exist within the socio-ecological movements (Guha, 1988). Such ideological difference need to be highlighted in the context ecological degraded world (Sujatha, P. 1997). Likewise, Latour's Seminal work on *Politics of Nature* (2004) emphasizes that the ideological deficiencies in ecological movements weakens the struggle against the monopoly power of state and capital. However, due to space constraint such ideological differences and deficiencies in ecological movements are kept outside the scope of this thesis; rather it highlights the issues stimulating sustainable technologies and practices such as solar energy in contemporary society.

capital of Singrauli; Tehri and Naramda dam project in UP and Gujarat; the need for safe and secure (green) energy led to the forced cultivation of Jatropha for bio-diesel by deforestation of forest and land acquisition witnessed in several developing countries such as Malaysia, India, etc. For instance, forced acquisition of land for Jatropha cultivation in Andhra Pradesh (Prasad and Parasuraman, 1997), recent peasant agitation in Rajasthan against Jatropha cultivation and TERI project on Jatropha cultivation among A.P. framers[65] reveal market and elite controlled society eliminate the need of the poor and also increase the magnitude of risk. Second, the emergence of anti-drought and anti-desertification movements, such as pani panchayat (Despande and Reddy, 1990) and Mukti Sangharsh (Phadke, 1992), and ecological movements such as Chipko (Guha, 1994), expose the various issues of agricultural crisis, food insecurity, and exploitation of natural resources. Third, various science and technological movements, such as the people science movements of Kerala Sastra Sahitya Parishad (KSSP), organic or Non-Pesticide Management (Quartz, 2010), focuses on the alternative technological solutions to the mainstream energy and agricultural problems by creating awareness about the dominant model of development that India adopted.

The new social movements are the reaction, resistance and struggle against the technological dominance, monopolization and unscrupulous exploitation of resources-nature and human. In fact, this struggle is against the model of development that produces mass destruction to life[66]. For instance, at every stage of development, from life to death,

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[65] This is my personal experience with the engagement of TERI sponsored programme on Jatropha cultivation in EPTRI. This was supported by British Petroleum. The need for bio-fuel from the First World country made forced cultivation of Jatropha plants in the name of profit maximizing form of agriculture practice. However, the data reveal that the Jatropha cultivation led to serious problems in health among farmers who cultivated Jatropha and also pushed farmers into more economic hardship.

[66] The social suffering, pain and poverty circulate on the following grounds: 1) displacement of people due to mining and extraction of coal and hydro power projects (Sagar, 2002); 2) low labour absorption leading to

from production to consumption, the more the energy is consumed, the more the entropy is created. The more the natural resources are plundered resulting in the form of environment degradation, climate change, loss of life and bio-diversity, the more the violence is created in society. This exploitative nature-culture interaction resulted in monsoon failure, reduced the level of ground water, which severely affect the food production and agricultural activities. At present, the nexus between food and energy crises is the product of this process of development. These issues of vulnerability of life forms are expressed through the subjective experience of individuals, and groups who participate in the process of production and reproduction of suppressed and subjugated life. For instance, the conflicts and contradictions of the contemporary society indicates the dualistic nature of social relations and existence - death vs. instinct, nature vs. culture, equity vs. efficiency, exclusion vs. inclusion, human vs. non human, rich vs. poor, material vs. non material, renewable vs. non renewable. This has become a cultural and social product of modernity, which creates stigma and collective identity crisis (Barry, 2009). It reveals the nature of inner contradictions of life conditions and organisation, which introduces death as part of a life process. These social phenomena are ontologically subjective, but epistemologically objective.

increase in non-agricultural work, unemployment and reduced wages of agricultural labourers; 3) loss of employment, traditional activities and cultural heritage; 4) increasing poverty and ecological degradation made poor to dependent more on the nature for livelihood; 5) looting of all medicinal plants and other bio-diversity reserves and affects the wildlife sanctuaries; 6) loss of sustainable practices leading to massive exploitation of resources from common land; 7) breakdown of the traditional institutions of management of common property resources led to the pressure on common land for cutting trees; 8) perceived natural resources as rights of the commons and exposes the several ways these resources are eroded and abused; 9) prevalence of drought and desertification led to the soil erosion and loss of plants and bio-diversity; 10) the contamination of water resources by mixing sewage and drainage in fresh water lakes; and 11) geomorphologic change in ecological structure led to the loss of resilience power.

Alvares (1994) describes development as triage and plunder. In the name of development, the energies of labour and resources are exploited in the legitimized way on the one hand, and also socially excludes and subjugates the marginalized section and the below poverty people from this mega project of neo-liberal development, on the other hand. It makes nature and labour the victims of such politics of development. Viswanathan (1997: 16-47) argues that development as a technocratic project creates modernity as violence. This technocratic project emphasizes on reductionist approach that limit science as an object. It benefits only a particular section of the community, and technology for development of humanism became a doom's day project. Consequently, science-society relations acquired a new form. At large, crisis is not just the nature's natural change cause damage to the environment which we talk about. But we look at how society is constructed, organized and produced the same structure of domination, and hierarchy. The dominant socio-political values become an instrumental means to reproduce the same structure of domination on which the production and consumption rest. The technology and resources through which the programmes on energy securitization exist reinforce the values of the dominant sections and undermine collective benefits to all. The investment in nuclear energy in India is a case in point. It not only brings the long-standing contradictions between the layman and technocrats in the modern day political system into the lime light but also shows the direct relationship among energy, science and development. One can conclude by using Nandy's (2004) remarks that this insane society has its own inner logic which encourages destruction as instrumental rationality for development. Uberoi (1978) argues that this is a positivist version of growth in which human values are undermined by providing importance to the fact. This practice of science violates the law of nature, thus nature-culture interactions yield no growth in future. In short, we fail to look at development from two vantage points: one, development's economic cost of social risk; and two, development's economic profit on account of reducing the social risk. Thus, we end up with the politics of development as an anti-developmental process in India.

Environment and Climate Change: Adaptation and Mitigation

In the above context, the concern for environment and energy attempts to restructure the industrial society through demands for sustainability and inclusive development. Subsequently, these demands enter into the language of alternative practices within the larger development politics[67]. For instance, the issues of energy and environment have taken the centre stage of political and policy discourse leading to the emergence of climate and green politics – green economy and green social movements. This alternative readdresses the goals of economic development and growth, which incorporates the social values of sustainability, environmental justice and inclusion as a form of development. Habermas (1976) observes that crisis is a persistent disturbance of system integration. It means that systems imperatives are incompatible and unable to integrate hierarchically. The continuity of systems imperatives becomes a larger question with the existing mode of goal values and system elements. Structural continuity needs alternation of both goal values and system elements. With the climate change and resource constraint, the modification of goal values (sustainability, environment justice and inclusion) and system elements (technology / resources) of development witness the nature of social change

[67] This process is called reflexive modernization by Giddens, Ulrich Beck and Scott Lash. Giddens (1990) refers reflexive modernization as social practices that are constantly examined and reformed in the light of incoming information about those very practices, thus constitutively altering their character. It means how human actors reflexively engage with one's own self understanding of environment, and also attempts to change the course of future with such understanding. It systematically deals with inherent dangers of life such as the notion of risk, hazards and how to overcome through the concept of safety, security, etc. In this context, various institutional strategies of climate change attempt to overcome the man-made environment disasters through technological and institutional innovation as a solution. This is what is called reflexive development in which science is part of the critique of development politics (Pieterse, 1998).

taking place in the midst of a crisis-dominated social life. Etzkowitz and Zhou (2006) argue that public understanding of climate change (science) mediates the technology-created impact and solution for the same through the development and implementation of sustainable technologies. The political and institutional strategies provide scope for the institutional re-framework in the process of economic development and growth. It emphasises that creating a conscious socio-political will is considered equally important to achieve consciously created social objects (social and ecological transformation). The socio-political will is based on two strategies: adaptation and mitigation. The former attempts to look at the strategies (radical change in culture, lifestyles, conservation of forest and energy, sustainable agricultural practices, etc) to adapt to the conditions of climate change while the latter focuses on the strategies to resist climate change (technological solutions, reducing the consumption of fossil fuel) by shifting to technologies and resources that are clean and green. These two are seen as the solutions to the environmentally degraded world. However, in the lights of environment and energy issues, these two strategies also readdress and reformulate the concept of wellbeing and the focus of the welfare state which turn to strategies for reducing poverty and social suffering. This model of development focuses on the growth to de-growth position or post-growth, which emphasizes on distribution of work, income, assets, rewards and benefits, and equal sharing of burden. These measures are focused on redefining, reshaping and redirecting the growth of economy. Several metaphors, such as the end of cheap oil, the dawn of post-oil economy, post carbon economy, third industrial revolution, etc., represent this paradigm shift.

Within the above socio-political context, the new concepts, methods or practices are introduced to mitigate the crisis situation so that the social problems come to the state of rest, which makes the system to survive. Therefore, innovation is used as a language and a discursive formation for restoring the equilibrium, which is assumed to be losing in the present form of economic development and growth. It contributes to the new commercially viable economic ideas for ecological and economic modernization. As part of this process, encouraging technological innovations are manifestly implied in the process of mitigating the various forms of crises. Giddens (2009: 11) in his book on *Politics of Climate Change* pointed out as follows:

> We can anticipate, and should do our best to encourage, a surge of technological innovation in response to both climate change and energy security. Without such innovation, it is impossible to see how we can break our dependency upon oil, gas and coal, the major sources of environmental pollution. A turn to renewable sources of energy is essential, and it has to be on a very large scale.

To ensure the paths of sustainable development, the socio-institutional framework on climate change encourages technological initiatives like increasing scientific and technological capabilities, investments in techno-scientific research in various renewable energy technologies such as solar thermal, solar photovoltaic, wind, biomass, hydrogen, etc. These initiatives attempt to advance the knowledge frontiers in cutting down the cost of new renewable energy sources by focusing on technological innovations and mass production. In this context, though renewable energy technologies are considered as unviable ideas (in terms of cost and applications) for development they become possible ideas of development. In this situation, like other countries, India has taken several initiatives to adopt and mitigate climate change.

India's Climate Change Negotiation, New Institutional Initiatives and Politics of Compulsion: India's political stand on climate change negotiation consists of three main arguments (Singh, 2012). (1) India argues that the developed nations are responsible for climate change and they should bear the cost of transferring technologies and funding. It needs relaxation in IPR laws for environment friendly technologies. (2) India argues that differentiated responsibility should be the ethical concern of climate change protocols. (3) Though India agrees to take voluntary action, it disagrees to legally binding agreements. Like other Western countries, India's institutional framework on National Action Plan on climate change focused on mitigation and adaptation to climate change (Govt of India, 2008). The action plan tries to mitigate climate change and environmental degradation through eight innovative ways. They are: 1) National Solar Mission named after, Jawaharlal Nehru National solar Mission (JNNSM); 2) National Mission for Enhanced Energy Efficiency; 3) National Mission on Sustainable Habitat; 4) National Water Mission; 5) National Mission for Sustaining the Himalayan Ecosystem; 6) National Mission for Sustainable Agriculture; 7) National Mission on Strategic Knowledge for Climate Change; and 8) National Mission for a Green India. One can divide these eight innovative strategies into four main areas: 1) energy; 2) agriculture; 3) water; and 4) sustaining ecosystem.

In the aftermath of these initiatives, various scholars claim that India is neither solely responsible for higher carbon emission rate nor it has higher economic growth but only shares a social and environmental burden of development (Deshmukh *et al.*, 2010). Though the First World countries are solely responsible for this disaster, they are less concerned about effective and radical responses. Even the comparison of the per capita emission and per capita energy consumption exposes that developed countries rate of consumption of energy and carbon is more than that of the developing and underdeveloped countries (International Energy Agency, 2010; Integrated Energy Policy 2012; Sharma, S 2010). However, various scientific reports of Inter-Governmental Panel on Climate Change (IPCC), various international protocols (Kyoto) and talks (Copenhagen Accord and Cancun agreement), tend to force India to accept the international norms on climate change. India accounts for 56% of industrial energy consumption which lead to the outlet of 82% of direct CO_2 emission (International Energy Agency Report, 2011) which is considered to be higher than the global standards and account for 77% of total direct CO_2 emissions. By 2035, India will become one of the biggest emitters of carbon-di-oxide next only to China and the USA (International Energy Agency Report, 2010). This may run the risk of being considered as a violator of international norms under the climate change regime, if India fails to conform to the global norms; it has to incur the burden of violation, which exists in the form of carbon trading, CO_2 taxes and implicit pricing via regulations and standards.

Nicholas Stern *et al* (2007) report on "The Economics of Climate Change" reveals two vantage facts. 1) Climate change impacts growth and development. Also, stabilizing the climate involves economic cost. It means to reduce the rate of emission, huge public expenditure is required. 2) Climate change is a market failure. It indicates that the impacts of climate change affect the future generations or developing and underdeveloped countries, who are not responsible for the same (Nagel *et al*, 2008). However, the dominant group responsible for climate change is liable to pay for the consequences created by climate change. The absence of liability ends up with externality in free market trade and thus, the social cost of emitting greenhouse gas is at free of cost (Stern, 2009: 11-

14). There is no procedure to measure the additional cost that is incurred out of the action in the course of production and consumption. At present, with the global actions on climate change, the cost of emission is taken into account, which results in more economic cost than social benefit. Simultaneously, the cost of energy resources is growing faster with the rate of decrease in conventional sources of energy and increasing consumption of energy with the growth of population (Giddens, 2009). It is an economic prediction that the cost of renewable energy and cost of conventional energy would meet at the point of equilibrium (Meadows *et al*. 1975). At this stage, the capitalism takes other sources of energy as a means of production and consumption to stabilize the various forms of crisis, which is considered to be the part of climate change and resources crises. Thus, the first (climate change) and the second (resource constraint & cost of mitigation) become the general conditions of production, which reduce the profitability of the capitalism and its accumulation. In this context, though fossil fuel is considered as the cheapest finite source of energy, it is considered as an unviable option the present crises constrained world.

With the above compulsive forces, India is liable to take various initiatives in developing new renewable energy technologies and development of new sectors such as solar, wind, biomass, etc, become priority areas. In this context, the reemergence of solar energy technology development exposes the First World countries' objective of enforcing their norms and values of knowledge production in India. Like other international mechanisms such as WTO, IPR regime, Dunkel Draft, the protocols on climate change influence the Indian government to take political actions in favour of them. The solar energy becomes an instrumental means for the objectives of achieving the First World concept of sustainable development. Reddy, A. K. N., (1999) criticizes that the implementation of solar energy technologies comes with the motive of Western countries notion of sustainability, consequently, hence it becomes a politics of sustainable development. In India, solar energy is considered and contextualised as part of the larger structure of development that influences new growth strategies by incorporating renewable energy source as part of production and consumption. Subsequently, the international norms on climate change latently functions as enforcement in the form of encouraging developing and emerging economies to take initiatives. Thus, the action plan on climate change is an external force of compulsion that makes India to take initiatives on solar energy.

Solar [Energy] Securitization, Burden of Climate Change and Criticism of NAPCC:

Several scholars have criticized the strategies to tackle climate change. The criticisms are as follows. Capitalism perceives crisis an opportunities for creative destruction to restore the notion of profits through various business opportunities (Mueller and Passadakis, 2009). Nature is perceived as new source of raw materials (Amin, 2011). Organisation of new green industry is emerged with climate change and environmental degradation (Alvater, 2004). Triple crises (energy, food and finance) are opportunities to plunder and develop (Shiva, 2009). For instance, the mitigation strategies against climate change are based on two instruments: one is deficit spending on renewable energy technologies such as solar, wind, biomass etc[68]; and two, is diffusing the burden of climate change through the market regime. This criticism exposes that the economics of neo-liberal policy is reintroduced in the form of climate change action plan. This model of development, based on sustainability and inclusion, attempts to increase the value of capitalism by maintaining and increasing the rate of profit and growth by converting natural resources into private

[68] The nature has become the reconciliation for the lost humanity and justice since renewable energy technological innovations have become the means of production and consumption.

property (Amin, 2011). Consequently, the new initiatives reflect the vested interests of a particular group, which shape the choice of strategies (political, economic and technology) and leads to further accumulation of capital through renewable energy technologies which are patented. These strategies are mainly employed to create market-based demand in the short term and to increase productivity in the long term. For instance, the political interventions reveal such attempts through politico-economic rules (incentives, tax rebates, and concessions) enforce the marke-based approach as a solution for climate change. This is what is evidenced from the political opportunistic discourses on climate change and its strategies to mitigate the same.

For instance, though the NAPCC policies on climate change initiatives are welcomed by various interest groups such as environmentalists, industry, R&D scientists, civil society, etc., the action plan has been severely criticized by various scholars from different vantage points: though NAPCC is considered as a safe path to multilateral negotiation in the international discourse on climate change (the Indian Express, 2008) it has several other lacunae; although NAPCC provides strategic outline to mitigate climate change it is an inadequate plan when we consider the impacts of climate change and the issues of development in India since 60% of the population depends on agriculture as mode of production and is untouched by the developmental paradigm; NAPCC is neither a plan nor a vision (EPW, 2008) since it lacks in-depth knowledge of what the contemporary Indian experience (suffering and pain) are about (Goswami, 2008; Suman, 2011); it provides less opportunity to decentralized ways of mitigation strategies (Micheal and Pandya, 2009; D'Souza & Raajen Singh, 2010; Adve, 2010); NAPCC is a secretive process which excludes the voices of the common people by retaining the same structure of development in the name of clean development mechanism (D'Souza & Raajen Singh, 2011; Equations Report, 2011); Bidwai (2008) argues that the exclusionist policy exposes the undemocratic practices focused on the market-led growth and marginalizes the millions and promote, deep social and regional inequalities (quoted in Adve 2010; Thakkar 2009); the NAPCC as a climate policy provides less consideration to the issues of water and food, and it provides importance to the energy scarcity such as dam construction and energy technology development (Micheal and Pandya, 2009; John D'Souza & Raajen Singh, 2011; Adve, 2010). For instance, in India energy demand has been increasing and to meet the economic growth rate of 8-9 percent India requires 8, 00, 000 MW power production by 2030 as against 1, 60, 000 MW in 2012. It shows that the primary energy consumption increases by 5 to 7 times. Singh (2012) argues that the primary energy demand in India is set to grow from 400 million tones of oil equivalent (Mtoe) to over 1, 200 million Mtoe by 2030. Likewise, the consumption of electricity is set to rise from 660 kWh per head to over 2, 000 kWh by 2032. The urgent need for energy sources other than coal is a need of the hour. Based on this economic fact, Government of India is in the continuous process of formulating energy securitization as a means to economic security. Similar to the introduction of multiple new nuclear power plants, thermal plants and hydro power projects, solar energy technological initiatives are part of the larger securitization process. Rapid increase in economic growth consumes 49% of the energy production followed by buildings 29%, agriculture 19%, and others 7%. India faces acute energy crisis due to shortage of coal. It makes India depend on imported coal as well as oil. To avoid such dependency the regime of incentives and subsidies focused on creating R&D (supply-push) and development of market (demand-pull) policies to realize the renewable energy resources (such as solar energy, bio-mass, hydro and so on) and energy efficiency technology (John D'Souza & Raajen Singh, 2010). Overall, the urgency to make India a country free from energy dependency results in massive plan on solar energy.

The implementation of solar energy policy, India requires Rs. 90, 000 crores. Subsequently, the twin subsidy programmes – Kerosene, diesel and LPG, and on account of solar energy, will create double burden on the national exchequer. However, in some of the Western countries such as Germany, the UK and other European countries, the non-solar power producers pay extra charges on the consumption of electricity. Over a period of time, India also might adopt a similar policy. Spain is an exception which employs the policy instruments of deficit spending to reduce the consumer burdens (Deshmukh *et al*., 2010). However, the present European Economic crisis has forced Spain to withdraw its deficit spending gradually. With the solar energy policy in India, the following are likely to happen: a) Government burden will increase (taxpayers money will be spent in the form of subsidies); b) Dual tariff policy or cost will be equally shared in the electricity bills (customer takes the burden); c) NSM provides less importance to rural electrification programmes; and d) Middle class and lower middle class will have to bear the burden of solar energy plan implementation. One can say that rural poor will also be affected by this. In reality, the rural poor do not pay any electricity charges as of now, because they are given electricity free of cost or at a very low tariff in many states in India. Hence, the solar energy policy needs re-articulation in the context of tariff and regulations.

Conclusion:

From the above understanding, it is clear that in what socio-political context technological and industrial initiatives on solar energy have emerged; and also how science, energy and development are related to one another in India. With the politics of climate change and resources constraint, two phenomena are clearly evidenced. One, as part of the energy securitization, solar energy is incorporated into various scientific and technological initiatives and also energy programmes like nuclear, coal and hydro. Two, the innovations in solar energy technologies become an instrumental means to achieve the larger agenda of developmental needs. This brings the different social actors into the process of new knowledge production in India. The present study explores the present problems of Indian PV industry and techno-scientific knowledge production in India to examine the factors affecting technological innovation in photovoltaic.

Understanding the Trajectory of Solar Photovoltaic Technology Development in India

Introduction:

At this juncture, this chapter critically looks at the development of solar photovoltaic technology to unravel the context in which the SPV technology has been nurtured, developed and commercialized in India. This is to describe the various phases in the history of the SPV technology and how technological, scientific, political and economic factors shaped the trajectory of SPV technology in various phases. This historical understanding of technology development in solar energy unfolds two intervening factors: one is the continuity of resistance, and two is the resistance to continuity. The continuity of resistance indicates the factors which prevent the development of the SPV technology whereas the resistance to continuity indicates breaking the resistance against the SPV technology and attempting to develop and use it. This chapter looks at the evolution of the Indian SPV industry and the production of scientific knowledge in SPV technology in particular and solar energy in general. Though the chapter's main concern is with the issues of scientific knowledge and industry development, it also brings the issues of external factors of energy sector and issues of development in India. This would reveal the trajectory of the SPV technology development and how such development has been projected over the decades, since 1950s. One can divide the development of SPV technology into four phases in Indian context: First phase, the emergence of PV technology and its social context; second phase, the new initiatives and disintegration of solar energy programmes; third phase, the import of technologies in the era of globalisation, reasons for the failure of market development programmes; and fourth phase, new energy policies and the emerging issues in the implementation of National Solar Mission (NSM).

The story of Biotechnology in India, according to Visvananthan and Parmar (2002), was created within a politics of anxiety and desire in India. Similarly, the solar photovoltaic technology has been constructed within the context of external force of compulsion and the influence of internal urgency in India. It was a failure of political rationality to visualize solar photovoltaic (SPV) technology as one of the main stream technologies of India such as Information and Communication Technology, Space Research and Development, automobile technologies, pharmaceutical (and Biotechnology) etc. The SPV technology was even less considered as a political choice to increase power generation like increased food production through green revolution. Consequently, the technology always found resistance to penetrate into the social structure of the Indian society. The technological development in SPV unfolds many ups and downs but finally exposes the nature of struggle or resistance it faced to become a part and parcel of our scientific and technological culture and society.

SPV Technology and its Controversies:

At present, there are two controversies that exist in the conversion of PV science into PV technology. The first view describes that the application of solar PV is commercially impossible. The production of PV technology, from processing silicon to the final product of PV system, consumes more energy and subsequently, the energy output from PV technology is considered lower than the energy input at the time of production. The input-output ratio in terms of energy consumption and production makes PV technology non-viable for large-scale energy production. For instance, cost-benefit studies show that in manufacturing, PV technology costs outweigh benefits in terms of difference between the cost of production and benefits gained from energy generation based on SPV technology (Alsema & Nieuwlaar, 2000; Green, 2000; Jackson & Oliver, 2000; and Barker, 2005). Manufacturing of PV technology from processing silicon to PV system involves energy intensive work. The production of PV technology will increase demand for energy, thus putting pressure on electricity generation. So it is highly impossible for a developing country to setup silicon processing, PV ingot, wafers and cell production (Indian Semiconductor Association Report, 2008). By emphasizing on the economic viability of SPV technology, it curtails the scientific knowledge production in SPV.

The first view also holds that the maximum theoretical efficiency of first generation solar cells was already achieved at the laboratory level and conversion of scientific knowledge into technology yields low output though there is a fundamental increase in the SPV cell performance. Consequently, the scientific knowledge production in the first generation of solar cells reached the stage of saturation and further R&D is difficult to carry forward. The technological defects such as low efficiency, immobile, fragile nature of technology, technology failure in tropical regions due to the inability to absorb high temperature, and requirement of huge space affect the R&D investments in first generation PV technology. It pushes the scientific knowledge production to the second and third generations of PV technologies. Despite the low costs compared to the first generation of PV technologies, the second generation solar cells produce low energy output compared to first generation and the materials of cadmium telluride have serious environmental affects. At the same time, the third generation of SPV technology still exists at the level of laboratory. These factors curtail the transfer of PV technology from laboratory to industrial applications.

However, at present, the reduction of cost and increasing efficiency are the key factors which drive R&D in solar PV technology. What is required at present is new scientific belief that could reinitiate the solar energy R&D at the level of scientific research and technology development. This is what guides the present advanced research at successive generations of technology development. It also influences the academia-industry relations in fostering industrial R&D and plays a major role in encouraging rapid progress in R&D and industrial investments.

Second view describes the unfavourable policy conditions and strong control of the state in energy sector which resist solar energy from being part of the mainstream energy production since its inception in 1950s. Winner (1991) argues that technology is inherently political. He describes the nature of solar energy as egalitarian and democratic that has the potential of becoming a decentralized energy production which the state-controlled energy system does not want to have. This is because, Scheer, (1994 and 2004) argues, conversion of solar energy into electrical energy, with the help of solar devices, involves little labour, machine and other products and energy can be produced by anybody at any place. Thus, it reduces the economic cycle by and large. Though it reduces the cost of production such energy devices decrease the whole process of economic production and thus, brings the circulation of economy down. Solar energy as an instrument of development stops the cycle of economic expansion. Subsequently, the state employs the logic of capitalism, the notion of monopolization and centralization, to expand the process of production by fossil fuel based energy system. It brings the argument that everything is determined by market forces (Zeluck, (n.d); and Alvater, 2004) and consequently, it eliminates the solar energy to be part of the mainstream energy production. Thus, solar energy becomes the politics of market (Barbara *et al*, 2009). Therefore, institutionalization of capitalist rationality has become the ideology and practice of science and technology in the modern state (Habermas, 1991). In fact, the market is a social and economic construct that establishes the economic relations between cost, resources, and wealth and thus, accumulates capital by exploiting the cost differentials of labour and raw materials[69]. It adopts the technology and resources which focus on profit maximization. Subsequently, the policy consideration, in solar energy, has been undermined from the mainstream R&D development and energy production, since 1950s onwards. One should not limit this argument only to solar energy but also renewable energies in general. Ray Reece (1979) argues that solar energy R&D stopped because of the politics of collision between corporate power and state in monopolizing the centralised version of energy production (quoted in Lacy, 1982). Subsequently scientific knowledge production is affected adversely by the motive of profit maximization. In this context, solar energy technologies or alternative technologies are in an underdeveloped condition. Solar energy technologies are kept away from the society in the name of cost economics.

Phase 1: Pre-independence-1970: Emergence of SPV Technology and its Social Context

Factors Impeding the Progress of Solar Energy Knowledge Production and SPV Industry Development:

In general, there were two important factors which curtailed the further progress of solar industrial R&D and industry development: building scientific institutions and fostering public sector-based development in production and control of energy; and assumed failure of applications in solar (thermal) technology.

[69] Marx defines surplus value is the difference between the input and the output value. Capitalist selection of raw material and labour is based on the assumption that how much surplus it can provide.

First, with the advent of independence, India's economic manifesto focused on the immediate transformation and growth of Indian economy through the imitated Western model of state intervened capitalist development. The modern origin and development of power sector and the establishment of scientific institutions had its root within this framework. This is clearly reflected in the intellectual discussion which focused on the choice of technological selection and paths of development. The argument between two eminent scientists, namely Dr. Homi Bhabha who is considered as the modern architect and father of Nuclear energy and Dr. D. D. Kosambi who favoured solar energy technology as a resource to feed economy and development (Jishnu, 2008). The ideological positions and vested interest of elite scientists/politician and economist nexus played a vital role in establishing the goals of various scientific and economic institutions in India (Kosambi, 2008; Viswananthan, 2002; and Gadgil and Guha, 1996: 181-184). This social contract reflected in the formulation and articulation of Indian Scientific Policy Resolution (SPR) of 1958 and the subsequent energy approaches in India. For instance, the establishment of new scientific institutions and introduction of west-oriented science and scientific practice deliberately affected the idea of taking solar energy in policy discussion and implementing the solar energy technology for energy and development needs. In this regard, Sharma, D (1976) claims that it was a choice between what is affordable and what is not as a science and scientific research eliminated solar energy technology from S&T policy consideration in India. Solar energy, according to Rao, R. (1973), was ignored to be considered as one of the priority areas of Indian S&T system.

Likewise, on the one hand, Atomic Energy Acts of (1948) and (1962) provided specific importance to the energy security as vital for national development and hence, a prime means of securing the state (Abraham, 2012). In this context, Reddy, A. K. N. (1991) argues that Indian energy policy focused on need based approach of industry rather than people centred approach. It focused on the end-use energy model or regression model which takes demand into the account and considers the supply side. It provided importance to macro-level picture of energy demand (industrialisation) and neglected the micro-level demands such as household energy demands in rural (urban) areas. It was a Western model of energy policy (Mitra, 1992). On the other hand, the control of the energy sector – public sector firms and production and distribution system - was kept in the hands of state governed institutions. It led to the emergence of various institutions for various resources that controlled the energy sector and thus the control of energy as a whole was dispersed. For instance, the energy sector in India was controlled by different agencies such as Atomic Energy Commission, Central Water and Power commission, Ministry of Mines, Ministry of Petrol and Chemicals and the State Electricity Boards based on region and commodity. This socially excluded the private sector participation in energy sector and the consideration of technological choice of solar energy was completely ignored due to high cost and non-technological viability in terms of energy production and as a commercial product. Consequently, the knowledge production in solar energy became limited.

Second, in the pre-independence era, according to Viswanathan (1985: 152), solar energy was given more importance in the context of oil politics. However, the applied research on solar energy in India started in the early 1943. It emerged in the context of building scientific institutions for socio-economic development of the country. As part of CSIR, solar energy was the first and the most publicized venture into applied science and technology at NPL. It was the brain child of the eminent scientist S. S. Bhatnagar who focused on the solar thermal cooker. Immediately after the demonstration project, it was transferred to the industry for commercialization. But, the social acceptance of the technology yielded low reception at public and was considered as a market failure (*ibid*, 152-154). Since, the solar energy technology was considered as economically not feasible and it was difficult to use the technology when there was less sun radiation. It affected the penetration of solar energy at the initial stage though solar energy technology was proved technologically feasible. Scientists' and politicians' perception that technological feasibility contributes to market success and socio-economic development was falsified with the technological innovation in solar energy in India. It shows that much of the criticisms came from within the scientific communities at the international and national levels. Anderson (2001) says that this irritated Nehru and others on applications of solar science which does not have economic viability. This has changed the people's (government\scientist\industrialist) perception of industrial science in solar energy and much of the scientist preferred to confine themselves to scientific publications and peer group evaluation rather than of applying science to the energy needs. This course of action witnessed two phenomena: first, it curtailed further progress in the area of solar energy though there was intermittent technological development programmes introduced in the later phases; and second, this created the social belief that solar thermal and solar PV to be the same.

Establishment of SPV Scientific Knowledge Production and PV Industry Development:

Indian Science was nurtured with the thought of making India a global super power; a thought which was influenced by the international context. At this stage, PV technology, as a source of power, was a new phenomenon in the world. As an energy producing technology, PV technology was considered uneconomical in the production of energy since technological capability and efficiency was very low compared to other fossil fuels. However, it emerged as an ideal source of energy producing technology in places where other source of producing energy is impossible, such as remote social spaces and satellites. Consequently, PV technology acquired importance in specific areas of applications such as space, telecommunication, defense and remote power supply and became an important instrument for the immediate socio-economic and political transformation of a country (Perlin, 1999). For instance, the era of space exploration, both manned and unmanned mission, was ushered in the 1950s & 1960s in various countries such as the U. S., Russia and Japan. This technological dominance established a neo-socio-political world order through defense and space research programmes. These space research programmes employed PV technology as one of the major technological components in space crafts and satellites to produce energy for their self functioning. At the initial stage, it was this specific necessity that drove the western countries to produce scientific knowledge in PV technology at various laboratories such as RCA, Bell and academic science at Wayne State University and University of Delaware in USA.

Under the influence of Western science, Indian scientific community established various scientific research programmes such as space, defense and atomic energy, and also considered them major scientific achievements. Thus, India claimed to be a part of the socio-political world order dominated by the power of science and technology. It was under such circumstances that the solar photovoltaic took its birth. Despite the high cost and low efficiency of SPV technology, Indian scientific community made several attempts to cope with the western developments of S&T in SPV. Thus, the first phase of research initiatives were socio-politically constructed in the context of the programmes of space and other limited industrial usages. It is evidenced that PV technological (& solar thermal) research was carried forward in various Indian academic institutions and laboratories such as Central Salt and Marine Chemical Research Institute, Bhavnagar; Central Building Research Institute, Roorkee; Central Arid Zone Research Institute, Jodhpur; Indian Institute of Technology, Madras; Indian Institute of Technology, Delhi; BITS, Pilani; Motilal Nehru Engineering College, Allahabad; University of Roorkee; Auroville Centre for Environment Studies, Pondicherry, etc. It is noteworthy to mention that some of the initiatives in the Indian academic research were followed by transfer of technology to industry. In 1966, Institute of Solid State of Physics (SSP) initiated R&D activities at the level of silicon solar cells and employed imported silicon slices to fabricate silicon solar cells. The process of know-how was acquired from foreign countries, and the production of solar cells began in 1977. The Indian Space Research Organisation (ISRO) and SSP entered into a collaboration agreement to produce high quality solar cells for space research programmes, which led to the fabrication of diffused silicon solar cell technology of both p+ on n as well as n+ on p types at the laboratory scale. Later, it was evaluated at Delhi laboratory. Subsequently, in 1971, India developed its own know-how process in the fabrication of silicon solar cells, which has been released to the National Research Development Council (NRDC). As a result, cost effective solar cells for space programme has been successfully fabricated and developed in India. In 1973, the cost of one Watt stood at Rs. 3000. However, Baskaran (2001) claims that India employed foreign silicon technologies for the space satellites such as Aryabatta, Baskara I and II. It indicates that though India was capable of producing indigenous technology, because of low efficiency levels import of technology was preferred. The results of scientific research might have yielded benefits at a later stage but not at that point of time. In a way procuring technology from outside dampened the spirit of indigenous technology development in SPV.

At this juncture, several firms were interested in adopting the knowhow and subsequently, the indigenous technology was given to Electronic Corporation of India Ltd (ECIL) to produce silicon solar cells for a space research programme. Likewise, in 1969, the production of poly silicon materials for semiconductor usage was initiated and Mettur Chemicals and Indian Institute of Science (IISc) entered an agreement to develop chemical processes for silicon-based materials (Indian Crystal Report, 2008). In this context, Indian PV industry started producing cost-effective technology for space research programmes. However, the research initiatives were scattered across research laboratories and the need for new knowledge production in SPV emerged out of industry specific usage (internal consumption). But the developed PV technology had limited range of applications such as energizing a transistor radio, using in outer space, used as photosensor by the space science technology centre, etc. Therefore, the real challenge was to convert the space technology (and laboratory scale) into terrestrial technology or mass application.

Phase 2: 1970s-1990s New Initiatives and Disintegration of Solar Energy Programmes

Social Reactions and the Context of Oil Crisis:

Various scholars (Rangarao, 1974; Reddy and Prasad, 1977; Pendse, 1980 & 1984; Reddy and Reddy, 1983) have criticized the western paths of development based on monopolistic exploitation of natural resources in which fossil fuel energy and science are part of such development process. They also predicted that the rapid increase in the consumption of fossil fuel energy would create burden on the marginalized sections and below poverty people since India has the low capacity of purchasing powers. It creates a larger gap between science and democracy and also deteriorates India’s development agenda and makes the country dependent on external resources and technologies. So they have encouraged technological self reliance in the sphere of energy production which could reduce the burdens of mainstream energy production and consumption and also emphasized technological inclusion of renewable energy technologies (RETs) into the mainstream energy policies. In this context, the need for huge R&D investments in renewable energy technologies and adoption of foreign technologies were encouraged as an immediate strategy to develop indigenous technologies not only to counteract crisis but also to develop India as an energy surplus country. Thus, in the 1970s, there were two major social and economic factors which had taken a centre stage in intellectual debate and policy discourse: first, the issues of widening gap between material progression and social development; and second, the oil crisis (1973) – created a (new) social consciousness of technology, resources and the development. It provided the room to develop new political strategies to mitigate energy crisis that were largely formulated under three categories: (1) enforced immediate adoption and utilization of energy efficient technologies; (2) encouraged investments on new renewable energy resources such as solar, wind and Bio-Mass; and (3) proper management of power production, distribution and consumption of energy.

The above scenario unfolds the context in which solar energy (and renewable energy) initiatives emerged, encouraged and how solar energy technologies were later sidelined in the process of development in India. Such focus largely emerged within the energy sector and can be classified into three categories on the basis of the arguments and themes focused on: (1) studies articulate the socio-political and economic reasons for the need of solar energy (and renewable energy technologies) in India; (2) these studies conceptualized energy crisis as socially embedded in the crisis of development[70]; and (3) such studies also provided suggestions to tackle the present problem of energy crisis and also how to foster sustainable development. These studies argue that renewable energy technologies such as solar, wind, biomass, as appropriate technologies[71] and a culture based approach is required to integrate the programme of poverty eradication within the energy crisis. Within the paradigm of sustainable and inclusive development, the variables of poverty, inequality, energy, development and technology are interlinked with each other.

New Technological and Institutional Initiatives in Solar Energy:

As part of the strategies to meet the oil crisis, a scientific report was drafted by CSIR and NCST. It called for government participation in solar energy S&T development by providing liberal funds for R&D activities. It also recommended the commission of solar energy under DST or CSIR and suggested Indian scientific community to enhance the solar energy technologies for commercial purposes. The Indian political architecture on solar energy was formulated, articulated, and initiated in this context in 1974. It focused on three main areas that attempt to develop and deploy indigenous solar energy technologies: (1) R&D initiatives on solar energy and RETs; (2) new industry initiatives at various levels of productions such as wafers, cells and modules; and (3) subsidy based market initiatives programmes (DST-CSIR Report, 1974).

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[70] With the growing demand for energy and the oil crisis, the developing countries need an alternative approach to the process of development which focus on conservation of energy and decentralized energy option through renewable energy technologies. This reduces the global threat in terms of climate change and makes developing countries more reliant on indigenous energy production and satisfies human basic needs. In that sense, the developmental crisis would be reduced in India (Reddy, A. K. N. 1991).

[71] These scholars understand energy crisis as development crisis and emphasize biomass (& solar thermal) technologies as appropriate technologies to solve the rural energy problems through self sufficient energy production. They considered solar energy as the best choice to transform rural India as socially developed. The forerunner of this argument was Dr. Amulya K Reddy whose academic contribution to solar energy was widely recognized in India. In a larger context, the concept of appropriate technology was defined by Mahatma Gandhi to criticize the development based on westernization and modernization in India. His philosophy of development is circulated within the boundaries of village self-sufficiency. Dr. Amulya Kumar Reddy employed Gandhi's concept of self sufficiency to solve the energy crisis in India (Refer this larger argument in Reddy, A. K. N. 1989; & 1994).

Subsequently, the Government of India initiated various programmes and scientific and financial institutions for solar energy in particular and renewable energy in general. The increasing R&D investments and industry oriented growth were introduced through various activities in academia-public research laboratories - industry collaborations. Thus, the second phase focused on two activities: one addressed the development of indigenous PV industrial base; and the other addressed the development of solar PV technology for terrestrial and commercial purpose. For instance, in 1976, several scientific research initiatives on first and second generation solar photovoltaic silicon and amorphous silicon cell technologies were introduced by the Government of India in various academic and public research institutions such as National Physical Laboratory (NPL), Bhabha Atomic Research Centre (BARC), Solid State Physics Laboratory (SSPL), Indian Association for the Cultivation of Science, IITs and universities. It paved the way for the development of indigenous technologies. As a result, India has achieved 11 to 13 per cent efficiency in first generation crystalline silicon technology and future R&D efforts were aimed at achieving a 15 per cent efficiency in first generation solar cells. Subsequently, the indigenously developed technologies were transferred to PV firms under the Government of India's first sponsored industry project on National Solar Photovoltaic Experimental Demonstration (NSPED). This made Central Electronics Limited (CEL) to start the indigenous production of first generation solar cells in India. In the late 1980s, the first ingot and wafers' production was started by a private player called Metkem Chemplast Group. The production was based on know-how developed by the Indian Institute of Science (IISc). This R&D programme was supported by the Ministry of Non-Conventional Energy Source (MNES), which led to the establishment of production capacity of 40 Tons Per Annum

(TPA). However, the production was stopped due to high electricity costs, forcing the company to employ imported technologies. Later, Bharat Heavy Electrical Limited (BHEL) started the production of first generation and second generation solar cells.

Likewise, in 1981, the Government of India has set up a Commission for Additional Source of Energy (CASE) to promote renewable energy technologies for energy productions. Under the Government of India, the Department of Non Conventional Energy (DNCE) (1982) was inaugurated to formulate and guide plans and programmes to deploy and develop solar energy and RETs. The role of DNCE was to coordinate various scientific researches mainly focused on development of technologies such as first and second generation solar cells, and on reducing the cost of technologies by focusing on the improvement of silicon material technology and efficiencies. It created a new scientific institution called Solar Energy Centre in 1987 to develop, test and evaluate solar energy technologies through industry and R&D collaborations on technological demonstration and deployment. In 1987, the Indian Renewable Energy Development Authority (IREDA) was established to facilitate development of RETs and commercialisation by providing financial and technical assistance to entrepreneurs and consumers. As a result, several grass root level programmes on solar energy were introduced to disseminate solar energy technologies and RETs.

The initiatives, in India, also include international collaboration on technology development and deployment in solar energy; (1) the Bonn Summit (1978) and Brandt Commission encouraged technological ties in solar energy between the first and third world countries; (2) the United Nation Environment Programme on demonstration units in energy mix of solar energy, wind power and bio-gas to meet the energy requirements of rural communities; (3) in collaboration with West Germany, India had a programme on developing low cost solar energy technologies using easily produced and operated equipment; (4) Along with West Germany, 25 research organisations were involved in the development of solar plants for rural application; and (5) subsidized solar irrigation pump was supported by France throughout the Third World.

Limited Participation of Private Sector and Progress of Scientific Knowledge Production:

Though the initiatives and the research goal were to develop and commercialise indigenous technology, but most of the time it was stopped at the stage of demonstration. The main reason is that scientific knowledge production in India relating to solar PV was limited to the specific industrial application or even small scale application. For instance, India's space programme – Indian Remote Sensing Satellite (IRS) employed its first indigenously developed solar panels. Though the Indian industrial R&D on PV technology for space purpose was quite well established in the first generation technology, yet it failed to create mass applications of PV technology. The developed technologies had limited potentials for commercialisation though at the laboratory scale India achieved 14 percent efficiency in the first generation solar technologies followed by the development of second generation solar cells. However, the indigenously developed second generation amorphous silicon technology was also employed at 0.5 MW power plants to test and gain experience for future application of solar power plant. The mass application was questioned within the framework of market viability and economies of scale in comparison to fossil fuels. The capital cost of the solar energy outweighed the benefits of the solar energy technology. The unfavourable cost-benefit ratio discouraged the development of PV technology, which also curtailed the transfer of technology from laboratory to industry. Industrialists perceived solar energy from the vantage point of industrial (mass) applications. Such assumption was immediately disposed off under the laws of thermodynamics – describes solar energy is impossible to produce heat energy or electric energy required for industrial production. This energy input is not sufficient for the energy requirement of heavy industries such as steel, aluminum, etc. Consequently, investments in solar energy considered capital risk. This severely affected the industry participation in the production of PV technology and the government also stopped funding R&D. This resulted in stopping the process of knowledge production in R&D laboratories.

For instance, one of the industrialists who participated in an industry-academia seminar on solar energy remarked as follows:

> *"As one of the participants pointed out, I came to this seminar, being from the industry, with a view to learn something and find out the methods by which our heat inputs in the form of energy inputs would be replaced immediately ... But for industrial applications of solar energy... the present work done in the field of solar energy falls short of the industrial requirements (quoted in Patel, 1978)."*

Technology Policy Statement (1983) and import substitution policy provided importance to the inward oriented approach that focused on technological self-reliance and indigenous technology development. Consequently, SPV technology programmes were highly limited to the public sector units such as CEL, BHEL, Bharat Electrical Limited (BEL), ECIL, etc and public research laboratories such as the NPL, IACS, etc. The private investments in R&D and negligible private players were severely affected by this growth model. It curtailed the development of knowledge and technological base of Indian SPV industry. For instance, there were only three firms namely; Udhaya Semiconductor, Indian Renewable Energy Systems and Tata BP which have established the operation as suppliers of PV technological systems, and later they started the production in modules and followed by cell productions. There were quite a number of private firms such as Hindustan Browni, Jyoti, Tata BP engaged and interested in the production of solar energy (especially in thermal). However, they were much concerned about the policy that existed at that point of time. At this stage, there were very high customs duties on imported PV technologies (Wright, 2003: 32), and most of the private firms were reluctant to invest on solar energy due to the uncertain market and high costs of production and inadequate scientific manpower and technological capabilities at the level of modules, and cell productions hampered the development of technologies and industry growth. In this regard, for instance, N. H. Tata emphasized the problems of policy in India. He pointed out that government should invest in indigenous R&D and human resources development to build the indigenous manufacturing base in solar energy for which, he argued, licensing and planning procedure needed to be simplified (Hansavivek, 1979). Furthermore, inadequate fiscal incentives to producers and purchasers of renewable energy technologies may fail to create strong market relations between manufacturers and consumers. Without such incentives private sector participation would be difficult in building the indigenous solar energy industry in India. Since the strong monopoly structure of public sector undertakings and government control over the energy sector exist. Consequently, in the 1980s, it attracted minimal participation of private firms and created the impression that solar energy technologies had only low potential opportunities in the country. This had serious repercussion in establishing the base for the indigenous PV industry in India. Furthermore, the technological collaboration between Indian PV firms and foreign firms was absent. To put it in the words of Ghosh (1991a):

> *"There are certain renewable sources of energy which are already well known and in use, e g, biogas and solar heating and cooking. R and D efforts (at Jadavpur, Calcutta) appear to indicate the achievement of an efficiency of 14 per cent (in regard to solar*

photovoltaics) at the laboratory stage. The Japanese claim that efficiency of 19 per cent has been achieved in this regard, but there is no corroboration of such claims. At any rate, an efficiency of 14 per cent would compare favorably with even present US standards. The only problem lies in our failure so far to manufacture the required hard-ware in the form of silicon wafers and amorphous silicon on a viable, economic scale. This, then, would be a thrust area for R and D efforts in the Eighth Plan. Meanwhile, considering the foreign exchange outgo involved in the import of primary sources of energy (in the form of oil and coking coal), there is every case to permitting large-scale import so for the required raw materials (and for allowing foreign collaboration, where necessary) for the manufacture of cheap, durable, portable and easily usable photovoltaics. Unfortunately, the concerned government departments (as well as technocrats) appear to be opposed to such collaboration arrangements. This is a strange situation. We are prepared as a nation to freely permit foreign collaboration arrangements for the manufacture of cosmetics, junk foods and elitist durable consumer goods (like VCRs), but we are not prepared to allow collaboration arrangements for an item which will light up the homes of millions of rural poor at a ridiculously low cost. (Even though this is a matter of detail, it is a vital issue, for the establishment speaks under the slogan of self-reliance. We are prone to lock all skylights and windows when the front door is wide open, through profligacy in the use of imported oil, and an absent minded permissiveness in regard to collaboration arrangements for elitist consumer goods.) As it happens, there are some good proposals-there is one, which any sensible government would have promptly approved, for large-scale manufacture of 'highly functional, efficient, durable, and cost-effective photovoltaics, with guarantee of export of part of the pro-ducts to ensure foreign exchange neutrality-but our establishment is opposed to approval of such proposals, for our own scientists have been working away in parallel to rediscover this process".

On the other hand, due to the frequent failure of solar thermal technologies such as driers and cookers, people perceived that solar PV was also bound to fail. It made people to believe that solar PV technology is the same as solar thermal. Further, misunderstandings about PV energy output, the space required for producing energy and the energy requirement of rural households made solar energy devices a public joke. It created a wide belief that the use of solar energy was impossible at that juncture. This kind of intervention changed the mindset of Indian industrialist even towards the decentralized energy option and R&D in solar energy. They tried to oppose the idea of co-generation of hydro and solar by saying that hydro will become costly if we include solar. At that juncture, these kinds of interpretations completely prevented the inclusion of solar energy from any specific large scale programmes like Mega Watt power production. Subsequently, solar energy was not considered as a priority sector. As a result, funding agencies such as financial institutions also did not come forward to support the industry and technology development. Several programmes were discontinued in the middle due to reasons such as lack of funding, failure of technologies, low level of commitment from local or state governments, etc.

Low Level of Commitment and Vote Bank Politics:

Two reasons expose the low level of commitment to solar energy in India: one is the little national consensus in framing coherent energy policies; and two is the state politics in energy. There are two factors which show why India could not achieve national consensus on energy policy: first, the continuous political shift in the government affected the strong political commitment and will towards mitigation of energy crisis (Panikar, 1991) and people centred energy policy; and second, there was no dialogue among various institutions, which controlled the framing and planning of national energy policy in India. With dominant rent seeking behaviours, the coherence of political strategies in framing the holistic approach to solve the energy problem and crisis was misplaced in the development process. In this case, the separate government agencies functioned as a business enterprise, which looked at their profitability. Each agency attempted to increase their operation by enforcing their agenda on energy development. As a result, consensus on bringing solar energy as mandatory could not emerge at that point of time and also made renewable energies as just supplement in Indian energy system.

Second, in the 1980s, the heavy investments in industrial production and rural development witnessed heavy import of energy sources created the deeper trade deficit in India. Since, the income earned out of the trade relation was lesser than the trade expenditure and thus ended up in trade deficit. Consequently, it resulted in external borrowings to meet the local developmental needs in the 1980s. At this context, the IDA\World bank offered loans to start power plants for Third world countries. It reveals the nexus between energy and debt. Following the energy crisis, Pendse (1980) reveals, India advocated the slogan of "surplus power supply" to meet the needs of industrialisation and rural energy requirements. For instance, to meet the energy requirement of the development needs such as agriculture, industrialisation and urbanization, the Government of India's Five Year Plans had invested 30% of the GDP in the 1980s in fossil fuel based energy resources. Since, the Indian economy was characterised as low energy productivity but of high energy intensive work (high input but low output), it witnessed heavy imports of energy sources such as oil, clean coal, diesel and kerosene. Out of which, the middle distillates such as diesel and kerosene were more compared to other forms of energy. Through populist policy, the central and majority of the state governments' programmes entered into social energy contract mainly to capture the rural and urban vote banks. It incorporated and provided free electricity, subsidised diesel and kerosene to satisfy the energy needs of the country, which witnessed heavy investments in consecutive four Five Year Plans to address the issues and demands of energy and resulted in losses in the trade balance sheets of state electricity boards. These large subsidy programmes and investments eventually pulled the market forces for fossil fuel based economy. Within this larger energy politics, Visvanathan (2002) refers, renewable energies such as biomass, solar were resisted successfully. Scholars considered this as a failure of political rationality which could not achieve "surplus power supply" or address the energy (development) crisis. It nurtured social inequality in terms of energy consumption pattern and thus, form the energy stratified society (Reddy and Reddy, 1983). Finally, it was evidenced that India neither could develop and commercialise its indigenous technology nor mitigate the energy crisis at that point of time.

Phase 3: 1991 –2008: Era of Globalisation of Technology and Participation of Private Sector in Energy Production

At this juncture, there are two points that need to be recollected to understand how solar energy programmes were resisted at the larger policy level in India: first, the implementation of Energy Act (2003) provided scope for renewable energy purchase obligations, till then the suggestions provided by various committees and scholars[72] have never been part of the energy policies and programmes; and second, the under-estimation of renewable energy potentials and underdevelopment of technological capabilities based on scientific institutions and manpower led to the non materialization of solar energy programmes in the previous and the present decade. For instance, various scientific and financial institutions such as CEL, BHEL, SEC and IREDA were found inadequate in terms of manpower, technological and scientific assistance and funding.

Private Sector Participation in Energy Sector and Failure of PV Market Development Programmes:

India witnessed a balance of payment crisis (great fiscal imbalance) that arouse mainly out of oil import bills and led to the state of economic crisis, in 1991. On the other hand, the paucity of resources and the paucity of physical capabilities of energy production made the

[72] The detailed description of energy policy in India: (i) Report of the Energy Survey of India Committee [ESIC: 1965). (ii) Report of the Fuel Policy Committee – recommendation to draw coherent energy policy – which should be an integral part of the national plan [FPC: 1974). (iii) Report of the Working Group on Energy Policy – to review the developments in the energy sector within and outside of India (WGEP: 1979]. (iv) Report of the Committee on Power [RCP: 1980] (v) Modelling Energy Demand for Policy Analysis – the need for a national energy modeling system in order look at various energy use and option and help identify policies energy system management [Parikh: 1981]. (vi) Towards a Perspective on Energy Demand and Supply in India in 2004-2005 – projection of energy demand and supply (ABE: 1985). (vii) Perspective Planning and Policy for Commercial Energy [Sengupta: 1981) – it aimed at analyzing the optimal strategy of supply of energy need of the economy to ensure the achievement of the targets of growth, distribution and efficiency by meeting the final demand for different energy forms at least resource cost. This model also took into account the substitution between commercial and non-commercial fuels.

Indian government to liberalise energy sector by allowing private sector participation in power production. This political strategy was mainly initiated to tackle the energy problems and crisis in India (*D' Sa et al.*, 1999). Though it was implemented in the Eighth Plan but the Ninth Five Year Plan evidenced full fledged participation of the private sector in the energy sector. Consequently, this is one of the major reasons that attracted the participation of private capital in the energy sector. The high capital cost of production made the private sector to establish secret agreements with SEB for power purchase. It led to the formation of a closed contract between government and private sectors in energy. This led to the emergence of a government-business nexus, which partly shifted monopolistic control to oligopolistic control of energy production. But, the government still has the control over the energy production and distribution in India.

In this context, India was the only country to have the largest and the extensive programmes in renewable energy, and established the Ministry of Non-Conventional Energy Sources (MNES) in 1992[73]. The responsibility of framing and organizing policies and programmes on renewable energy were entrusted with the MNES. The World Bank report recognised the energy shortage in rural areas and encouraged the supply of energy gadgets such as SPV home lighting system to rural villagers. However, it covered only small upper strata of the rural areas and left the rest in the doom days. In 1993-94, the Government of India launched massive market oriented programmes in solar energy (Bhattacharya and Jana, 2009). It focused on the phased commercialisation of solar energy for which the Ministry got 1.377 billion Euros as a loan from the World Bank. Subsequently, IREDA supported 85 projects under PV development programmes

[73] Note: In 2005, it was renamed as Ministry of New Renewable Energy Source (MNRE).

(Simplicio, 2003). In collaboration with IREDA, MNES found four potential niche markets for PV technological systems: government, government driven, private leasing and direct sales on the open market. It formulated innovative financing mechanism for the commercialisation of PV technologies so that end-users could afford to purchase the necessary equipment (Ibid, 2003). It employed intermediaries to provide loans to consumers under four different financing models; the corporate model, which uses leasing and hire purchase mechanisms; the cooperative model, which uses rental and leasing mechanisms; the NGO model, which uses leasing, hire purchase and rental mechanisms; and the dealer model, which uses direct sales to users (Harish *et al.*, 2011).

Understanding the government as a participant in market development programmes on solar energy shows the nature of procurement and distribution system that prevails in India. With the constrained open market, State Nodal Agencies (SNA) and Akshya Urja became responsible for procuring and distributing solar energy technologies such as SPV lighting system, lantern, SPV water pumps, etc. The Ministry of Non-Conventional Energy Source (MNES) provided a capital subsidy to the manufacturers to reduce the cost of the equipments for the end user. The financial routing led to the formation of closed social contract between various actors MNES\IREDA\financial intermediates and manufacturers. On the one hand, though the MNES strictly followed the evaluation based bidding system but most of the time the closed group violated the norms and ended up in corruption charges. This was witnessed with the reduction in various benefits such as tax depreciation, increased interest rate, etc. On the other hand, MNES encouraged competitive bidding process for the lowest subsidy rate to discourage manufacturers' dependency on state funding. Most of the time, the private firms faced tough competition with public sector units such as BHEL and CEL to get the competitive bidding. However such measures resulted in negative results since the private firms imported obsolete technologies from Asian countries such as China and Taiwan. The monopoly of public sector units, such as CEL, BHEL, BEL, eliminated the private sector from the local market and also the lowest price quoted by BHEL virtually stopped subsidy for solar energy (Radulovic, 2005). Eventually, it pushed the private firms to get technologies which are competitive in global market. For which, the policy relaxation and import of technology provided the scope to dump the PV technology. It became the easiest way for the newly started traders and PV firms to survive in the tough dual competition (within the industry and outside the industry). The weak institutional structure and low technological potentials virtually collapsed the PV technology programmes and the demand for solar energy drastically reduced, which pushed MNES to think of other programmes on renewable energy, such as biomass (*ibid, 2005*).

Energy specialist and environmental activist such as Reddy, A. K. N (1999) have severely criticised the politics of PV technology implementation in India. Such programmes were employed with the objective of achieving environmental standards for first world countries, which was set in the Earth Summit and Kyoto Protocols. So, the cost and benefit analysis reveals that SPV was costly to Indian rural people though it is sustainable in nature. Subsequently, it had low market position in India. For instance, the cost of 37 Watt home lighting system (HLS) stood at Rs. 18, 500 compared to 20 Watt SPV HLS at Rs. 12, 500. Because of its cost, solar energy in India is considered to be an elitist energy source and not an egalitarian source of energy. Further, he argued that the egalitarian character of technology comes with the reduction of cost. In future, it may be suitable for energy production and rural development, but now it offers high profit market for enterprises. Providing end-use-device to end users is a must but such device should increase the income and also the quality of the life. In this case biomass is the best energy option for India. Rather than investing in solar, one could effectively use investments to create various other programmes in rural development. In the 1990s, the solar energy was more of a government sponsored programme and consumers belonged to the category of large organizations in the private sector such as telecom, and railways. In rural areas, for instance, the government subsidized SPV pumps have benefited large and medium scale farmers rather than marginal and small scale farmers. However, there are certain success stories such as Solar Electric Light Company (SELCO), PV water pumps in Punjab and Tata BP -Aryavartat (Harish *et al,* 2011) reveal that solar energy PV technology is non-elitist which contributes to economic development of the rural households. These private programmes such as SELCO were successful without employing any government subsidies.

Globalisation of Technology and Decline in SPV Knowledge Production:

As part of the liberalization policies, a complete strategic change was witnessed in the government stand on industry development and R&D in India. Like East Asian Economics, India relaxed its policy to develop the local industrial base and invited foreign firms to participate in the development of technology intensive areas. But such attempts undermined the development of indigenous technological capabilities and industries. It has the inner meaning of globalisation of technology in Indian context. Indian SPV industry and R&D is one of the best examples of this course of action. It had two repercussions in the development of PV industrial base in India: First, with the cut on duties in solar cells, modules and PV technological system, the newly started PV firms focused much on the export market, especially European countries. This has increased the production of SPV modules followed by SPV cells in India. At this stage, India was the second largest producer in mono solar silicon technology, which was indigenously developed. However, Indian imports have also been increased since basic infrastructure facilities for production of raw materials and wafers, ingots etc. were completely absent. Though the relaxation in cell production prevailed but the cost of production and limited market for SPV cell consumption stopped funding in the backward linkages. This led to imports of cells, modules and PV system in India. It further added to the problem by fixing the reductions on duties on import of raw materials and wafers, which further affected the development of industrial base at the last stage of production. This is the area where government encouragement was required but the government failed to recognize the problems of the PV industry and thus, the industry specific approach was ignored in policy consideration. For instance, the government policy provided the same structure of incentives as it was provided in the case of industry development such as: 1) soft loans for plants and machinery used in manufacturers; 2) concession rates on custom duty for the import of equipments and materials used in PV manufacturing (10 percent on wafers, 30 percent on solar cells, modules and system, 20 percent on capital equipments); 3) exemption from excise duty on most PV products; and 4) exemption from sales tax in several states in the country (Sastry, 1997; & Bhargava, 2001). Unlike Information and Communication Technology and Biotechnology, there was no programme for developing human resources and entrepreneurial development in Indian PV industry. Swaminanthan (1995) reflects as follows:

A more serious outcome of this uncertainty generated by annual changes in duties is the impact on indigenous Research and Development (R and D). The Budget 1995-96 has been particularly castigated for the harm that it is bound to have in the growing photovoltaic and electronic component industries. R Ramachandran (The Economic Times, March 25, 1995 and March 29, 1995) gives a fairly detailed overview of the record of government's funding for the Science and Technology (S and T) system of the country. He has shown how the generally good budgetary support to S and T till the Seventh Plan had been reversed since the Eighth Plan, which came along with economic reforms and policies of liberalization and globalisation. The budget squeeze was particularly severe from 1992-93 onwards; while there is a 10.59 per cent increase in the 1995-96 Budget over the 1994-95 Revised Estimates, this increase is largely due to the substantial hikes in the budgetary support to capital intensive programmes of atomic energy, space and ocean development. There is a real increase only in the funding for ICAR and the CSIR after two years of near constant budgets. On the specific impact of the Budget 1995-96 on indigenous R and D in the solar photovoltaic industry (SPV), we can do no better than quote Ramachandran in some detail: The worst suffer ersa s a result of Manmohan Singh's largesse of duty concessions to foreign firms this time round are going to be the domestic solar photovoltaic (SPV) industry and the electronic component industry... The Indian photovoltaic industry can now be said to be well established comprising large and small capacity public and private sector units with capability in the entire Value chain of SPV systems production. There is shortfall in the indigenous capacity to poly silicon wafers and some raw materials which is currently in the through imports. So one could perhaps make a case for duty reduction on raw materials. But extending the cuts to solar cells, modules and even complete systems which involve 100 per cent value addition is bound to push the industry against the wall. The SPV industry is notorious for (dumping by foreign companies particularly MNCs. like Siemens, who are sitting on huge inventories. Added to this will be the increased influx of rejected batches of solar cells and modules, particularly from Russia. Indeed the government term globalisation has come to mean open invitation to imports and MNCs, by intent rather than supporting indigenous industry to become global. That alone can explain these illogical reductions in duty structures (The Economic Times of India. March 25. 1995).

There are three factors which inherently played different roles in resisting the implementation of solar energy at large scale: First, the incorporation of private capital in energy sector; macro level changes in policy condition led to the globalisation of technology and production; finally, institutional mechanism of distribution failed to disseminate the technology to the poor. It is a complete failure of an institutional system which pushed solar energy away from the process of development. In this context, it was difficult to comprehend the contribution of R&D initiatives to solar energy technology development. However, the solar energy R&D is still at an exploratory level (Sinha, 2011) cost effective and efficient technologies are yet to come from Indian scientific laboratories (Harish *et al,* 2011). The conclusion that one can draw from this is that either solar R&D programmes would have been scrapped fully or the solar R&D might be kept at the level of knowledge production. The Indian scientific laboratories might have reduced its R&D efforts of developing new technologies with the advent of globalisation of technology (& assumed market failure of solar energy technologies). This may be correlated with three other important aspects of knowledge development: first, the recent report published by the NISTADS on sector wise allotment of financing to various programmes in energy sector unfolds that solar energy gets the least amount of priority in terms of funding (Abrol *et al,* 2008: 62) in scientific knowledge production. Second, though India is emerging as one of the top five countries in SPV patents, UNEP (2010: 34) report suggests that solar PV is the only field where India shows no effort. There is little difference in the patenting rates between 1978-1987 and 1998-2007. Third, there is little academia-industry interaction that exist in terms of developing new technologies in contrast to other industries such as pharmaceuticals and IT in India. However, NISTADS report also suggest that Indian scientific institutions have well established international collaboration on PV technology R&D, which witnesses slow progress of internationalization of PV R&D since 2000 (Sinha, 2011).

Phase 4: Since 2008: New Energy Acts and Policies

India is at the stage where it has virtually lost the opportunity to develop of SPV technology and industry. At present, climate change negotiations play a predominant role in fostering the clean and green technologies development, in which SPV technology is considered as important instrument to mitigate the same. Several negotiations on climate change politically enforce all the countries to take immediate action to stop the man-made disasters. In these circumstances, India agrees to take voluntary action to mitigate climate change, which resulted in the articulation and formulation of National Action Plan on Climate Change (NACPCC). Under this larger political action, Jawaharlal National Solar Mission Plan (NSM) is not only a mitigation strategy but also focuses its attention on energy securitization in the midst of acute power shortage in India. However, there are other programmes and policies focused on renewable energy in India since 2000 as follows:

1. Indian Electricity Act (2003) – all states should compulsorily purchase power from renewable energy sources (RPO).
2. National Rural Electrification Policy (2005) – aims at providing access to electricity to all households. The policy focuses on the dissemination of off-grid solar PV application to rural households. For instance, Rajiv Gandhi Grameen Vidhyut Yojana (RGGVY) and Akshay Urja Diwas are major programmes.
3. National Tariff Policy (2006) – Mandates each State Electricity Regulatory Commission (SERC) to specify Renewable Energy Purchase Obligation (RPO) with distribution companies in a time bound manner (Arora *et al*, 2010).
4. Semiconductor Policy (2007) – encourages semiconductor and PV manufacturing firms through various capital subsidies of 20% for manufacturing Plants in SEZ and 25 % of for manufacturing plants outside of SEZs. However, this was withdrawn in the mid 2010 (Singh, 2011).
5. Generation Based Incentive Schemes (2008) - provides Rs. 12 per KWh as incentives for grid connected solar (both thermal and PV) power plants.

6. Different states have different schemes and incentive packages for solar PV and thermal technology. For instance, APIIC introduced FAB city as special Economic Zones for semi-conductor production and PV cell and module production.

7. Solar Energy Corporation of India (2011) –the purpose of this institution is to set up 'demonstration plants' to encourage indigenous solar technologies and industry.

NSM is a domestically funded mitigation action plan. Its target is to achieve 20, 000 MW capacities by 2022. The mission plan has three phases 1) 1100 MW, 200 MW off-gird and 7 million Sq meters thermal (2010 -13), 2) 4000- 10000 MW, 1000 MW off-grid and 15 million sq meters (2013 - 17) and 10000 MW, 1000 MW and 5 million sq meters thermal (2017 - 22). The central government provides special incentives for production, generation (Power Purchasing Agreement PPA & feed in tariff) and usage capital subsidy for certain products of PV technology. The NTPC Vidyut Vyapar Nigam LTD (VVNL) carries out the mission plan (MNRE, 2009). Like the 1980s, NSM focuses on the three main areas: first, is the development of indigenous technology and R&D; the second focuses on the development of indigenous Indian solar industry; and the third is new initiatives in market development programmes. It is like an old wine in a new bottle and faces different set of problems at various levels: first at the level of technological option and fixing subsidies for solar energy power production; the second, is about no linkages between different programmes under different ministries on renewable energy and the third, large scale subsidies exist on fossil based energies such as kerosene, diesel, electricity, etc.

Technological Change, Technological Option and Fixing Subsidies:

Though NSM creates a huge demand for solar energy, the weak manufacturing base and technological gap makes Indian PV module and cell producers to import technologies from foreign firms. This technological gap creates trade dependencies (in the place of oil dependency) to meet the solar energy targets in India. So the Indian manufacturers may depend on the well established East Asian (Chinese and Taiwan) manufacturers for cheap import of wafers, PV cell and modules, which occupy 40 percent of the market concentration in the world. On the other hand, in order to develop the local manufacturing base of Indian PV industry, NSM employs the protectionist strategy. It emphasizes that solar power plant producers should employ indigenously produced silicon cells and modules so that it strengthens the local base of the Indian PV industry[74]. But, the solar power plant producers counter argue that the first generation PV technology is incapable of absorbing much heat and in the long term the performance of the technology fails. It would be a loss for the solar power producers. Consequently, the present shift to second generation solar PV technology happens through the import of solar thin film technologies. Since, in NSM, there is no restriction on importing the second generation PV technology. This created controversy as solar power producers prefers to import second generation technologies from foreign countries for power plant projects. Compared to the first generation technologies, the second generation technologies are cost-effective but less potential than first generation technologies. This has serious implications for the development of Indian PV industry and R&D. For instance, the majority of industry investments rest with the first generation of PV modules followed by PV cells. Once the imported second generation thin film technology picks up in the market, this may pull down the market for first generation PV technologies. On the one hand, this would eventually undermine the development of indigenous PV industry which is based on first

[74] The first batch of solar mission plan mandates the power producer to employ indigenous modules technologies but they can use imported PV cells and second batch onwards both cells and modules should be manufactured in India.

generation technologies and also encourages import culture, which stops the local technology development programmes. On the other hand, it may lead to monopoly since there are very few firms which exist in thin film and also may lead to the dumping of second and third rated PV technologies which create negative impact in the Indian market. Furthermore, this may limit the industry at the end stage of production and investments in backward linkages such as silicon processing, ingot and wafers production may get little attentions from the investors and PV firms, which is already lagging in India. One of the major reasons for these phenomena is that the frequent technological changes and mass production reduces the cost of PV technology prices. It reduces the cost of electricity per unit. So the solar power producer who quotes the lowest price in comparison to the power tariff set by CERC may have the chance of winning the bid. This is what happened in the first phase of NSM. Paliwal (2011) says that the power producers who were committed to providing power at the cheapest rates were selected. This is called reverse bidding. This method of selecting power producers have been retained in the second batch too. This kind of bidding process encourages the culture of importing rather than encouraging the Industry development.

Solar Energy as Supplement and not the Mainstream Energy Production:

There are two government programmes under two different ministries which focus on the rural electricity off-grid distribution: First, under the Ministry of Power: Rajiv Gandhi Grameen Vidyutikaran; and second, under the Ministry of MNRE, the NSM. In domain of distributed energy, solar energy plays a vital role. This would create different forms of subsidy allocation to different programmes. What is implemented under the two programmes has still not reached the 60 million people who depend on kerosene. On the other hand, the Indian government allocates huge subsidies to kerosene and diesel compared to lower subsidies to solar energy. This creates conflict between technology option and business option. Solar subsidy stands at Rs. 8640 crores compared to kerosene which stands at Rs. 36, 000. Parallel to this, the state government subsidizes electricity to farmers and consequently, most of the rural village pays very little electricity bills and the deficit has been incurred by the state utilities. At present, it shows that solar energy is a supplement and not the replacement for conventional sources of energy. Various trade prediction and government investments show that there is an increase in thermal and nuclear power plants in India. This would be required to meet the present growth rate and subsequently the viability of solar energy becoming a mainstream energy production technology is impossible till 2025.

Conclusion:

The sociohistorical account points out that the solar energy was a grand political strategy that took shape in the context of oil crisis and the politics of sustainability, and it has been considered just an alternative (& a specific) source of energy production. Consequently, it was not a part of the development discourse based on inclusion at all. The choice of the technology selection (e.g. solar energy) had always been determined by the politics of compulsion (space programme, sustainability and climate change) and the economics of urgency (oil crisis, resources scarcity and energy securitisation). In this case, solar energy received a differential treatment in terms of subsidy from the government but such treatment failed to create an impact in the Indian society. It made technology development as continuously discontinuous. The government’s approach failed to see things as connected and in a continuum. In this case, Visvanathan (2002) argues that our attempt to develop India as a developed nation failed to recognize both: a) discreteness where it was necessary to look at it as discrete entity; and b) not as a continuum that failed to see continuity among discrete entities. In this context, we see deficiencies in the process of a developing society like India. This is highly contextualized in the energy sector which mediates science and development. This leads to a widening gap between science and democracy, and neglects to look at the technological needs of the country.

Two main reasons for this gap are the different aspects of the S&T system such as the science-politics nexus, industry-market relations shaped and influenced the technology development in photovoltaic. However, unlike Western countries, the role of civic movements played a minimum role in fostering technology development in photovoltaic (Barabara *et al*., 2009) since much of the focus was given to biomass technology and wind technology rather than solar photovoltaic. In the Indian context, the photovoltaic is considered as an elitist technology though it has some grassroots success stories. Different facets of S&T system, which acted as a continuity of resistance, are clearly reflected in tracing the different phases of photovoltaic technology development. In this case, photovoltaic is perceived as market goods in contradiction to public goods. However, one can see the development and applications of photovoltaic in various space and telecommunications programmes, but these are highly limited to specific niche areas. Irrespective of these considerations, taking the photovoltaic from the laboratory to the public became a difficult task, despite various R&D initiatives in 1980s. Those programmes were highly limited to academic settings and public sectors units. In this regard, the government policies on industry development failed to recognize the nature of industry and R&D which ignored the problems faced by the SPV industry in India. For instance, there is no public policy on human resources in the area of solar energy, which affected the entrepreneurial development. In the absence of subject knowledge, the manufacturers imported the outdated technologies to withstand in the market competition. It ruined market potentials and constructed negative beliefs about solar energy in India. This problem was not well addressed by the government and the complete chain of distribution was rendered unviable and ineffective. All these events contributed to the resistance to continuity, which successfully retarded the development of Photovoltaic.

From the above understanding of the trajectory of SPV technology, two positions need to be understood from the actors point of view academia and industry to understand the factors undermining technological innovations in solar photovoltaic. Consequently, in the lights of the above argument, the study attempts to focus on its two themes: First, photovoltaic (PV) industry’s perspective to unravel the nature and structure of the solar PV industry and the constraints faced by the PV industry in innovation to unfold the factors curtail the growth and transition of PV industry in India; and second, it attempts to understand the various problems in the social practice of techno-scientific knowledge production and subsequently, the transfer of knowledge from laboratory to industry.

Rise and Decline of SPV Knowledge Production (1980-2008): The Indian Academia and In-house R&D Perspective

Introduction:

This chapter attempts to discuss the rise and decline of solar photovoltaic scientific knowledge production and technology development in India. The actors account illuminates on what happened to the techno-scientific knowledge production in the area of solar photovoltaic, and how various social, economic, political, scientific and technological factors shaped and also curtailed the transfer of SPV technology from laboratory to industry since 1980 to 2008. It rests on five factors that are narrated by the solar energy scientific community in India: 1) Economics of knowledge production explains the loss of scientific interest on knowledge production relating to solar photovoltaic and technology development; 2) publication, culture of imports and limited funding led to the decline of knowledge production in solar energy research; 3) limited academia-industry interactions and lack of new technology development initiatives; 4) the patent regime that undermined the indigenous technology development; and 5) the political construction of PV technology exposes the response to oil crisis at different points in time, with no continuous and sustained government support hampered the continuous production of knowledge. Subsequently, this chapter describes the scientists' experience and their accounts of scientific practice in the process of SPV knowledge production and technology development. By analysing the experience and accounts of scientists, the study identifies the specific reasons for the under development of the SPV technology in India. These are extensively dealt in the present chapter to answer the first objectives on this study: what factors govern techno-scientific knowledge production in Indian scientific laboratories; and how it constrained the transfer of knowledge and technology to industry.

Social conditions for the Emergence of SPV Technology Development: New Technological Initiatives, Research Targets and Technological Achievements

In the aftermath of oil crisis in 1973, the scientific knowledge production in SPV gained its momentum at the international level, and corresponding to that the Government of India formulated larger goals for SPV technology development. It was introduced as mission-mode R&D so the goals focused mainly on two main areas of technology development: one is to develop and transfer SPV technologies to industry; and two is to train and develop human resources to facilitate PV industry development. The former is largely conceived as a mission mode research at NPL a public research laboratory whereas the latter was pursued as individual research in academic settings in IIT Delhi and IIT Bombay. Apart from this, in-house R&D had been established in various public sector units such as CEL and BHEL. For instance, corporate in-house R&D in BHEL focused on technology development and also on aiding of industrial production on SPV cell, module and technological system. This R&D unit was fully funded by the MNRE in 1990s. In general, the research on two generations of technologies such as silicon and thin film were initiated. Although the infrastructural and laboratory facilities for doing science and technology development did not meet international standards, the scientific community have the best individual scientists and research teams at the academic and public research laboratories. This created conditions for the formation of solar energy scientific community in India. The following is the summary of the account given by the scientists:

> In 1980s, the biggest achievement was the formation of a group, comprising of scientists who could work together, and also building scientific laboratory in SPV technology. So we had imported laboratory equipment from abroad. The development of manpower and laboratory were the biggest achievements at that point of time. We all were the specialists in the science of solar cells.
>
> Another scientist from IIT Delhi said:
>
> I was associated with one of the best groups in PV technology, in the 1980s. Our strong point was our scientific expertise in comparison with investments and other lab facilities.

> Ultimately, from 1978 to 1990, excellent scientific research work was done in the area of solar energy in India.
>
> Another scientist from NPL mentioned:
> The mission mode research initiatives started doing research on different generations of PV technologies to explore different ways of reducing the cost of production and to increase the technological efficiency. However, the research was pursued with the aim of achieving the target of industrial efficiency. So, the primary target of the knowledge production was to achieve the maximum efficiency of crystalline and amorphous silicon technologies. We did hard labour to achieve the maximum efficiency at that point of time, with limited resources. However, the government incentives for the production of solar energy were provided only where the general transmission of electricity is economically non-viable and impossible. The application of solar energy was limited to the only to those specific areas, for instance, remote places, satellite, military operations, etc. The research was never meant for day-to-day usages such as home appliances, individual set up.

At the initial stage, the research targets and initiatives provided long term scope for the development of PV technologies. But, it was highly limited to specific applications and industrial R&D dominated the Indian scientific knowledge production. With consciousness of oil crisis, issues of energy were mainly considered as an immediate socio-economic problem of the country. Consequently, PV technology development was limited so as to address the issues of energy needs of the country. However, the research targets were to develop and demonstrate economic and commercial viability of SPV technologies for space and commercial applications. The main aim was to increase the standards of technological efficiency and to reduce the cost of the PV cells. According to DST-CSIR Report (1974), this was to convert the space technology into terrestrial technologies, which is possible only through increasing the efficiency and reducing the cost of the technologies.

Despite this target, the research practice varied from academic to public research laboratories. For instance, in 1980s and 1990s, IIT Delhi was one of the core institutions that focused on amorphous thin film technologies. However, primary focus of scientific research turned out to be production of scientific knowledge for the sake of knowledge pursuit. Majority of the scientists in IIT Delhi and IIT Bombay, focused mainly on publications, and training the scientific manpower rather than on technology development.

One of the scientists from Physics Department in IIT Delhi said:

> In Indian context, the values of knowledge for the sake of knowledge predominate, especially in universities. Our earlier research targets were not to achieve commercialization but to explore more about the area of PV science and technology. So, we have just done research without looking at the aspect of commercialization in the 1980s. The primary focus of research was to publish but not to commercialize the same.

However, there are individual scientists who also focused on technology development such as solar tracking technology from IIT Delhi in collaboration with DRDO. Likewise, there are two scientists from IIT Bombay who developed different techniques and technologies in PV and also got patents for their inventions in 2000s.[75]

> One of the scientists from the Centre for Energy Studies in IIT Delhi mentioned:
>
> In the 1990s, I was engaged fully with the applied science and less concerned about basic science. Mostly we worked in the area of solar tracking. The technology is an embedded controller. We demonstrated to the DRDO but however due to some technical aspects it was implemented at a much later stage.

On the other hand, at NPL, in the 1980s, the solar energy research was conducted to explore the possible ways of technology development in SPV. In the course of time, in NPL, the scientific community achieved different levels of efficiencies in both the generations of SPV technologies at the laboratory scale: First, 12 percent efficiency was achieved in the first generation of silicon technology; 2) 6-8 percent efficiency was achieved in the second generation of thin film technology. Ghosh (1991a) unfolds that in the 1980s the R&D efforts of Indian scientific laboratory achieved an efficiency of 14 percent in first generation technology of photovoltaic cells. However, Dr. Satish Chandra

[75] Patent Information from the Scientist of Dr. Chetan Singh as follows: 1) Method for forming metal contact on a surface of a solar cell covered by an anti-reflective coating (ARC) layer (3506/MUM/2010); 2) A solar cell having three dimensional junctions and a method of forming the same (3467/MUM/2010); 3) Novel Front Metal Contact Patterning Scheme For C-Si Solar Cells (1787/MUM/2010); 4) 360o Sun tracking and self-cleaning of solar PV panels (1838/MUM/2010); 5) An improved Solar photovoltaic module-(Indian patent application No 1051/MUM/2007); 6) Method for making thin film devices intended for solar cell or SOI applications; 7) Method and apparatus for continuous formation and lift-off of porous silicon layers; 8) Method for formation and separation of porous silicon layers (US patent # 6649485).

Ogale in his Solar Conclave Presentation (2010) provides in-depth knowledge of what has been achieved so far in photovoltaic technology in NPL.

Table No: 5. 1 shows the achievements in successive generations of SPV technology made in NPL.

Technology	Project Funded	Technology Developed	Patent Information
Single and Poly Crystalline Silicon	NESPAD (MNES)	▪ Process for polycrystalline silicon TCS route ▪ Processes for mc-& c-Si solar cells fabrication ▪ Directional Solidification (CLM): mc-Si growth ▪ Process Industrial Si solar Cell ▪ Process for High efficiency Si solar cell	• Application of Porous-Si as ARC, 1st time (Indian Patent No. 156459) • Reusable graphite mold process(1988-92) (Indian patent (1999; Patent No.182633) & US patent (1995; Patent No. 5431869)
Thin Film Amorphous	MNES	▪ a-Si: Hand alloy-based PV started in 1984 ▪ Device quality a-Si:H,a-SiC: Hand Si Ge: H (all doped and undoped) ▪ Fabrication of efficient p-i-n solar cells (single junction) and double tandem devices. ▪ Optimized small area solar cells (1cm to 2) involving textured TCO/a-SiC: H (p)/a -Si: H (i) and a-Si: H (n) / metal layers with, appropriate graded doping, buffer layers etc. were fabricated and demonstrated.	Very little technology got patent.

Complied by Author, Source from Dr. Satishchandra Ogale (2010) Solar Conclave Presentation, MNRE

The scientific community considered it as the greatest achievement with limited resources at that point of time. From the 1980s to 2000s, though the indigenously developed SPV technologies, across the academic and scientific institutions, successfully demonstrated the technological feasibility at the pilot programme, a limited number of technologies and associated knowledge were transferred from the academic and scientific laboratories to the industry. It means that the SPV technology was not commercialised on a mass scale for industrial and terrestrial application. One of the senior scientists from second generation of SPV technology at NPL recollected as follows:

> I am the only one left over in the second generation of thin film research in NPL. In 1980s, we demonstrated the economic viability of amorphous silicon thin film technology. In 1984, we had Rajiv Gandhi solar mission on developing solar cells. There

> were three major scientists involved in developing solar cells". They are: K. N. Chopra from IIT Delhi, A. K. Barua from IACS and Prof. Veeray VC from Poona University. We all worked under the guidance of these experts and the government assigned specific responsibilities to accomplish it. There were five to six different themes on solar energy. It was a task based research and all the groups were allotted specific assignments. Our task was to develop amorphous cell and modules with standard technological efficiency and economic viability. It was basically to fit the technology into industrial applications. We achieved 6-7 percent efficiency in the second generation thin film and completed the task that was allotted to us in the late 1980s. The technology was also tested by the IACS. However, the technology was not transferred to industry.

One of the senior Scientists from Solar Energy Centre in Gurgaon also mentioned:

> In 1980s, the amorphous silicon (thin film) was developed by IACS, Kolkatta and BARC, under the MNRE project. Both, the technologies were developed by the Indian scientific community and there was no international collaboration on those projects. On the other side, the NPL and Indian Institute of Science (Dr. Vasudeva Murthy) also developed first generation crystalline silicon, which was transferred to CEL. Multi-crystalline is India's own technology and nobody gave this and also we indigenously fabricated the amorphous silicon technology. However, the knowledge production and technology development were not equally distributed in various scientific institutions in India. In other words, the success story of SPV technology is very limited and the technology is also not economically viable in terms of cost of conventional energy sources. Due to various political and economic reasons these technologies never created any impact in Indian society. The cost was the major barrier and slowly political interest on solar energy came down.

There are five major factors which hindered the development and transfer of technology from laboratory to industry, and subsequently scientific knowledge production and the emergence of new scientific specialty were also thwarted in India. As mentioned earlier, these factors are: First, reasons largely falls within the economics of knowledge production and the politics of reasons; second, publication of papers and research shift; third, low level of academia and industry interaction; fourth, patent regime as an obstacle to indigenous technological efforts and innovation; and fifth, political construction of PV technology.

Economics of Techno-Scientific Knowledge Production in SPV:

In general, understanding, the economic viability of SPV technologies largely falls under two intersecting points: (1) there are certain and proven things in SPV technologies; and

(2) there are uncertain and unproven things in SPV technologies. The first point indicates that the viability of SPV technologies are possible in those areas where grid connected electricity is uneconomical and impossible. In that case, the SPV technologies are assumed as (scientifically and economically) reliable and efficient alternative technologies of energy production. Majority of the research emerged in the context defense and space (Perlin, 1999). Despite technological feasibility, the second point claims that SPV technology is yet to prove the commercial feasibility, technological reliability and efficiency, when compared to fossil fuel and other forms of energy technologies such as Nuclear, Hydro and Wind. In this case, R&D in SPV is claimed to be uncertain and inefficient area of knowledge production which is unable to meet the market expectations in terms of cost. So the economics of scope in developing new technologies is affected with this course of meanings and actions. This became the major yardstick through which SPV technologies were measured in terms of economies of cost. Nowotony *et al.,* (2001) point out that this phenomenon as the first order of economic rationality is conjoined with the second order new economic rationality. The investments and calculations of profit are determined by the economic logic of material objects and scientific results.

One of the Scientists from IIT Bombay said:

> When economics entered into the science of solar cells, it was found that materials like silicon are not economically viable because the cost of producing solar cells on a large scale is impractical in terms of applicability. This is partly due to the production cost of electricity per unit was much lesser than solar energy. So, the cost of energy economics entered the production of SPV in competition with oil resources, which were considered to be cheap. Whereas the silicon in the purest form, it provides 16 to 17 percent energy efficiency which cost per watt comes around 4 to 5 dollars. This is far more expensive. This is the proven fact which played a vital role in the process of knowledge production and technology. So the research demonstration and industrial expectation of a technological viability was totally in diametrical relations. It affected the transfer of technology from laboratory to industry in mass scale.

To elaborate this point above mentioned, NPL as a public driven R&D, at the earlier stage of SPV knowledge production, the prime motive of the scientific community was attempted to explore the possibilities of developing new theorization, new methodologies and instrumentation which focused on new technology development and also new material research. At that point of time, there was no difference between basic and applied science in approaching the problems of technological development. Thus, Viswanathan (1985: 144) claims that the distinction between pure and applied science is not only a scholastic, but also a political distinction, in reality it is very difficult to determine where fundamental research ends and applied starts. However, in the case of SPV, the viability of technological demonstration at the level of laboratory (pilot project) was not adequate to meet industry expectations. The gap between the scientific knowledge production and the industrial requirements has widened with the non-viability of PV technology. It means that there was a fundamental difference between the laboratory and industrial efficiency of photovoltaic cells that were developed at the laboratory scale. For instance, various problems were emerged in the context of application: (1) first generation of silicon technology is stable, but the cost of technology is more because it involves so many processes; and (2) second generation of thin film technology is unstable, but the cost of technology is less. To bridge this gap, the scientific community attempted to rectify different technological problems associated with the SPV technology.

One of the scientists from NPL recalled:

> At the initial stage of technology development, we did not differentiate basic and applied sciences, both were considered as important for the development of a SPV technology. However, at later stage, the developed technologies had several defects so we limited our knowledge production at the level of application. Since the technological application was always in the limelight of controversy in terms of commercialisation. It affected the backward linkages with scientific knowledge production in basic and material research development. So knowing the subject knowledge of solar science is limited only to the application of science. Consequently, the scientific knowledge production declined due to low technological capability. As knowledge, it is a simple method that is conversion of sun radiation into electricity but in application it is the most complicated subject of science.

Gibbons *et al*., (1991) claim that quality control of new knowledge production is context based and use dependent in nature. Thus, finding economic and scientific solutions to technological problems of SPV technology became the main motive of techno-scientific research, which obviously provided importance to practical dimensions of science. So, the techno-scientific knowledge production focused mainly on increasing efficiency and reducing the cost to make it economically useful technology. This became standards of SPV techno-scientific practice and acted as a social control of knowledge production.

One of the scientists from NPL reminisces:

> The only problem, with the second generation technology, was the faster degradation of the materials employed in the construction of thin film technology. It also affects the technological rate of efficiency that reduces the energy production. However, the efficiency rate of the technology was around 6-7 percent which is the great achievement at that point of time. It was the highest in the country. We produced in a short period of time. We also made the option of two cells to reduce the depreciation rate of the technology by keeping one cell over the other to increase the efficiency and to stop faster degradation of cell. It enriches the lifetime of the solar cells. The different materials are required to construct the technology such as amorphous carbide, indium seleiude, etc to produce a solar structure. The optimization of the technology was low. After the demonstration of technological viability, the funding was stopped. I do not want to comment on-why the funding got stopped.

For instance, the major concern of second generation SPV technology was the rate of depreciation compared to first generation technologies. Since, the amorphous silicon technology degrades faster and affects the rate of technological efficiency, the scientific community attempted to adopt different materials such as amorphous carbide, inidium selenide, etc and tested to develop better technology. They tried to keep one cell over the other to see if any change in the reduction of technological degradation occurs. Finally, the scientific results enriched the lifetime of the SPV cells and also successfully demonstrated at the pilot programmes. However, the technology was not adopted and transferred to industry since the optimization of technology was low. It indicates that technology was highly immature and not viable for commercial purposes and involved high risk in converting small scale applications to mass production. Thus, it created a gap between the invention and innovation – a realm of uncertainty was thus introduced into the scientific practice of SPV techno-scientific knowledge production. With this structure of norms, the links between science and innovation are disconnected in SPV in India. These all affected the production of application oriented knowledge.

With the mission mode research in SPV technology, the language of increasing technological efficiency and accountability of the scientist had entered the field of techno-scientific knowledge production. It reduced the scientific community's interest on technology development. It is partly visible in the inability of the scientific community to address the potential needs of the industry. Since the expected industrial outcome was not achieved, it also affected the further R&D investments in SPV. As a result, the scientific (social) credibility of SPV technoscience was lost and was also questioned within the larger framework of what is good science. It is determined by the practicality of technology to achieve larger socio-political goals. In short, attempts to take science to market failed with the impracticality of technology. Within this hard objective scientific (social) fact, SPV technology politically failed to get recognition in policy recommendations, due to subjective value judgments of what is good science. Functowicz and Ravetz (2003) argue that the judgments based on subjective values and scientific facts play a vital role in determining what science is to be practiced and what not. Solar SPV techno-science was more vulnerable to this practice of science and its relations with science policy making in India.

One of the scientists from IIT Delhi recalls,

> The lack of scientific interest, in the solar energy, is partly driven by the scientific community's inability to deliver the potential need of the industry. On the other hand, it increased the social accountability of the scientist in the name of technological efficiency. None of the scientists came forward to work in the area of solar energy. On the other hand, the gap between the knowledge production and industrial expectation actually reduced the interest of the industry and government towards the knowledge production in SPV technology.

However, at the laboratory level, the scientific community developed efficient PV cells in both the generations of PV technologies, since they employed high quality materials to construct the technologies. So the performance of the technologies at the laboratory scale yields maximum scientific results. However, converting the same laboratory scale into large scale applications reduced the rate of efficiency and energy output from PV technology. At the industry level, one of the major reasons for such degradations was the employment of low cost materials to attract the mass market, which ultimately affected the technological performance of PV technology. It was considered as a technological failure of solar energy. The economic rationality of employing low quality of materials, in construction of wafers and cells, was largely due to two factors: first, is to attract the consumer market; and second, is to gain profit within a short period of time. This attempt eventually led to the failure of products in consumer market. This means industry and government were not interested in developing high quality products at affordable prices. Finally, they come to the conclusion that scientist did not meet the government and industrial expectations on solar energy research. Thus, it became the politics of knowledge production for discouraging techno-scientific research in SPV in the name of what is affordable science to developing country like India. This aspect clearly produced the larger gap between science policy and science studies in the area of SPV.

One of the scientists from NPL mentioned:

> Conversion of knowledge into commercially viable products needs integration of research into the production lines. We get good results at the laboratory conditions but the same technology failed to yield the same result in industrial applications. This is basically because in the laboratory we employ high quality materials, which are costly in the fabrication of PV technology but the industry employs different materials, which are relatively cheap to minimize the costs and sell in the commercial market. As a result, technological failure occurs in the context of market. These factors are the major reason for the failure of PV technology. Finally, at the end of the project, we write a report, after three years that suggest SPV technology as economically non viable in nature.

The University Culture: Reflections of Mode 1 Knowledge Production

One of the major reasons for the larger gap between science and policy is about the nature and character of academic knowledge production. To substantiate this point, the normative concern of the industrial laboratories and IITs foster the culture of technology and patents, which facilitate the culture of entrepreneurship into the laboratory science. However, in reality the scientific practice is constructed within the culture of university. This produced different effects on knowledge production and scientists. At the level of knowledge production, the core social values of knowledge production for the sake of knowledge ultimately shaped the practice of SPV technoscience at NPL and IITs. The real concern is about the conflict of interest between the academic dimension and the practical dimension of a scientific practice. The latter gives importance to the commercialization of science. For instance, though solar SPV technoscience is partly constructed with practical interest, it is the academic values that dominate knowledge production, since the majority of scientists were from university background and were socialized into the ethos of values of excellence rather than usefulness. It shows that the practice of technoscience, at the level of IITs and public research laboratory, was located within the larger social-construct of basic knowledge production, though the rudimentary importance was given to applied science. This played a major role in affecting the production of knowledge that benefits industry.

The paper-patent conflict which prevailed in NPL (Viswanathan, 1985) and the emergence of entrepreneurial science is a recent phenomenon in IITs (Krishna and Chandra, 2009). The social values of academic science possibly, thus, affected the culture of doing science for the market in India. In this context, majority of the scholars commented on the difference between the type of research required for industry and type of research carried out in laboratory (Mani, 1995; Katrak, 1997 and Ray, 2004). This difference is a social product of cultural differences that is between the culture of pure science and the culture of technology development. Hence, one can say that it is the kind of socialization and training of the scientists influence what kind of knowledge is being produced. The different cultural practice of science at university and industrial laboratory was historically nurtured since colonial context in India. At the scientist's level, it created a tension among scientists who were groomed in a culture dominated by pure science and who were only later introduced into the culture of technology development, which emphasizes different set of values. Subsequently, majority of the research problems were framed within a disciplinary theoretical approach and oriented towards basic understanding of SPV technoscience. Gibbons *et al*, (1994) refer to this character and nature of science as Mode 1 Knowledge Production.

Two scientists from different institutions such as IIT Delhi and NPL recalled same point as follows:

> The Indian research on material science very much lagged in terms of finding new materials, etc. PV technology is based on the construction of silicon material. No one wants to take a challenge on material science development. Construction of PV technology needs good background from material science. Unfortunately, the material science development relating to solar energy is one of the less focused areas. For instance, energy production depends on the material capacity of the PV technology. Energy output reduces, if the material degrades at a faster rate. Employing different materials are prime targets of research. At present, this is to increase the efficiency of SPV technology. However, we are groomed in the culture of academic settings that less

> focused on technology development. Though we follow the culture of technology development, but our practices are shaped by culture of university. Thus, the theoretical interest of science dominates rather than practical interest of science that has limited us within the disciplinary background. The knowledge on other disciplines is necessary for the development of PV technology.

Reward System and Knowledge Production at the Level of Publication:

Like mentioned earlier, majority of the scientists focused on the publication of papers in journals and less on the practice of technology development. There are two factors which can be said to be responsible for pursuing scientists to focus on publications: First, publication improved the chances of promotions of individual scientists within the academic institutional settings; and second, the number of public and private firms, that could afford the SPV technological licensing and bear the costs of industrial production, was very few. First, various studies expose the social fact that the Indian system of knowledge production is highly focused on producing publications (Mehta and Sharma, 2001; Sardana and Krishna, 2006; and Joseph, 2011). In the case of SPV technoscience, scientists were focused only on the knowledge aspects of SPV since the technology development in the area of solar energy was difficult and publishing papers may come quickly. Hence the scientist preferred to work on publishing papers rather than on developing technological product. The major reasons are the three Ps (develop paper, publish paper and get promotion) – this became the strategy for scientists to climb up the professional hierarchy. It pushed technology development to the back burner thus calling into question the nature of very existence of the scientific and academic institutions such as NPL and IITs. This indicates that reward system of organisations recognized only publication for recruitment and promotion. Efforts of persons who produced technological solutions/prototypes/patents were not recognized in the 1980s. But now the situation is different. Applied science and patents are also taken into account in rewarding scientists with positions and perks. Locating in a historical context, Haribabu's (1991: 84) study, points to scientist's practice of publishing paper in journals (especially in international) enhances the possibility of career opportunities and recognition among the peers. These aspects affected the continuous involvement of scientists on technology development of SPV and socially limited the scientist at the level of publication. One of the senior scientists from NPL recalled:

> CSIR is not like IIT and university based research system but focuses on the industrial research. If the scientists focus on the theoretical physics, then he/she can go to university based research system. The mission is to deliver industrial products. There is no mission and there is no output. For instance, ISRO has only one goal that is to launch satellite. It has to deliver even if the actors change. But in NPL though the mission is to do industrial research but all other sorts of works are carried out. Here, the important work is to produce technology but we always focus on the publications. The variation exists in the present structure of practices. As a result, the people will question the very existence of the purpose. Everyday contradiction is based on two things: produce technology or publications. Get one paper published in Nature, we get promotions immediately. It is very difficult to produce technology than to publish a paper. This is what happens in NPL.

One of the Scientists from IIT Bombay recalls:

> The career development was based on the number of publications and also there was no guarantee that the person who has two patents will get job in university. This was a social force driving the knowledge production in Indian context, in 1980s. But the number of person needed into the production of technology was higher than persons required to produce a single publication. However, such technology needs a firm to convert into a product. In the Indian context, except a few public sector units, there are very few private firms which came forward to purchase Indian made technologies developed in India. Consequently, we also limited our efforts to publication rather than development and commercialization of PV technology.

One of the scientists from Solar Energy Centre recalls:

> It is all about the supply and demand of the product. There is no demand so no supply. Consequently, it affects the knowledge production and technology development. First, one needs to look at the Indian market. Indian economy is dominated by middle class agrarian society. Basically, daily electricity requirement for a household come around 2 to 3 kilowatt electricity and in village that is very less. These requirements were met with the general electricity, which is cheaper and safer. This supply structure reduced the demand for solar energy technologies. At the same time, the government provided various subsidies for non-conventional energy mode.

One of the other major reasons for the lack of technology development is, the scientific community thought that there is no point in developing this technology since there is very little demand for such technologies available in the Indian market. The efforts required to develop technology is higher than that is required for publishing paper by individuals. Entrepreneurs are required to convert the technology into a commercial product. In the Indian context, except BHEL and CEL, there were very few private firms which came forward to purchase the licensing of indigenous PV technologies. Other studies in the Indian context emphasize that import of technology led to decrease in the internal R&D efforts of developing countries (Chandra, 1993; Aggarwal, 2000; Kumar and Aggarwal, 2005; and Ghosh, 2011). The Indian private PV firms were reluctant to invest money in PV technology since the mass market was weak and moreover the majority of the PV firms were located at the end stage of production. The industry basically depends on the imported technologies from foreign firms. Likewise, they do not have any compulsion or incentive to approach universities or other R&D institutions for technology development. It indicates that the state and agencies have not evolved appropriate policies and relevant policy instrument to promote indigenous innovations in SPV. Weak institutional structure in promoting patent and technology transfer hampers diffusion of knowledge to industry (Clancy, 2001; and Krishna, 2001) and also curtails the continuous process of device making in solar energy. Institutional weakness is clearly evidenced in SPV at three different levels: one is at the national policy on transferring technology to industry; two is about an industry specific approach; and three, academic and scientific institutional approach to transfer technology. For instance, the new technology transfer agencies were not vibrant and has limited role in transferring technologies from laboratory to industry within the industrial laboratory and IITs, until 2000. Krishna and Chandra (2009) study reveals that technology transfer agency is of recent origin in IITs that came into existence with aim of commercialization of science. These new mediating agencies came into existence with intervention of Science, Technology and Innovation (STI) policy in 2003. So the knowledge productions and development of technologies stopped at the demonstration level due to low market space. One of the Scientists from the in-house R&D in BHEL mentioned more or less the same view as above:

> Industry comes to picture, if there is market for the product. And also, it is applicable to all kinds of investments from R&D to production. Market is the base for the development of knowledge and knowledge implementation. At last, the entrepreneurs look for the scope of product to be sold in the market. No market no research - this is the strategy for industry based research on any technological product. This has become the business model that is developed by first world countries. This is what happened to PV technology and its innovations. So, industry is not interested only in publishing papers but they are interested in a device that has commercial values.

The low market space not only determined the supply but also the development of process and product technologies. It limited the scale of industrial (Public and Private) participation in the area of solar energy R&D. For instance, the industry participation depends on the notion of the market demand. "No market-no research" – has become the business model and strategy in the contemporary society. Market determines the knowledge production and knowledge implementation. The inadequate public R&D investments and the limited market space and the import of technologies curtailed the transfer of scientific knowledge production into technological innovations. Furthermore, the biggest barrier for technological innovation in SPV is that the industry expects immediate return on investments that is not possible in SPV technologies. It takes at least a decade of gestation period to pay off the initial investments. Industry hence tends to be skeptical about the certainty and profitability of technological innovations. Thus, the tendency to make short term profit has dominated the Indian industry.

Academia-Industry Interactions: Lack of Collaboration on New Technology Development

Most of the academia-industry interactions emerge in the context of need based scientific knowledge production. Gibbons *et al*., (1994) argue that the academia and industry interaction takes place when the market interconnects discovery, application and use of science. However, the study observed the frequent academia-industry interactions, but these are highly limited to public sector units, large scale private firms and academia. Such interactions depend on three factors: (1) new technology development programme; (2) consultation services; and (3) to train manpower and to test modules and cells. Majority of the interactions between academia-industry rested within the second and third categories of work.

First, as part of the new technology development programme, various institutions collaborated to develop new technologies. However, these interactions were limited to public R&D institutions and public sector units alone. For instance, the team working on first generation solar energy, at NPL, had some process patents and also had scientific collaborations with public sector unit. This group transferred design system based on multicrystalline silicon technology to the CEL. One of the scientists from NPL metioned:

> P. K. Singh group transferred the technology to the CEL that was developed in the NPL. It was way back in the 1980s and 1990s. The interactions between NPL and CEL resulted in publications and technology development.

Likewise, the corporate in-house R&D has collaboration with leading defense based R&D institutions such as DRDO, ISRO which mainly focused on specific industrial R&D for military programs such as space and telecommunication. However, these kinds of new technology initiatives are very limited since the market demand for solar energy was also very limited in India. One of the scientists from in-house R&D recall;

> As a corporate R&D, it also collaborates with the space and military organization such as DRDO, ISRO, etc. for instance, with ISRO, we have developed high power SPV panel deployed for G-SAT – 4 Satellites. The corporate research on solar energy covers the space and military programme. This is another reason that we develop solar energy technologies for specific usage.

Second, scientists provide consultation to in-house R&D for specific scientific/industrial problems. In the Indian context, majority of the scholars claim that the academia-industry linkages were restricted to consultancy services to the industry (Chandra, 2011). This type of interaction is to get clarity in domain knowledge such as various problems in device making, understanding the basics of material science in SPV, etc. Technology development in SPV involves two main areas: one, material research; and two, to make device structure such as PV wafers, PV cells, and modules. In certain exceptional cases, the corporate units provide funds for fundamental work on SPV science to know the properties of materials and its viability for technological applications. Scientists claim that the in-house R&D provides support mostly for device making rather than on new material research. The overall performance of the SPV cell get improved when there is a basic research at materials level, but Indian in-house R&D provided importance to applied research and device making. Subsequently, corporate in-house R&D claims such interactions contributed to process innovation such as coating, new process on texturisation and also increased efficiency by one percent in amorphous thin film technology. These innovations are incremental in nature, which yielded little breakthrough in technology development and commercialisation. Despite this, majority of the research collaborations ended up yielding no significant results because corporate in-house R&D claims that the Indian academic scientists are more theoretical in nature and that helps in enhancing and understanding the subject knowledge but not applications in technological forms. The firm is not only interested in theoretical aspects of technology development and publishing papers but they are interested in making devices to commercialization science. Papers in academic journals come very quickly but the conversion of the same into commercially viable technology failed. Therefore, there is always a gap between academic research and industrial applications and expectations of the corporate sector. Academia-industry collaboration has yet to create an impact in SPV in the forms of technological breakthrough. One of the scientists from in-house R&D mentioned that,

> We fund project to IITs, Universities, etc. We hire or fund the project to the academia but it depends on the situation of what we need. Mostly, need based R&D projects are allotted to academia. Solar energy research at the level of wafers or cells requires the understanding of basic, applied and experimental aspects. Therefore, we involve academicians in the R&D process for instance, to understand the cell efficiency and its device structure. The final outcome of the interaction mostly results in publication rather than in patents. This yields little benefits to the business model. In other words, the economic outcome of the interactions is very low. However, one cannot negate that this interaction also contributed to the improvement of the existing process or product. We have also invented unit process – such as coating, new process on texturisation and other things that gave about one percent improvement. In the sense, the interaction also contributed to the patent filing but such patents did not contribute to any path breaking product or process development. It means that the commercial success of the knowledge production is minimal. There is no great thing happened in our synergy and I am not happy with the way the academicians work. In academia, you do research on same topic for the next ten years. In Industry, we need results immediately. Academic fellows cannot match our expectations.

Third, Public research laboratories such as NPL provided training to industrial manpower. For instance, in the 1980s and early 1990s, the first generation group at the NPL had the indirect collaboration with Indian private firms such as Udhya Semiconductor based in Tamil Nadu. The collaboration was based on two factors: one is to train the technical manpower and two, is to test and evaluate the modules and cells. At that time, the technical manpower was completely lacking and public research laboratory had become one of the R&D institutions that provided supportive role in training manpower for industrial production since there was no formal vocational education to train the manpower for industry development. In this context, the academic course on solar science and technology was offered as part of the course work under a larger framework of Energy Studies. At this point of time, there was no specialization in solar energy studies in India. One of the senior scientists from NPL pointed out that,

> We indirectly help firms in testing, setting the production process, etc. We do not have any joint ventures with any firms in India. One of the reasons is that the Indian firms purchase foreign technologies for production and product. We are in touch with Moser Bear, Udhaya Semiconductor, etc. It is mainly to test the PV modules, and providing indirect training to the workforce. Since, there is no formal education in solar energy at the level of B. Tech and M. Tech. The production process is affected due to lack of knowledge based workforce. We meet the requirements of the industry. The scientific laboratories provide training for the workforce in green industry. The workforce structure is not based on the skills but based on the unskilled labourers. It is also evidenced that the industry is located at the end of the production process.

In the 1980s, NPL functioned as a testing laboratory for PV cells and modules since there was no separate institution to test and provide standardization certificates to the industry. Subsequently, it also maintained various standardization methods and also had advanced infrastructural facilities for testing the PV technologies at various stages. However, this position is declined with the inauguration of new laboratory for new testing and standardization at Solar Energy Centre. The functions of NPL such as testing, standardization and measurements in PV technology were taken over by this new institution which had been functioning under the Ministry of Non-Conventional Energy Sources. Subsequently, the role of NPL was reduced only to scientific knowledge production and technology development. It affected the upgradation of new infrastructural facilities in testing and standardization in NPL though in recent times NPL also functions as testing and evaluation of PV cell and PV modules. However, this is only for firms which voluntarily come forward to test their SPV cell and modules.

Research Shift and Decline of New Specialty:

The university culture of Indian laboratories and market-industry linkages are identified as the major cause for the reduction of projects and decline of funds from the government and the industry. Subsequently, in various scientific and academic institutions such as NPL, IIT Bombay, IIT Delhi and BHEL in-house R&D, solar energy research declined. Krishna (2000) argues that the top-down culture of setting research priorities decide what science is to be practiced and what cannot be. The top-down culture of science refers to bureaucratization and politicization of science – hierarchical culture of science at industrial laboratory and science politics nexus in deciding the research priorities of academic and scientific institutions. With the science-politics nexus, SPV as a techno-scientific research was introduced as a mission mode research in 1970s and then declined after 1990s. For instance, at NPL, team based research gets priority whereas in universities individual research is given more importance. In public R&D institution at NPL, the higher authority especially the elite scientist determines the research priorities and most of the time it is based on political-elite scientist nexus which determines the research goals and science practice. In early 1990s, most of the directors from NPL came from non-solar energy background and argued against the R&D investments and technology development in solar energy. The rationality of PV technology development projects was determined by the factor of non industrial application of solar energy. So the higher authorities had directed the scientific groups to work on different research problems and industrial applications that are not directly related to solar energy. One of the senior Scientists from NPL said:

> NPL provides scope for the group research rather than individual research. So, the research priorities are determined by the higher authorities who sit at the top. The elite scientist political nexus plays predominant role in setting the research goals and science practice. We follow the same. In 1990s, the funding was stopped so they shifted our research priorities to some other areas of research. In 1990s, most of the directors were from non solar energy background that curtailed further investments in solar energy. Most of them argued against the solar science.

For instance, the first generation solar research group, at NPL, was moved to work on photo dynamics. Likewise, the second generation groups were assigned the task based on the following themes: 1) silver coating for safety razor blades to increase the rate of efficiency, 2) carbon films and field emissions; and 3) need based automobile parts. One of the senior scientists from NPL recalls:

> In the 1980s, I worked in the area of first generation solar cells and was involved in the technology development programmes. However, in the beginning of 1990s, government slowly reduced funding for solar energy research so we stopped doing research for quite some time. So the research on solar energy especially crystalline silicon came to the state of rest. It is not only for crystalline technology but also the second generation solar cells. In the meantime, the research group worked in other areas such as photo dynamics, etc.

Another scientist also from NPL in the Second Generation Group recollects:

> Once the funding stopped, we shifted our research priorities to some other areas such as silver coating for safety razor blades (increase the higher rate of efficiency), carbon film, field emission, etc. After that, second generation scientific group was disintegrated and some of the experts were asked to work on other areas of research. For instance, we also asked to carry out the need based automobile parts. It not only affected the knowledge production on solar energy but also technology development came to state of rest.

Likewise, in the middle of the R&D programmes on second generation Amorphous Thin film technology development, the MNRE has stopped funding in-house R&D in BHEL that forced the corporate R&D to get funds from head office. At the beginning, corporate sector was reluctant to invest in R&D but after sometime, the corporate sector allocated funding but in the meantime the R&D efforts were stopped. One of the scientists from in-house R&D mentioned:

> In the beginning of 1990s, the second generation amorphous silicon R&D unit was inaugurated and funded by MNRE but after 1999 the Ministry stopped funding research. For some period, we also stopped doing research and finally, we asked funding from the head office. At the initial stage, because of weak market conditions, the BHEL corporate head office was also reluctant to fund solar energy research. But after sometimes, corporate allocated funding by that time we were relaxed our goals of solar energy research. It affected the continuity of knowledge production.

On the other hand, SPV Technology development requires large number of scientists and engineers from different disciplines. Lack of inter-disciplinary approach to techno-scientific knowledge production affected the overall technology development in SPV. For instance, lack of inter-linkages between disciplinary studies of SPV such as Physics, Chemistry, etc and Engineering Studies of SPV in energy studies, electrical and electronics, etc undermined the possibilities of acquiring interdisciplinary knowledge of SPV. Subsequently, the transdisciplinary approach to techno-scientific knowledge production was curtailed in various research laboratories from IIT to public research laboratories. It shows that there has been a long standing gap between various institutional practices of science such as engineering studies and disciplinary studies in sciences in India. As a result, SPV techno-scientific knowledge production completely functioned as socially isolated R&D in various laboratories of Indian academic and public research institutions. One of the major reasons for these phenomena is that solar research has the potential to become a path breaking area at the level of material science research for energy production. This is the scientific credit and profit which no scientist wants to share. Therefore, some of the scientists claim that certain specific institutions and elite scientists got continuous funding from the government or public sector units. Subsequently, there was little scientific collaboration existing between the scientists, and scientific research was carried out totally in isolated R&D centres, scientific groups, individuals, etc. The continuous discontinuity and limited funding largely reduced the scientific knowledge production in technology development as an isolated phenomenon rather than collective. Various scientists from academic and public research laboratory told as follows:

One of the Scientist from NPL pointed out:

> One cannot say that the solar energy funding was completely stopped in India. There are exceptions to it. For instance, IACS is one of the CSIR institutions which got continuous funding from the government. Likewise, the first generation solar energy group in NPL also got funding but these projects were more like individual projects rather than collaborative or group activities. In IACS, A.K. Barua is one of the eminent scientists in the area of solar energy in India who got continuous funding for solar energy. He is the number one person in solar energy in India and also the chairman of National Solar Mission Plan.

> One of the scientists from IIT Bombay said:
> At the same time, making a PV cell or device needs various inputs from other disciplines such as electrical and electronics, new material research, etc. However, it was very difficult to coordinate all the institutions and individuals in the solar energy research. So the knowledge production was found as isolated without linking one discipline to other.

One of the scientists from IIT Delhi reflected as follows:

> There is incoherence with engineering science and technology to the backward integration of R&D at the cell level. Finally, the R&D incoherence with the market linkages affects the development of solar technology. Disintegrated form of knowledge production affects the overall technology. Nobody linked the various stages of R&D in PV technology; as a result we have been lagging in understanding solar energy research as whole. Therefore, we can see the isolated R&D in solar energy. For instance, the material scientist does not want engineer to be involved in unless he develops the best material. Solar technology development requires more number of scientists from different discipline. In India, solar energy is more located at the level of science rather than technology. It is limited only to the laboratory level of research rather than at the level of technology. The social collectiveness in technology development is lost in the Indian context compared to other developed countries. The group was disintegrated because the solar has the potential to become a path breaking science at the level of energy production. This is the scientific credit and profit no one wants to share.

It has various repercussions: continuity of scientific knowledge production was affected, doctoral research had come down and developing specialization was completely restricted. It largely depicts the working conditions and performance of the Indian scientific community. For instance, enrollment of students in solar energy research programmes drastically decreased with the reduction of funds for research. Consequently, the resources for pursuing the Ph. D programmes were completely affected. One of the scientists from IIT Delhi claimed that only one silicon wafer was provided to carry out the research corresponding to the doctoral thesis, duration of which is 5 years and the weak infrastructural facilities in terms of books, journals, laboratory equipment, and guidance affected the new knowledge productions. Furthermore, the bureaucratic procedures were involved to import wafers and other equipments which were necessary for technology development. They faced a range of practical problems and had to write letters to higher authorities for funds, importing wafers and equipments, etc., research needs. Gupta's

(2010) study throws light on how premier institutions like IITs exist with minimal resources and creates academic dependency in the present. This culture of epistemic practice influences knowledge production and scientific productivity. In NISTADS Report, Sinha (2011) suggests that majority of knowledge production in SPV has least citation rate. Pattnaik (2003) argues that citation is an important tool to understand scientific productivity. For instance, majority of the students in IIT Delhi repeated the same experiments for more than a decade that indicates the depth of knowledge production in SPV. The missing point was new thought about how to make science work. All these social conditions made SPV research underfunded, uncoordinated and thus reduced the interest of scientist and students in SPV. One of the scientists from Solar Energy Centre unfolds his past experience about his Doctoral Research in SPV:

> I did my Doctorate degree from IIT Delhi. My area of research was crystalline solar silicon cells. I was provided with only one wafer to complete my doctoral thesis on solar energy. It is for the period of five years. Most of the time, I concentrated on taking care of the wafers. At last, most the students get pissed off from these social conditions of knowledge production in solar energy and went to aboard. Some of the students shifted their research to other areas of science. The kind of job you get is determined by our doctoral research. Solar energy research is less focused from the market perspective. So, the weak market for the solar energy discipline added fuel to the fire. The number of JRF holders registering Ph. D under solar energy was declined drastically.

One of the scientists from Solar Energy Centre told his experience as follows:

> In 1989, I completed my Doctoral thesis in SPV technology at Delhi University. My specialization was in solar PV cells. At that time, SPV was a hot area of scientific research. This area requires advanced scientific knowledge in basic science to increase 0.01 percent efficiency. It involves various activities such as grinding the wafers, polishing the wafers, making solar cells were a tough job in our period. It involves optimization and evaluation of technology. It takes lot of time, energy and requires patience. It is both scientific and capital intensive area of research. It was also considered as one of the new areas of research that could touch millions of lives. The biggest problem was employment in this area of PV. Most of them who opted for PV research either stopped doing research or went abroad. Since, there were fewer manufacturers and government projects that initiated the research activities so student stopped doing research. Suddenly, the opportunities reduced drastically that further affected the scientific knowledge productions and technology development. At the same time, most of them shifted to other areas such as Pharmaceuticals, Bio-tech and IT.

On the other hand, weak career opportunity and infrastructure for SPV compelled some of the scientist to migrate abroad and also forced the students to shift to other areas of research where opportunities were abundant in India. These factors produced two effects within the academic and scientific institutional settings: one, the continuity of knowledge base in SPV was lost and affected the two processes of R&D, namely know-how R&D and know-why R&D; and second, the scientific group completely disintegrated and most of the scientists lost the interest in the area of solar energy. The separate stream of discipline based on new scientific specialization was unable to develop in the Indian context. These curtailed the solar energy research opportunities and device making process. At present, academic science lacks various shortages at various levels of research. As a result, the technology development has neither fully stopped nor moved further but it became stagnant in India. As a result, the scientific practice is lost in SPV industrial R&D in India. Consequently, India is at the beginning stage of technology development in SPV. This is what Jairath (1984) largely conceptualized as a ‘crisis of science and scientific community’ in India. Ultimately, the study observed how socio-political interest on SPV technology has been declined in India.

Patent Regime and Local Technological Efforts:

There are several examples one could cite to show how the patent regime affected the indigenous efforts of PV technology development and its commercial potential in India. In spite of scientific community developing the technologies, the patent regime restricted the further process of technology development in India. The Indian scientific community faced great difficulty in securing patents for their inventions. For instance, in the late 1980s, first generation scientific group at NPL had faced several difficulties in filing, processing and getting patents for invention in the first generation technologies. This was in the area of process technology. It took more time to get the acceptance from the US patent office. By that time, most of the foreign firms had similar type of process technology. A very few firms in India came forward to take the technology developed by NPL, which ultimately ruined the commercial potential of their invention. These acts reduced the pace of technology development in the first generation SPV.

One of the Senior Scientists from NPL in First generation PV technology mentioned:

> We have five to six Indian patents. I have one US patent. At that point of time, very few had the similar kind of technology. It was the process for the preparation of polycrystalline silicon ingot. We started working in the year of 1985 and applied for patent in the beginning of 1990s but finally we got the patent in 1995. Unfortunately, we did not transfer the technology to industry. The major reasons are: 1) in India there is hardly any firm in solar energy came forward to take technology and 2) around the world one or two players control the technology and productions. They had their own technology and did not want to borrow other technologies. It was a good technology but unfortunately could not transfer to industry. My patent number is 5431896, 1995. The US patent is the process patent in poly crystalline silicon technology. We have also filed the same in India with a little change in technology. We have designed system based on process that was developed in collaboration with CEL. It is in the area of multi-crystalline silicon. All the patents belong to the period earlier than 2000s. After 2000s, there is no patent. The patent process takes a long period of time. It is not the matter of for patent but how the technology is economically exploited. In this sense, our technology development yielded low economic results. There is a difference between failure of an effort and making zero effort. We are lagging behind in converting knowledge into money.

Another example from in house R&D of public sector unit indicates that the foreign firms file the patent to block the research in corporate R&D. For instance, Solarex has innovated and patented the amorphous silicon technologies that got market rights for the period of 10 years. It curtailed the corporate R&D efforts in the similar field of R&D and innovation. It indirectly stopped the R&D activities in developing countries like India. Due to uncertain and low economies scope of research in terms of economic results, the scientific and economic viability of the research is highly important than the scientific /lab efficiencies. For instance, achieving one per cent industrial efficiency could result in huge economic benefits. Any achievements in the SPV technology in the developed countries block the R&D efforts in developing countries. So every time, the Indian corporate R&D reassures that new technological innovation is not the imitation of foreign technologies and knowledge. In PSUs, it is very difficult to get the technological efficiency. One of the scientists from in-house R&D mentioned:

> It is not only about the intellectual manpower, resources and funding but it is also about the matter of patenting system itself. The foreign firms file patents and it stops the research in other developing countries. We had a good start in the in 1980s but we stopped in the middle. In the meantime, the foreign firms have gone ahead of us. Now we are lagging and every attempt to patent make us to ensure that we are not replicating the same. For instance, solarex innovated and patented amorphous silicon technology that provided it for the period of 10 years. It has directly affected the innovation activities and stopped the knowledge production process in developing countries. Due to dry area of research, achieving the economic results is very difficult. We may achieve some scientific results but that result should be economically viable. Converting the same scientific results into economic profit is impossible because of several reasons 1) replication of the same results and technology, 2) economic viability of scientific result is important and not the mere knowledge for the sake of knowledge. Very good papers may come up but what is the guarantee for economic and market viability of a product. This discourages the research. It is very difficult to improve the efficiency of a cell. Achieving the 0.1 percent efficiency is appreciable achievement. It involves huge investments and requires resources. Every work comes to the stage of rest, if the same patent structure prevails.
>
> At one point of time, we developed indigenous solar cells but because of reduction in the cost of wafers in the world market our product got crashed in the domestic and international market. In PSU, it is difficult to manage these things and there were lot of questions like why didn't the R&D management think ahead of others. So head office decided to import technologies rather than investing in R&D. You cannot predict what is going to happen in the next moment. It depends on how fast you invent things and get patent that determines your position in the market. It is absolutely true in the case of SPV industry since the technological innovations are faster than ever before.

One of the scientists in corporate in house R&D claims that to increase one percent efficiency in SPV technology, is very difficult and requires physical energy and investments. The corporate scientists publish papers frequently in reputed international journals however converting such knowledge to industrial efficiency is very difficult. At one point of time, the corporate R&D has made indigenous solar cells however; the price of wafers has come down more than PV cells that ultimately crashed in the international market. As a corporate unit, on the one hand, it was unable to accommodate with the new technological development and limited market development, on the other hand. So it became out of control and further the higher authorities reduced the R&D investments in local technology development and made the firm to import technologies. From laboratory to industrial applications based on viable technological products had come to the state of rest due to the above conditions. Therefore, the earlier research initiatives in industrial R&D and technology development were undermined to produce its expected results.

Political Construction of SPV Technology Development:

The government attempts to address the immediate social issues and problems rather than having long term perspective of sustainable and inclusive technologies for development. Although in the 1970s India had ambitious initiatives, nothing could be materialized since solar energy was not developed as a mainstream R&D initiative to achieve the larger goals of sustainable energy production and self reliance. But, it was perceived as a supplement for the mainstream energy production and technology development. Consequently, the political discourse on solar energy technology development has often been shifting its priorities from knowledge production to technology development and demonstration projects. Finally, it never crossed the hurdles of the pilot programmes in India. One of the scientists from IIT Delhi recalled:

> There is no continuity in research as in the case of others. The commitment to research and device making comes to stage of pause or nil. There are always discontinuities in research especially in the area of solar energy. It depends on the funding and the government stand point on solar keeps on changing. Whenever there is energy crisis, the availability of funding will be more; once the crisis ends the funding ends. The government policies in shifting priorities in solar energy R&D killed the best research groups in solar energy. The SPV technology is victim of politics of opportunitism – if we need we include it and if do not need we throw it out of policy. For instance, the government priorities on solar energy has been shifting continuously, since, 1980s. As a result of it, industry production came to the stage of pause. Government policy on encouraging private firms to start electricity production from wind, thermal sources etc

> was considered as intervening factor that hampered solar development. This affected the research trajectory in every energy research in various institutions in India. Oil crisis created the awareness of alternative energy supply that lasted for short period of time. It has become cyclic in nature.

Since SPV technoscience is one of the "victims" of political opportunitism that employed the strategies of providing importance to technological initiatives in SPV when there is an energy crisis and stopped funding once the energy crisis takes the back seat. The research practice modeled as a response to the external crisis, without considering a long term goal on developing science for developmental needs of the country, especially rural energy needs. In short, SPV programmes were constructed as a response to the gamut of crisis. For instance, the articulation and formulation of DST-CSIR report (1974) on different technologies on solar energy was an immediate attempt to know and understand the status of existing energy technologies to meet the energy securitization. This socio-political force made SPV as a big science model when there is demand for techno-scientific knowledge, but such initiatives were never carried forward whenever the situation and demand got relaxed. This ultimately undermined the scientific knowledge production in SPV and became the part of politics of science. The practice of science and Indian scientific community is lost in the paradigm of economic and political realms that affected the research agendas and goals of technology development in India. Due to discontinuous political commitments, solar energy research initiatives could not be pursued consistently. Thus, the development of SPV science has always been contingent on various factors that affected the technology development in India.

One of the scientists from NPL mentioned:

> The SPV technology is fully based on the semiconductor industry. For instance, integrated circuits and other semi-conductor chips are the products of the silicon wafers. So the PV technology research has its origin in semiconductor research but the

> application of SPV scientific and technological research for the emergence of microelectronic industry was limited. We see hardly any developments in the microelectronic industry in India. In Indian context, very few firms engage in the area of semiconductor and all the PSUs are predominantly located as power electronics. There is a difference between power electronics and microelectronics. Our PSUs engage in the development of electronic devices in the area of power electronics. It created to produce power systems in India. The processing technologies of solar energy and semiconductor are almost same. However, the development of semiconductor industry in India is lagging at present since there is no political vision of how to look the SPV technology. The inter-linkages between SPV industry and semiconductor were not well developed since none of them understood the economic profitability of SPV technology. We limited this SPV technology only to the power production. It is a big question right now.

On the other hand, there was little political vision regarding the development of semiconductor industry and PV industry combined in India. Unlike East-Asian countries, India failed to recognize the strategic importance of development of silicon technology. As a result, the application of SPV technology for other industrial usage such as microelectronics industry for the productions of micro chips by employing wafers and polysilicon did not receive any attention. This aspect of SPV industrial R&D was one of the neglected aspects of the PV technology development in India. Consequently, the industry participation in the production of polysilicon, ingot and wafers did not increase since there were few private firms that could come forward to invest in the business of semiconductor and photovoltaic. One of the major reasons for this is that there was no effective policy framework that linked research, teaching, education to industry development in solar photovoltaic in India. At present, these factors created the phenomena of technological dependency and culture of import in Indian PV industry, due to weak infrastructural facilities and technological capabilities. Finally, the lack of linkages between R&D and market affected and continued to affect the development of solar technology. Hence, innovation system could not effectively contribute to the technology development and industry development in India.

Political-Corporate Nexus controls PV knowledge production:

Compared to other forms energies, solar energy technologies are completely different in form, content and its social characters. Winner (1986) argues how vested interest shapes energy policy and technology. He describes technology as part of the power structure, which shapes the social relations. Understanding the nature of technology and its content would reveal the nature of power and authority it contains. On this basis, he explains technology has politics in two ways: a), the invention, design, or arrangement of a specific technical device; and b), the inherently political nature of technologies. Based on this, he claims that a technology could be differentiated as centralized and authoritarian or egalitarian and decentralized. From this vantage point, solar energy is seen as egalitarian whereas nuclear energy as centralized. Subsequently, irrespective of its opposition from civil society movements, nuclear technology has occupied its prime position in energy and science policy by citing reasons of national security and civilian purpose (Abraham, 2012). One of the scientists from Solar Energy Centre mentioned:

> Our MNRE budget was Rs 500 Crore. It is one tenth of the BHEL budget. We get monkeys, if we offer peanuts. This is what is happening right now. It does not happen in Japan and Germany. It is all the lobby and vicious circle that was created by the big refineries, atomic energy, etc. Can we stop them? How do we change this mind set of the people. When TLS (pseudonym) was the secretary of the Ministry of Power, he cut down all the investments on solar energy and, now he talks of solar energy. Now, he repents for his mistakes. These are the people, institutions and policies, who put us twenty years behind the technology development in the area of SPV. Finally, the blame comes to the scientists and the development of science. This is the complex situation that needs to be understood in the realm of solar energy. It shows in which context science develops. You do not let others work, you do not provide laboratory facility, you do not provide adequate investments but you need output. How is it possible? Why the bloody bureaucrat should be the head of MNRE? Why not a scientist? As a scientist, I respect this technology but the bureaucrats consider this technology as useless because they were brought up like that. Bureaucrats never respect you. He doesn't even ask you to sit. First is to realize the potentials of this technology and two, stop importing diesel and oils from other countries. Start our own indigenous energy production. We live in a totally opportunistic world. Think that there is oil crisis in future. Everybody talk about solar energy technology. Whose mind set is this? I, as a scientist definitely won't do this. This happens in an institutional and political setting. What is need of the hour is the proper

> institutional setup that fosters solar energy. One should thank the recent NSM but we need to wait and see.

One of the scientists from IIT Bombay mentioned:

> Ultimately the cost of electricity, diesel, and subsidy determine the research in solar energy. The fossil fuel has the economic advantages compared to the solar energy. But in the case of Germany, the resources and ability of the civil society organization forced the technology to be part of the society. The firm responded to the market situation effectively. The ideal place for solar energy is Germany where we get optimum radiation. In Indian context, neither market nor scientific community and political environment contributed to the solar energy. The choice of technology is much reduced since the subsidy rates are higher for other forms of energy. The obvious choice of selecting the energy forms become the monopoly. The market monopolization through the technological monopolization is witnessed in the solar energy.

This has become the point of political preference for nuclear technology or fossil fuel based energy production that carries capitalist ideology and vested interest in implementing the technology and resources on behalf of solar energy technology. The state-capitalist nexus controls the science and technology of solar energy. For instance, the energy sector is completely controlled by the PSUs, which are predominantly controlled either directly or indirectly by the government. Hughes (1999) claims that it is a system which fosters technological order of the society in which energy production, distribution and consumption determine the structure. It is called as locked in position or a path dependence which controls the choice of political decision, will and commitment (Barabara *et al*, 2009). Consequently, the choice of the technological selection is not given but socially enforced through the act of monopolization. Within this structure, India as a participant in solar energy technology development is unable to carry forward, since these forces controlled and controls the production of scientific knowledge in solar photovoltaic in particular and solar energy in general.

Concluding Remarks

This chapter provides the scientists' accounts regarding their experience in knowledge production relating to technology development. It is interesting to see the various factors thwarted the development of PV technology in India. The shift away from solar energy research occurred due to inconsistency funding and shift in policy priorities. Hence, the politics of knowledge production and technology development and transfer reveals the missed links between the laboratory and industry. So, the political construction of PV technology limited the PV technological innovation to the level of demonstration. In this process, the patent regime the SPV opens up another story of India's efforts at indigenous technology development. The continuous discontinuity in knowledge production made indigenous technology development in solar energy a distant dream. In fact state policy with its shifting priorities actually influenced and hindered the growth of science in the area of solar energy. However, one can also understand the academic practices exist at the level of Mode 1 knowledge production that gives importance to knowledge excellence and teaching as priority rather than technology development and transfer. This is actually a social product of colonial science that provides separate identity to Indian science. Thus, the historical context of scientific practice shapes the knowledge production process. At the same time, the importance of context of application was diluted with the import of technology and lack of institutional mechanism in fostering linkages between academia and industry. Overall, this chapter explained the how the gap between science policy and science studies is created in the area of SPV technoscience. Further, the study narrated the factors responsible for rise and decline of solar energy research in India. The next chapter would like to focus on the factors contributing to the reemergence and revivalism of solar energy research in India.

Revivalism and Reemergence of SPV Knowledge Production (2008 to date): The Indian Academia and In-house R&D Perspective

Introduction

This chapter explores the factors that contribute to the new knowledge production and technology development in the field of solar photovoltaic. Through this exploration, the study also attempts to understand the thrust areas of SPV; the reasons for the shift in research from the first to the second and third generations of SPV; and issues relating to techno-scientific knowledge production and technology development. Exploring the dynamics of these interrelated phenomena would provide an understanding of the direction of development of SPV at present. Further, it exposes the social conditions in which academia and in-house R&D exist.

Social Conditions Influencing Re-emergence of Solar PV Technology Development:

Since, 2008, there are two sets of factors that seem to play a vital role in the revival of new knowledge production in solar energy in India: first, is carbon market, energy security and the growth of new sectors such as SPV and semiconductor; and second, is the advancement and development of new technoscience such as Nanotechnology, convergence of organic and inorganic sciences, Quantum Physics, etc., which influence new technological applications. As a result of the convergence of different fields the solar energy industrial R&D and technology development are reinitiated in Indian academic institutions such as IIT Delhi and IIT Bombay and public research laboratories like NCL and NPL.

Carbon Market and Energy security: The Growth of New PV and Semiconductor Sectors in India

At present, in the name of climate change and resource constraint, the SPV industrial R&D and technology development are reinitiated in the Indian innovation system. In response to climate change and its consequence, the Government of India announced the National

Solar Mission (NSM) Policy on solar energy technologies, in which SPV plays a vital role. To reduce the rate of emission and to obtain carbon credit, the internal objectives of the NSM provide scope to restart the programmes in solar energy technology development. The carbon credit functions as an economic instrument for PV technology development and environmental consideration gets due importance in it. R&D investments in renewable energy encourage India to reduce dependence on other countries for technology and fuel and thus contribute to self reliance and energy securitization programme. For instance, the Prime Minister of India, Dr. Manmohan Singh, while launching the National Action Plan on Climate Change as on 30 June 2008 mentioned:

> Our vision is to make India's economic development energy-efficient. Over a period of time, we must pioneer a graduated shift from economic activity based on fossil fuels to one based on non-fossil fuels and from reliance on non-renewable and depleting sources of energy to renewable sources of energy. In this strategy, the sun occupies centre-stage, as it should, being literally the original source of all energy. We will pool our scientific, technical and managerial talents, with sufficient financial resources, to develop solar energy as a source of abundant energy to power our economy and to transform the lives of our people. Our success in this endeavour will change the face of India. It would also enable India to help change the destinies of people around the world.

When this position was realized in 1980s and 1990s, the cost of the PV technology was higher. But now R&D investments yield more benefits than earlier expected. The SPV technology has the potential to lead to energy security and also to meet the energy demand in future. This socio-political factor has influenced the technology and industry development in solar energy and has created market demand for SPV technologies in the last few years. One can say that the practice of R&D in SPV science and technology is shaped by political responses to crises such as oil scarcity and climate change. The choice of political decision is influenced by external factors rather than internal social and economic problems. Hence, it is a politics of policy in the Indian context. Two things are evident from this: 1) political commitment and will is always shaped by compulsive force; and 2) It made solar energy technology development a discontinuous effort.

One of the respondents from NCL said:

> Often, the conditions of changes, in social and economic situation, made solar energy sometimes prominent and non-prominent in some other times. For instance, the recent natural disasters in Japan made India to relook at the solar energy research. Likewise, the oil crisis and oil price hike made solar energy inevitable and unavoidable. But now, it is the climate change and shortage of fossil fuel which made solar energy as prominent. What is driving the solar energy research right now is carbon credit and the increase in the prices of fossil fuel. Science has always been in the lime light for economic and political reasons.

One of the respondents from IIT Bombay mentioned:

> See what happened to Japan – it is a nuclear disaster. The Government is eager to invest money in nuclear rather than solar energy. But now, it is reconsidering nuclear technology as an energy option for India. I do not know whether this mind set will exist, once all the issues will settle down. However, the global targets on solar energy stand at 16 terawatts. It needs huge investment and all generations of PV technologies need to be employed in the projects. At present, we need clean and cost-effective technologies. These are the factors that play a predominant role in the development of PV technology for which we need effective R&D backup to the emerging PV and semiconductor sectors. India will be a big player in solar energy in the coming years.

One of the scientists from NCL mentioned:

> But now, in situations such as recession, oil crisis, the catastrophe in Japan made them rethink the paths of development in a sustainable way. The focus is more in the process of making the economy greener than just the development. The sustainable regime provides the impetus to the countries round the world to produce energy sources through green and clean technology. These factors stimulate the development of solar science and technology. As a result, there is a continuity and discontinuity in the history of solar energy technology.

One of the scientists from IIT Delhi pointed out:

> We have promising big industry players such as Moser Bear, Reliance, Tata, etc. investing money in solar modules and power stations. It is based on amorphous silicon. Once the economy drives on the path of sustainability then the oil economy will be replaced by the resources based on nature. Capitalism started making money out of cheap resources in the market. I don't think that we would reverse the same in what had happened in 1980s and 1990s. At that point of time, the solar energy in India had different role to play but the role of technology is completely different now. The solar energy research has reached the macro level research, that is, mass commercial applications.

At present, India is at diametrically opposite position in SPV technology development. On one hand, the conditions of possibilities of technology development are suppressed. On the other hand, the market demand for solar photovoltaic technologies is growing faster with the changing conditions stimulated by government policies. This creates the conditions for technological dependency on foreign firms and affects the process of innovation at the local level. Innovation is a chain process (Viswanathan, 1985) so one cannot develop technology at one point and wait for the market in other times. The market demand and technology development should occur simultaneously. Otherwise, it curtails the process of technological innovation. The development of SPV technology in India is the best case which explains this phenomenon. In the case of SPV, evidence shows the incoherence among the technology and market development programmes in government policy. For instance, the growth of global SPV industry and shortage of polysilicon, wafers, and SPV cells made India to import SPV technologies from foreign countries, since the backward integration in SPV technological developments are completely underdeveloped at present. Unlike in the 1980s and 1990s, the National Solar Mission (NSM) creates huge market demand, which attracts the Indian PV manufacturers to start new ventures and this makes the entrepreneurs to look at technologies that are cost effective and efficient technology. At present, majority of the local manufacturers import technologies from foreign firms through technological licensing and joint ventures. It pushes the Indian PV industry to the bottom of the global production and innovation. Various industry reports from India recognize the conditions and challenges faced by Indian SPV industry at present.[76] The conditions fall largely under three categories: 1) limited infrastructure facilities for raw material production of polysilicon; 2) low human resources in terms of scientific and

[76] 1) Solar PV industry 2010: contemporary scenario and emerging trends; and 2) solar PV industry 2008: Global and Indian Scenario recognizes the conditions and challenges faced by Indian PV industry at present.

technical manpower and weak technological capabilities; and 3) facing challenges from China and Taiwan. These factors pose a major threat to the Indian PV industry.

The strategies of National Solar Mission (2008) rightly identify the lacunae of Indian PV industry and claim to transform India into a solar energy hub that focuses on providing high quality solar cells at a low cost and on building manufacturing plants from processing silicon to PV technological systems. Along with the special incentive packages, facilitating indigenous solar technology would help Indian SPV industry and semiconductor to achieve global status.

One of the scientists from in-house R&D critically mentioned this point:

> The fundamental problem is that there is no provision for making raw materials and research on PV. Right now, the problem has culminated with the imports of raw materials such as wafers and cells from China. The market is flooded with the Chinese products. The processes of production are simpler and easier but again making solar wafers, diffusion furnace and source, silver paste, the tap, the printer, the chemical, lamination, tedlor, glass and laminator all are imported from abroad. From the A to Z are imported from foreign firms. Overall, we lack the basic infrastructure for making raw materials and also doing research on those raw materials to improve the materials standards are lagging at present.

To avoid the technological dependency and to create new sector growth, the government has initiated various R&D programmes on alternative methods to develop polysilicon to PV technologies and SPV industry in India. At present, the industry and the government fund technology development, since innovations in SPV technology has a bright market demand and prospects for growth in future. Solar Conclave Report (2010) points out that the R&D strategies on solar energy focused on the following lines: 1) research at academic/research institutions on materials and devices; 2) applied research on existing processes and developing new technologies; 3) technology validation targets at field evaluation of materials, components and systems; and 4) Development of Centres of Excellence on different aspects of solar energy. All these scientific and technological initiatives aim to achieve grid parity by 2022. Subsequently, the big science model or mission oriented science is reintroduced into the programmes on Indian academic and research institutions. As part of this programme, academia-industry interaction is fostered by employing appropriate strategies like taking benefits from ongoing research, funding collaborative research with joint access to Intellectual Property Rights, etc.

One of the scientists from NCL said:

> We see hardly any developments in the semiconductor industry in India. In the Indian context, there are very few semiconductor producers and microelectronic industry but we find a lot of power electronics, which was established after 1950s. We have strong public sector companies such as BEL, BHEL, and CEL. These firms engage in the development of electronic devices but they do not belong to the category of micro electronics. These electronic devices are created to produce power systems in India. Basically, it is a backup for the energy productions. The processing systems on solar energy and semi conductor (micro electronics) are almost same. It is the big question as of now and right now the government provides various policy incentives to stimulate the new knowledge production and industry development.

However, one of the scientists from NPL claims that the microelectronic and semiconductor industries are yet to evolve in India and most of the PSUs are predominantly dominated in power electronics. The electronic devices are created to produce energy and they provide backup for the power sector in India. The late policy intervention in semiconductor also indirectly hampered the development of solar energy industry. It is the right time to start various scientific and technological initiatives on SPV technologies and semiconductor. At the same time, silicon technology should be considered as a strategic area of research, so that the priority for solar energy would also increase substantially. Any delay would be detrimental to the growth of Indian SPV industry. At the same time, the success of scientific and technological initiatives depends on the development and growth of SPV and semiconductor sector as a whole. Majority of the scientists claim that presently all the initiatives are at the starting point; one cannot conclude what is going to happen in the future.

Revivalism of SPV Science and Technology in India: Influences of New Sciences and Meeting Point of Cost-Efficiency level

Apart from the climate change and resources constraint, there are other factors which influence the production of techno-scientific knowledge and technology development. First is the new technological applications innovated in various East-Asian and Western countries such as Japan, Korea, Taiwan, USA, Germany, etc. Second is the growth of new sciences based on nanotechnologies, quantum physics, and merging of organic and inorganic sciences. The applications of new sciences have played a vital role in bringing down the cost and increasing the efficiency of solar cells. In short, this has increased the commercial viability of SPV technologies.

Considering the geographical conditions, the solar energy technologies are appropriate for tropical countries like India. However, most of the knowledge production is concentrated in developed countries mentioned earlier. The purpose for which solar energy was developed differs among these countries. For instance, the growth of PV industry in East Asian countries is associated with the historical development of electronic and semiconductor industries in contrast with Western countries which are oil-dependent. These two different purposes guided the R&D practice in the two different regions. The bottom-line in all these countries is the question of achieving cost effectiveness of the two generations of PV cells, which seemed to have been paid off by continuous and focused efforts. For instance, Japan's New Energy Development Organisation (NEDO) programme under Sunshine project narrates how the industry and government interaction fostered techno-scientific innovations in the solar energy. Market oriented programmes and favourable policy conditions helped industry to conduct in-house R&D that contributed to an increase in efficiency and helped to reduce the cost of the technology (Balaguer and

Marinova, 2006). Waldu (2007) claims that majority of the SPV firms in Japan such as Kyocera, Sanyo, Mittishibish, Kaneka Solar Tech, Sharp, etc ., are leaders of innovations. To substantiate this point, Sharp Trade Press Report (2013) shows that the firm has achieved the highest efficiency of 44.4% by employing concentrated triple junction solar cells[77]. Likewise, Photovoltaic Technology Plan in United States of America focused on fundamental research that aimed to develop high concentrated thin film industrial efficiency of 20 per cent (Waldu, 2007: 61). Table No: 6: 1 shows the achievements of laboratory efficiencies in successive generations of different PV technologies. However, the data in the table is an indicator of what has been achieved by advanced countries' scientific laboratories and in-house R&D in recent times. One should consider it as an insight into the advancement of R&D in SPV and not as a deciding authority. At the same time, another reliable source confirms the data on advancement of SPV R&D (Green *et al*., 2011).

(Table 6:1)

Successive Generations of PV Technology	Different Technologies in Successive Generations	Achieved Efficiency Level	Scientific Laboratories and In-house R&D
Multi-Junction Concentrator	Triple Junction Solar Cells	44	Solar Junction
	Double Junction SPV Cells	32.6	IES-UPM
Crystalline Silicon Solar Cells	Mono Crystalline	27.6	ALTA Device
	Multi Cyrstalline	20.4	Fraunhofer, Germany
	Thin Silicon Crystal	20.1	Solexel
Thin Film Technologies	Cu (InGa) Su_2	23.3	ZSW Germany
	cdte	18.3	GE Global Research
	Amorphous Silicon	13.3	LG Electronics
Emerging PV Technologies	Organic Cells (Various Types)	11.1	IBM
	Desensitized	11.4	NIMS

[77] Kindly look at the reference of Sharp Trade Press report on achieving the maximum efficiency on solar cells http://sharp-world.com/corporate/news/130614.html

The table in the previous page was done by author, Source, NREL (2013) [78]

One of the respondents from IIT Bombay mentioned:

> Now, the knowledge production in solar energy is getting revived. This is purely for political reasons. It involves carbon emission and resources-scarcity. The third reason is a demonstration of higher efficiency cells and reduction of solar energy cost of energy production. This is more important than the other two. It involves the consistent development of science and technology in solar energy. However, the firm or an R&D institution that continued to work has achieved the maximum efficiency and target. They are the leaders right now. The country consistently involved in solar energy R&D has succeeded in technological demonstration of high efficient solar energy cells. It is technically correct that the lab efficiency and industrial efficiency are now meeting each other. But, there are only three firms which have achieved the targets such as BP solar, Sanyo and Sun Power. Now the reported industrial efficiency is 25.5% in the first generation solar cells. None of the firms from India have achieved this path breaking work. Even CEL and BHEL have been working in the same area for more than 2 decades. The problem is how to reduce the cost of solar energy in the Indian context. This is what guides the knowledge production.

For instance, one of the scientists from IIT Bombay points out that USA and other countries such as Japan have constantly been working in the SPV material research and SPV cell technologies for more than 40 years. It has resulted in various product and process technologies such as material doping, silver paste, screen printing, HIT type of solar cells, etc. The continuous effort facilitated them to develop high efficiency solar cells that would increase the rate of profit by tenfold. Another senior scientist from NCL claims that the R&D investments and profitability is perfectly matching in advanced countries. For instance, the rate of efficiency and life time of SPV technology has been increased substantially by 15 to 18 percent and 15 to 25 years respectively. So the investments and profit earned out of SPV technology meets in terms of market criteria.

Innovations by global PV firms such as Sanyo, Sunpower, and BP solar have helped to achieve high levels of efficiency and cost effectiveness as mentioned earlier. Of late, further economic viability of SPV technologies became possible with the emergence of

[78] Note: NREL source on solar cell efficiency table frequently changes as per the new achievements so I have developed this table from the recent data which was available in the beginning of 2013.

new technoscience such as nanotechnology. For instance, one of the scientists from third generation SPV technologies group in NPL reveals that, with the help of nanotechnology, solar energy can be concentrated 100 times more than a regular PV cell. It shows the efficacy of nanotechnologies in generating energy from SPV technologies in an efficient and cost effective manner. At this juncture, the laboratory efficiency and industrial efficiency almost meet each other.

For instance, one of the scientists from NPL pointed out:

> "With the good controlled experiments, the increase in one percent efficiency increases the rate of profitability. It decreases the usage of wafers and reduces the cost of PV technology. This guides the research in the public research laboratory and corporate R&D social settings. The R&D investment decisions are determined by the economic results and advantage should be equal to the rate of R&D investments. This is happening at present which makes the Industry and government to fund industrial research in PV technologies. For instance, in America, scientist attempts to develop large PV cells compared to small size. This model attracts more radiation and increases the energy output. This gives more than 50 percent efficiency. This is basically the idea of other science and technology development that influences Indian knowledge production."

One of the respondents from NPL said:

> I started my work in 2004. Earlier, I worked in the area of material science. I did my PhD in Polymer science and my M.Sc was in Electronics. So polymer electronics become my area of research. It is a broad area of research. So my two specializations met in solar energy and facilitated my work on solar energy cells. This is a kind of thought that I never had before. In 2004, two to three Nobel Laureates visited NPL. I had the privilege to interact with them. They told us that solar energy is coming up, which made me to venture into the science of solar energy. Solar cells are a part of polymer and electronics. As of today, we are in the primitive stage of solar energy. We have just started the work in organic PV. It is the beginning of a new research base in solar. It is primarily to employ nano science and nano technology to understand and produce solar technologies. I am coordinating a CSIR project on development of solar energy technologies. This is the new field of science within the solar energy.

As part of the urgency to catch up with the international standards, the practice of SPV techno-science is revived in India. Table below No: 6: 2 shows the present R&D status of SPV technology in successive generations and it is a projection of what Indian scientific community is going to achieve on or before 2022.

(Table 6. 2)

Type of Solar Cells	Present Status of scientific knowledge Production (R&D)	Conversion Efficiency Targets (%)		
		2011-2012	2017-2018	2021-22
Crystalline Silicon Solar Cells	13-16 (19.7%)	18 (22)	22 (23.5)	24(25)
Thin Film – a-Si Solar Cells	(5-6%) (10-12%) Pilot Plant	8(13.5)	9(14.5)	11(14.5)
Polycrystalline Solar Cells	Cdte (12%) CIGS (13%)	10 (15) 10(15)	15(20) 15(20)	20(25) 20(25)
GaAs Concentrator Solar Cells	----	27	35(40)	40(45)
Dye/Organic Nano Based Solar Cells	2.5%	5-10	8-10 (15)	12-17(25)

Source, Solar Conclave Presentation (2010), Ministry of New Renewable Energy (MNRE)

Currently, the urge to catch up seems to be guiding R&D in solar energy in India. All the research institutions such as PRL, academic institutions and in-house R&D are in the process of achieving international standards. The gap in knowledge production makes the Indian industrial research and technology development programmes inferior and less competitive to science and industrial development in other countries. Abraham (1997) argues that the state of urgency emerges from the anxiety of being in the inferior status or out of time in the changing world. This urges the third world to take a research initiative to become a part of international efforts in scientific knowledge production. Prasad (2005) discusses how power relations in techno-scientific knowledge influence the scientific community in developing countries to take research initiatives. As a result, the anxiety is clearly evident in the Indian scientific community involved in SPV R&D. For instance, industrial research in SPV wafers and cell related research are yet to reach the state on par with international standards. To bridge this international gap in science and industry development, the PV science was reintroduced into the institutional setup in 2000 and has gained momentum, since the implementation of NSM.

One of the scientists from NCL mentioned:

> The research based on alternative technologies to silicon was not initiated because scientists perceived silicon as the best material for solar energy. On the other hand, the maximum efficiency of silicon material is achieved. As a result, the solar science came to a stage of pause that affected the further investments in the process of technology development. Right now, the other generations of PV technologies are developing faster in other parts of the world, especially in East Asia. This development of other science and technology is adding a new dimension to the understanding of solar energy. So the scientists are interested in exploring these new areas of science and technology in India. It made them to engage in solar energy as a part of the urgency to catch-up with international efforts.

New Technological and Academic Initiatives and New Research Targets: Shift in Research and Practice of Reverse Engineering

Emergence of New Transdisciplinary Modes of Knowledge Production and the Formation of a Hybrid Community:

In short, the external market demand and technological innovations from advanced countries create the social and political conditions for the 'context of application' based knowledge production in SPV. The context is also mediated by climate change norms and internal energy scarcity to meet the developmental needs such as Rajiv Gandhi Grameen Vidhyut Yojana (RGGVY). Unlike the previous programmes in SPV, the new scientific and technological programmes aim not only to demonstrate but also to transfer the commercially viable technologies to industry and society. The applications of solar energy is not limited to specific areas but for mass commercial applications. At present, solar energy can become a mainstream energy producing technology that would satisfy the needs of the ordinary consumers. However, like the previous programmes on solar energy, the SPV scientific community focuses on two main scientific issues: (1) to reduce the cost of the technology by focusing on the process and product innovations; and (2) to increase the technological efficiency. Now, the scientific community focuses on reducing the number of processes, increasing the efficiency and making commercially viable products. These are the research target that guides the three different generations of SPV technologies in various institutions such as NPL, NCL, IIT Delhi and Bombay.

One of the scientists from IIT Bombay mentioned:

> Informally, there are a number of CSIR, DST and MNRE projects under the development of PV technology. These projects are just like the mission mode research. The target is to develop the cheapest solar cells. Globally, people are looking for two answers in solar energy. One is efficiency and the other is cost effectiveness. We may find the rate of efficiency in the first and second generation solar cells but they are not cost effective. Though we use it, it is not commercially viable. The R&D process is focused on enhancing the percentage of efficiency and on cost reduction. However, these projects have a lot of inter-linkages from one area to another. The main aim of NCPRE is to bring together different scientists and the industry.

Another scientist from NCL said,

> At NCL, there are different groups works at different generations of technologies. Each group consists of more than 5 scientists. Across the CSIR laboratories, more than 50 scientists work in difference areas in different generations. It involves physicists, engineers, chemists, etc.

Unlike 1980s, the main areas of industrial R&D efforts are focused on the interconnected areas of technology development that concentrates not only on the process but also on product innovations. It largely circulates on the following grounds: (1) addressing the low capacity of absorption of technological related PV modules; (2) increasing the energy output by reducing the size of the modules; (3) decreasing the cost by reducing the wastage of resources in the process of production that focuses on the process know-how; (4) increasing the life expectancy of the solar modules by focusing on scientific research on new materials; (5) research to increase the efficiency of cell by focusing research on the properties of materials; and (6) new product developments and experimental research is at the level of PV technological systems. These industrial R&D efforts focus not only on know-how but also on know-why R&D. This is mainly focused on the question of increasing the technological capabilities in various organisational settings such as industrial research laboratories (NPL and NCL), academics (IIT Delhi and IIT Bombay), and in house R&D of industrial units. It also focused on training and collective learning programmes for which various initiatives are evolved and emerged from different institutions.

1. Council of Scientific and Industrial Research (CSIR)-Network of Institute for Solar Energy (NISE) programme attempts to develop new technologies in different successive generations of PV technology.
2. Indo-UK Collaboration in Solar Energy initiative is sponsored by the Government of India in collaboration with United Kingdom and it focuses on Advancing the Efficiency and Production of Potential of Excitonic Solar Cells (APEX) at NPL.
3. Centre for Excellence - National Centre for Photovoltaic Research and Education initiative in Indian Institute of Technology, under Ministry of New Renewable Energy concentrates on advanced research and teaching in IIT Bombay.
4. Solar Energy Research Initiative (SERI) Programme of Department of Science and Technology (DST) under Ministry of Science and Technology give importance to individual scientific projects at various academic institutions.

Understanding the techno-scientific projects in SPV, the network as a unit of scientific knowledge production is recognized as an important strategy to new knowledge production simultaneously focused on commercialization of science. Krishna *et al*., (2001) claim that this is a changing structure of science and concentrates on transdisciplinary modes of knowledge production and an open system of scientific practice in India.

Table No: 6: 3 Shows the Global Techno-Scientific Initiatives in India

Initiatives	Technologies	R&D Institutions	Industry	Academic Partners		Target
				Indian	Foreign	
CSIR - NISE	Crystalline	NPL	CEL	IITs and Indian University	University of Berkeley and California	Technology development and Transfer Patent
	Thin Film	NPL-NCL				
	Organic\inorganic	NPL\NIIST\ NCL\CECRI				
	Dye Sensitized	CECRI\NCL\ NIIST\IICT				
	Lighting Devices	CGRI\NCL\ NPL\NIIST				
	Energy Storage	CECRI\NCL\ CGCRI				
Indo UK Collaboration in Solar Energy	Advancing the Efficiency and Production Potential of Excitonic Solar Cells (APEX) Third Generations of SPV	NPL and IICT	Moser Baer BHEL	IIT Delhi and IIT Kanpur Indian Institute of Science	University of Cambridge Edinburgh University Oxford University	Patent/ Publication Spillover of Technology

Compilation by Author by Using CSIR-NISE and Indo-UK Collaboration Solar Photovoltaic Projects

For instance, Table No: 6: 3 projects the clear picture of global techno-scientific collaborations in India. Majority of scientific projects have interaction with industry, local and foreign scientific laboratories. One can drive two patterns of knowledge production: 1) CISR programme on CISR-NISE and Government of India funded Indo-UK initiatives focused on techno-scientific collaboration at the global level; and 2) MNRE and DST initiatives attempt to facilitate industry development by promoting scientific and technical manpower, and network based individual projects in across the technical institutes in India. To elaborate on the first, CISR-NISE initiative attempt to develop different technologies in successive generations of SPV technologies such as Crystalline, thin film, organic/inorganic Dye sensitized Lighting system and devices, energy storage in collaboration with various CISR R&D institutions, in-house R&D like Central Electrical Limited, and with foreign academic institutions like University of Berkeley and California.

Likewise, Indo-UK project on solar energy focused on third and fourth generations of PV technology called as excitonic solar cells in collaboration with the local public sector R&D institutions (NPL, NCL and IICT), academic institutions (IIT Kanpur and IIT Delhi, IISc, Bangalore), local firms like (MoserBaer) and foreign universities such as Cambridge, Oxford, Edinburg and Imperial College. This techno-scientific collaboration is a strategic alliance for sharing and nurturing know-how, knowledge information on scientific practices and to generate new process and product innovations. This shows the increasing importance of the fast growing SPV technology at the global level which was not found in 1980s and 1990s. It is becoming more and more knowledge intensive area and sharing information is required to upgrade the industry which is at the infant stage. All these activities are interconnected to produce new knowledge and also to obtain advanced technological accessibility in frontier areas. The Sinha and Joshi (2012) study shows that international collaborative effort on publishing papers has increased in recent times and thus, globalisation of R&D in SPV is occurring in Indi, but in a slow pace. This is what called as global techno-scientific collaborations (Archibugi and Michie, 1995; Archibugi and Iammarino, 2002).

Second, NCPRE focused on doing advanced research from first to third generations of technology in SPV and offers Doctoral programmes in SPV and B.Tech and M.Tech programmes in Energy Science and Engineering Studies in which SPV is offered as an inter-disciplinary specialization in collaboration with various departments such as Physics, Chemistry, Electrical and Electronics, etc. Apart from this, to address the immediate concern of lacunae in human resources, the initiative offers short term course work on SPV to its industry partners. In a way, with the appropriate mechanism, the industry participation is more an integral part of the teaching and research programmes at IIT Bombay. This enables industry to access information on existing knowledge about various technologies, technical information on production process, training and also to fund Ph.D programmes. Table No: 6: 4 shows the Local Technology Initiatives in Indian academic Institutions.

Initiatives	Technologies	Departments	Industry	Academic Partners		Target
				Indian	Foreign	
NCPRE	High Efficiency Crystalline Solar Cells	Physics Chemistry Electrical and Electronics Energy and Engineering	Industry Become Integral part of NCPRE with Appropriate Policy	Based on Individual Scientist (informal)		Human Resources Technology development
	Dye Sensitized					Training Industry
	System Modules					Short Term Courses to Industry
	Characterisation					Course at the level of M. Tech and PhD
	Energy Storage					
Initiative	Technologies	Indian Institute of Technology	**Actors Involved**			Target
DST-SERI PAN IIT Initiatives	All the technologies in SPV	Kanpur, Chennai, Bombay, Delhi, Kharagpur	Public Private Community Partnership (Thermax-ARCI, IIT Bombay and IIT Madras, University of Pune, CGCRI) This is in Solar Thermal			Achieve Grid Parity

Compilation by Author by Taking inputs from NCPRE and DST Websites[79]

Likewise, Solar Energy Research Initiative (SERI) attempted to develop hybrid technologies like Solar-Biomass and other generations of technologies in which public-private partnership is encouraged as a co-generations of technologies. For instance, Solar Thermax and National Thermal Power Corporation (NTPC) are part of this programme. However, this initiative is a more individual-based knowledge production mainly located at five different Indian Institute of Technology such as Kanpur, Chennai, Kharagpur, Bombay and Delhi and other regional Engineering colleges, and universities. Gibbons *et*

[79] Refer, these websites to more about the information on NCPRE http://www.ncpre.iitb.ac.in/ and for Solar Energy Research Initiatives http://www.dst.gov.in/scientific-programme/t-d-solar-energy.htm

al., (1994) theorized these changes as the new Techno-Economic paradigm, which leads to a radical shift in the structure of institutions to meet the new requirement of knowledge production and distribution. The interactions among the various social actors facilitate social production of scientific and technological knowledge which emerges out of the context of application to achieve industrial and socio-political goals. It leads to the emergence of Mode 2 Knowledge Production and indicates the characteristics of Mode 2 Knowledge Production in the Indian context.

One of the Scientists from NPL mentioned:

> Whichever the industry we take, the industry participation should be right from the inception. It is not the case were we develop technology and later we commercialize the technology. Academia-industry interactions have to go hand in hand. It does not happen in India. Though we have interactions, it is limited to certain areas such as Bio-Tech, Pharma, Software, etc. The transfer of knowledge from academia to industry becomes meaningful, if industry participates at the inception stage. The isolated R&D process yields no results. The successful transformation of knowledge into commercially viable products hampers the diffusion of technology. The development of science or even technology is confined to the four walls. For instance, India-UK consortium is a huge project to develop third generation solar technology. It is one of the initiatives funded by the Department of Science and Technology, Government of India. This project has the academia-industry interactions right from the beginning. BHEL is one of the public sector companies which plays a predominant role in this project. The UK foreign firms are contributing to the infrastructure and other equipments. These firms are a part and parcel of the project. This is the right way of doing industrial R&D that benefits human mankind. The project is for six years. It is a network project. But, the project is yet to take shape. We are still in the stage of preparing a proposal and it is under the review. The project starts in the next financial year.

One of the Scientists from IIT Delhi points out:

> At that point of time, the isolated research prevented the synergy but now it may not be the hurdles. The government is moving India as a base for knowledge intensive work. It fosters development of every field of research from software to solar. It grounds the culture for doing good science and R&D systems in India. We need the collaboration of various institutions within and outside of the R&D institutions. The spin of the technologies from one sector to the common man is required in the Indian context. Every project is sanctioned with three partners: the government, industry and scientists.

On the other hand, at the level of academics, the research practice happens more within the disciplinary boundaries though the transdisciplinary forms of research practice have recently started with various initiatives. Still a majority of the scientists work within the disciplines and they have less collaboration with industry and other academic institutions located in India. This is more relevant in the case of solar energy research. To elaborate this point, by examining 1808 publications, the recent study by Sinha and Joshi (2012), on the collaboration in photovoltaic research in India observes two vantage points: 1) till 2003, domestic single institute publication was higher in photovoltaic research that indicates lack of collaboration among various institutions; and 2) 2008 onwards, the collaboration on publications by domestic and other international R&D institutions have increased substantially. At the same time, considering the top 10 institutions involved in collaborative research, IIT Delhi has the highest number of domestic collaborations compared to foreign collaborations and likewise, NPL secures tenth position in domestic collaboration, but stays far behind in terms of international collaboration. NISTADS Report suggests that the majority of India's foreign collaborations in solar exist with USA, followed by Japan, China, France and Germany (Joshi *et al.*, 2008: 240). In this context, the study attempts to understand the nature of collaborations which are largely informal at the level of IIT Bombay and IIT Delhi. The interactions emerged with the professional relations that were established at the time of doctoral and post doctoral research. They aim to share knowledge, publications, and understanding of the theoretical background of solar energy. The outcome of these collaborations is largely focused on publication of papers rather than patents. With this collaboration, a few academia-industry interactions exist in publication and technology development (NISTADS Report, Sinha, 2011,).

One of the Scientists from IIT Bombay said:

> Academia explores the topic from a knowledge generation level whereas R&D institutions explore both knowledge generation and device making. For instance, at IIT Bombay, we do not have coherence at knowledge generation and device making. We

work on similar problems from different perspectives. So, total man hour invested for the same problem get enhanced and over all, we don't share what we do at the level of industry. Hence, the technologies are less developed in Indian context.

Another social Scientists from IIT Bombay reflected minimal collaboration among scientists:

For instance, one of the social scientists from IIT Bombay told that, he (a particular scientist) controls the whole NCPRE initiative in IIT Bombay. He has a number of patents and publications in solar energy. Most of the other scientists are not willing to join NCPRE since it is a group activity and overall scientific credit goes to a particular individual which they do not want. This, I personally experienced when I went to collect data from the NCPRE group. A majority of the scientists told me that they are just a part of the team and their roles are very little in NCEPRE. Though their names are in the list of scientists accepted to be a part of the NCPRE initiatives, their involvement is limited in nature.

Dynamics of Techno-Scientific Knowledge Production: Shift in Research from First Generation to Second, Third and Fourth Generation of PV Technology

The thrust area of research is focused on three generations of SPV technologies. However, in recent times, there is a reduction in industrial research relating to solar energy and technology development at the level of first generation technologies. In the NISTADS Report, Sinha (2011) argues that thrust areas of silicon has decreased and non-silicon materials like third and fourth generation solar cells such as dye-senitized, organic\inorganic areas have attracted the attention of the scientific community. As a result, the first generation solar energy technologies seem to be less funded than other generations of technologies such as thin film and organic-inorganic solar cells. There are several reasons behind this. One of the Scientists from NPL pointed out:

However, the knowledge production is focused on the second, third and fourth generations of solar cells. It is very difficult to produce a paper on first generation of silicon because it is the only area in solar energy that has been researched in depth. The rest of the generations are new so we may get good patents, if we work properly and sincerely. This makes the researchers to shift to other areas of knowledge production. For instance, my students told me that the polymer group has three to four US patents and also publications are coming up very easily. I replied to my students that if you need publications you go to third generation, if you want to put your brain to work, be with silicon. This is what is happening right now. The scientific interest does not depend on curiosity but on publication and patents. In this case, the third generation solar cell has a lot of scope for development.

Thus, silicon technology is scientifically well explored and widely applied in the microelectronic industry. So industrial research has reached the theoretical saturation point, after which scientific results yield minimal economic outcome for R&D investments. It indicates that maximum theoretical efficiency of a material has already been achieved; so it is very difficult to increase the efficiency of the technology and also to publish a paper or to get a patent on the first generation. This reduces the social (scientific) interest of the scientists and makes the majority of the scientists and doctoral research students to socially locate in the other areas of solar energy such as third and fourth generations of research since publications and patents may come faster in new areas in SPV technoscience. To elaborate this point further, at present, the aim of research on SPV is to achieve cost reduction in the technologies. The high cost of production, low efficiency and low profitability in terms of energy production and output result in a shift in R&D to second and third generations of solar energy technologies. But the efficiency of first generation technology is standardized and is good in terms of commodification. It is very difficult to achieve the same standard in any other materials. However, the second and the third generations of technologies are at a nascent stage. So there are a lot of scientific possibilities to explore the properties of solar cells and materials which make the scientists shift to other areas of knowledge production and technologies in SPV. At present, the same scientific problems have been taken over by second generation and third generation of solar scientific communities. They attempt to rectify the problems such as cost, unstable solar cells and low rate of efficiency of first generation solar PV technologies as problems of industrial science. The scientific community focuses on alternative materials such as alloys, quantum materials and new methods using hollow tubes of carbon atoms (carbon nanotubes), hetrojunction solar cells, by combining organic and inorganic (hybrid SPV cells) to produce cost effective as well as efficient solar cells to suit Indian conditions. However, though these are cheap materials but they are impure systems, which provide a lot of opportunities for new knowledge production in terms of scientific experiments, instrumentation and theorization. It is impossible to get the efficiency in an impure system. So the scientists attempt to engage with these materials to remove impurities by focusing on a new science and technology based on Quantum Physics, nano-science and technology. One of the Scientists from NPL pointed out:

> Silicon, as a material employed in the production of SPV technology, has reached the highest efficiency rate. Untill now, we cannot replace the efficiency achieved by silicon with any other materials. Now, we, the scientists in NPL, are searching for alternative materials and methods to tap the sun radiation for instance, alloy, quantum materials, inorganic polymers and hybrid methods like organic and inorganic science. There are generations of solar cells such as first, second and third. We are working in the polymer hybrid systems in third generation solar cells. It has a bottleneck. It is a cheap but an impure system. We cannot expect efficiency in this impure quality of polymer materials. Now people are looking for a system which is an alloy and includes materials like gallium. These materials are still costly since having a film grown at particular latex in gallium nitride or Copper indium gallium selenide is slightly less expensive. Therefore, it is a viable option because of less toxic contents, and also has sustainable life. We have a better future for solar energy, if these materials stay longer.

One of the Scientists from NCL mentioned:

> People started thinking that fourth and fifth generations of solar cells are based on the combinations of organic and in-organic composition, the quantum physics and quantum phenomenon are going to be employed in the construction of materials through the applications of quantum nanostructures. It is a multidisciplinary or a transdisciplinary approach. I always work with my new ideas and not with the others ideas. The science of SPV in the fifth generation is completely different from the earlier generations of solar cells. It is a new science focused on charged energy transmission. However, the CSIR initiative is up to the level of the fourth generation but American firms and R&D laboratories are now focused on the fifth generation solar cells.

The R&D efforts in these areas of SPV technology are still at the laboratory level and the industrial applications are yet to come. At present, the scientific community is guided by the motivation to develop industrial science and technology in SPV. For instance, scientists attempt to look at solar cells from different perspectives to understand the science behind the solar cells. The diversification of research is witnessed in the case of scientists engaging in different fields such as engineering (device making), collection and storage of energy to reduce loss of energy produced, new material research to produce more energy and in making good efficient cells. These are the driving forces that make government fund various projects in the area of solar energy and in academia-industry collaboration in various public research laboratories and IITs. These have become the thrust areas of scientific knowledge production and technology development in solar PV in India.

In the above context, the number of students who pursue doctoral research under the first generation of solar energy research has been decreasing. Consequently, there is a shift from first to third and second generations of industrial research in SPV. Despite this, the total production for the coming decade (2010 to 2020) is fully based on the first generation of solar cells. Investments in R&D are required to support fully the industrial production of solar energy. Though the rationality of the funding recognizes these aspects and also provides fund for industrial research and technology development in first generation solar cells. However, the decline in the enrollment of doctoral students makes the first generation industrial R&D and technology development less attractive.

At the same time, the first generation SPV group, at NPL, works at the level of process technology development. But the industrial research is mainly based on the incremental innovations and not based on radical innovation. For instance, there are more than twenty processes involved in the production of solar wafers and solar cells. The research group works at each stage of the process and it attempts to find a new process in the production so as to reduce the cost of PV technology. This industrial research may not increase the efficiency of the PV cell but it is to reduce the cost of the PV technology. One of the Scientists from NPL mentioned:

> First, we are working on unit processing. There are more than 20 stages in the process of solar energy. Working in different processes may contribute to the technology development. This may be effectively transferred to the industry at a later stage. This is what the focus on research right now. We should develop a technology that meets the international standards. Second, as it is of right now, we do not have any interaction with industry but we indirectly help firms in testing, setting the production process, etc. We do not have any joint ventures with any firms in India. One of the reasons is that the Indian firms purchase foreign technologies for production and product, since Indian PV industry is located at the end stage of production.

At present, the solar energy scientific community involved in first generation SPV research has little collaboration with the industry. They claim that the Indian firms import technologies and get the knowledge expertise from foreign firms. So the possibility of having the collaborations with academia is less at present as a result of liberal import policy environment. The Indian PV industry, predominantly dominated by small and medium firms, is specialized at the end stage of production such as modules lamination and system integration. So the requirement of R&D inputs is low at the final stage of production.

At present, interaction between academic and private firms is very limited in the case of first generation of solar cells. Furthermore, though the Public sector in-house R&D units and academia institutions work on a similar structure of scientific problems, there is little collaboration between industry and scientific laboratories. Consequently, there is no backward integration of R&D and industry at the stage of PV cell, wafers and polysilicon productions. Except NPL, the other institutions such as NCL, IIT Bombay and IIT Delhi are highly focused on the second and third generations of solar cells.

Practice of Reverse Engineering:

Despite these scientific beliefs, the commercialisation of SPV industrial R&D in SPV technology depends on decreasing cost and increasing efficiency by focusing on new material research. Unlike 1980s and 1990s, new material based energy R&D activities are encouraged and there is a focus on new theorization and development of new methodologies and instrumentation as the main motive of the research practice. The SPV industrial R&D is not only focused on incremental innovation but also on radical innovation. However, the real concern is that scientific practices driven by reverse engineering yield a little scientific output in terms of technology and knowledge production. It is based on adopting scientific ideas from the market or from various journals and publications and by replicating the same in the Indian context. Shiva and Bandyopadhyay (1980: 577) throw light on similar experience which occurred in 1980s. Finding the scientific problems through the practice of adopting and locating within the ideas which have already been explored, limits the emergence of new scientific ideas and the Indian scientific community follows what the West has been studying and experimenting. This shows how the Indian scientific community locates itself within Western science, without considering the impact on Indian knowledge production system. For instance, in IITs scientists perform simple experiments on device structures, testing, and have limited engagement in research and development of new materials. Taking the existing knowledge production to a higher level is limited in this model of reverse engineering, since the ideas are influenced by adoption and imitation of the existing knowledge and technologies that are available in journals and markets.

One of the scientists from IIT Bombay mentioned:

> Raising the revenue with the existing system is impossible. We do simple things such as device, methods, developing newer materials and so on. We are not honest with the work we do. The things will become more transparent, if we are honest of what we do. What we need right now, is new thought on solar energy technology development and how new science such as nano science and technology contribute to the same. The scientist understanding of science and practice of science definitely yield profit but such depth of understanding is relatively less in the field of solar energy in India. The hit and trial research does not yield results in the long run.

Likewise, at NPL, a group of scientists claim that they have achieved a maximum efficiency with existing materials and doing reverse engineering reproduces the same results. However, other group of scientists claims that India is completely lagging behind in solar energy research and it is time to start the research from the scratch. There may be a chance of doing reverse engineering in the beginning of the research to catch up with the present level of technology development and scientific knowledge production in the advanced countries. It indicates the adoption of technologies from foreign countries and upgrading of the technologies to new level is projected as an immediate concern of the Big Science Model. Within this model of science, we see only incremental innovations rather than any radical innovations. However, this time, the techno-scientific research in SPV is more focused on developing technologies and not merely knowledge in contrast to an earlier era. One of the scientists from NPL mentioned:

> Informally, there are a number of CSIR projects that aim at developing cheap solar cells but this project is just like the mission mode. The target is to develop the cheapest solar cells. The project is for six years. It is a network project. Globally, people are looking for two answers in solar energy. One is efficiency and the other is cost effectiveness. We may achieve the standards of technology but it may be outdated technologies by the time we achieve the target. We need some base line to start our research programmes. So at the initial stage, we may start with what is happening in other countries.

One of the Scientists from NPL pointed out:

> Our research is always driven by reverse engineering that never yields new knowledge. We have achieved a maximum efficiency with the existing materials and doing reverse engineering reproduces the same results. Now we are looking for a breakthrough in material modifications or system design. If material modification takes place, the paradigm changes may occur. The whole bottleneck is that we have reached the place which is called the stage of saturation. All the things are in the same state. With the same matrix and components, we cannot overcome the bottlenecks. We need to draw a newer

> curve or dimension to get a different posture. As a result, we are looking for new materials, devices, and methods of doing things. Scientists are working on it. Some are promising and some are disastrous. I do not think that with the existing system we can find solutions.

The technology development based on reverse engineering is predominantly practiced in research settings such as PRL, academic and in-house R&D. Despite this, some scientists claim that reverse engineering neither brought down the cost of PV technology nor it produced breakthrough in PV science. It made them think within a bounded set of ideas. It rarely allows them to go beyond a certain limit since it curtails the creative thinking and allows the scientist to imitate rather than to innovate. Expecting a breakthrough in technology development and scientific knowledge production is impossible with the same kind of scientific practice. Scientists also believe that they need new thought and belief about solar science and technology in India. For instance, some scientists work on new methods of solar science and technology, yet do not believe in what they do. It indicates that the scientists expect a kind of social recognition from Western scholars – a colonial mindset that still prevails in Indian scientific practice. The hegemony of this social hierarchy haunts the scientists' mindset which makes them to experience they are in a prison in the insecure world of Science. Nandy (1980) provides reasons to why Third world could not transform its scientific practice to attain autonomy in science; to get liberation from autonomy of science. He explains the method and the practice through which we produce knowledge consciously and sometimes unconsciously accepts the hegemony and dominance of Western science. It indirectly creates subjugation to Western hierarchy from which there is no escape[80]. Subsequently, scientists feel that they are in a

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[80] Dasgupta (2009) narrates the success and failure of scientific research done by J.C. Bose in which she describes that Bose theory of science was considered as philosophy of life, belief and conduct. Subsequently, his theory was rejected by his contemporary peers as non-scientific in nature. In simple, Bose theory considered as mere dogma than a subject of scientific inquiry. Legitimization of knowledge is an important

prison, thus liberation is denied. Ultimately, this undermines scientific creativity among the scientists especially in the Indian context. The extent of this suppression is evidenced, from Abraham's (2006) study, scientists' difficulties in publishing papers in international journals. This kills creativity, when scientists are unable to locate within the Western paradigm of knowledge production – includes science as a cultural and commercial activity.

One of the Junior Scientists from NPL mentioned:

> We ourselves do not trust what we get as a result. We need acclaim from somebody else for what we have done. It is like a pseudo-colonial psychiatry (Note: it is not psychiatry but Indian psychology which itself is the product of colonial mentality and practice of Western science) works at Indian mind sets. It doesn't work in others, for instance, American, European, etc. The synergy is lacking in India and still the colonial condition exists in India. The hierarchy of rules, the supremacy of the work and the low level scientists do not get any recognition for their contribution. There is no freedom of choice for the lower level scientists. Higher authorities simply dictate the term even though their contribution is low. The criteria for judgment should not be different for the lower level people and higher level people. The number of publication should not be the criteria for selection of team and work. A rigid structure exists and there is no doubt about this. These structural constraints make us aloof from the system though we do excellent work at our level. For instance, in India, we do better research than outsiders but that gets diluted by the people who do not do good research. The basket is full of good and bad apples that make the research system in India the worst.

The larger political and economic interests determine the research practice in Third world countries. For instance, in NPL higher authorities like director, the senior scientists define and dictate the research problems and also select the group based on the requirement of the project. Most of the time, the team selection is based on the criteria of number of publications and not based on scientific interest. In this structure, the liberty to pursue individual ideas is curtailed with the mission mode knowledge production. This is a rigid structure in which doing and practicing science is controlled by bureaucratic procedures. Further, junior scientist gets low credit though they deliver quality work. It prevents

criterion of scientific activity. Once such legitimization is denied it produces alienation from the world we are attached and kills the creative activity.

synergy at various stages of knowledge production and also makes the scientist to stay aloof from the system. Jairath (1984) describes that this as a feudal structure in which science is controlled by authority – bureaucratic and political. Over all, it indicates what shapes scientific practice and scientific creativity in Indian context and highlights how Indian scientists engage with science and the scientific community.

Inadequate Laboratory Facilities and Shortage of Scientific Manpower:

Inadequate Laboratory facilities:

The low level of R&D infrastructural and laboratory facilities in academic and scientific laboratories affects the doing and practice of SPV science in India. For instance, in India, one of the scientists from NPL claims that there are very few photovoltaic laboratories which can accommodate and pursue SPV industrial research from processing silicon to PV cell. It is much oriented towards the lab scale based knowledge production and suitable only for publishing papers rather than developing technology. The maximum size of SPV cell that one can develop and fabricate SPV cell is one cm or maximum of 2 cm. So, the lab facilities are inadequate to meet the international standards of wafers and cells technologies. With the same laboratory facilities, international standards of scientific practice and developing standard SPV cells for industrial application is impossible at present. Some of the scientists claim that they will be in the process of rebuilding their laboratory facilities once the funds will be released by various funding agencies. It is the need of the hour to upgrade the laboratory facilities to international standards. One of the Scientists from NPL pointed out:

> The scientific laboratories at the level of international standards are lacking in India. We are doing our best with the existing facilities. With the financial crunch, things get affected at large. Sometimes, we did not have enough money to buy cartridges. Now we are reviving all the things from the scrap because everything has changed in due course

of time. If it is the case, think of the infrastructural facilities available in public research institutions.

But we are in the first stage of research. Nano materials are being employed for which we need sophisticated infrastructure to develop science. The nano scale materials are used to develop solar cells which become a basic problem. We require X mm of nano materials to make a device XX mm nano material. It is a challenge. It is always developed in good laboratory conditions, therefore; the nature of degrading is slow. When it comes to the real settings, we need to take care of further insulation to avoid heat loss and degradation of the material. This is one of the challenging areas of research in solar energy. To be honest, we are lagging in advanced scientific laboratory that hurdles our technological innovations. Right now, we are in the process of acquiring all the technical and technological aspects of the solar energy. Fortunately, we have a lot of money in India now. It will take a minimum of two years to ground the real work. All the government institutions are ready to fund the project on solar energy.

From the scientists' perception, one can understand the inadequate facilities for making raw materials and its related research on SPV technologies in India. For instance, one of the scientists from an in-house R&D explains that in recent times in-house R&D consumes higher level of wafer usage but there are very little infrastructural facilities and R&D setups prevail to develop and improve the SPV technologies at the level of polysilicon. Facilitating R&D in raw materials yields benefits in bringing down the cost by reducing the number of stages in production. Ignoring research at the rudimentary level creates dependency on other countries, since the cost of the technology would be more locally. At present, there is a lacuna in PV industrial science and technology development: in the industry there is no R&D setup, and in the R&D setup there is no industry. This is the most crucial part of the inter-linkages which connects industrial requirements and industrial science in PV technological innovation. To a great extent, it also reflects the different nature of knowledge production that happens in the Indian academic laboratories and in-house R&D. For instance, though the corporate in-house R&D and academic scientific knowledge production focus on the same set of scientific problems, their approaches differ. There is no convergence in the technological innovations. Inadequate laboratory facilities are one of the important reasons for it. Still the laboratory is unable to meet the industrial needs. One of the Scientist from in-house R&D pointed out that:

> For instance, Solar Energy Centre (SEC) is in a pathetic condition. If you put a person there, who could not get proper food and hostel facility then how can you train people at SEC? S/he won't do any wonder. Some policy guidelines are required for PV R&D activities. The Ministry has dictated it but there is no implementation. SEC belongs to MNRE and it is supposed to do all the activities such as research and training, etc. How many solar cells have you seen? Or did you see the functioning of a solar cell? In the Solar Energy Centre they are supposed to test panels and cells performance. You need keep the solar cells under ultra violet rays for three days. Think of the situation, if the power comes and goes, then how will the performance be evaluated? They seriously lack manpower and technologies. Nobody monitors anything. The research situation is really horrible.

Likewise, the Solar Energy Centre is still functioning at the level of demonstration. One of the scientists told that he did not know how the structure has evolved over a period of time. At the SEC, there are no laboratory facilities to practice material research to understand the degradation of PV technology. The role of SEC is limited only to testing and evaluation of technologies. The scientific communication from the test bed to the scientific laboratory is absent at present. It indicates that the SEC is located at the end stage of technological development, which is demonstration, and not at the level of core R&D works which involves basic and applied science. There is no separate R&D unit to explore the properties of PV technologies, which are mainly imported from foreign firms for testing and diffusion. The inadequate research facilities reflect the way the R&D centre functions. For instance, one of the scientists from the SEC claims that it is necessary to have an R&D centre for testing and evaluation, to understand the various technical issues of PV technology. One can observe, study, and experiment with PV technology in different locations and geographical conditions. These activities are not an end in itself but a means to achieve the diffusion of reliable technologies to society. What is missing in this context is the field study and research in material science and other developmental aspects of PV technology. The separate R&D unit, scientific manpower and training programmes are required to have efficient interface with scientific laboratory and industry. As a testing and evaluation centre, the SEC provides standardization certificate for the commercialisation of PV technology in Indian market. However, such accreditation is less valuable in the international market because of the low level of technological capabilities and capacities for testing of PV cell and PV modules that exist at present. It reveals the standards of certification provided by the specialized scientific institutions for testing and evaluation. To rectify this, MNRE is encouraging FDI investments on testing and evaluation such as TUVRheinland in Bangalore and DuPont in Hyderabad rather than upgrading its laboratory facilities. One of the scientists at the Solar Energy Centre mentioned:

> Furthermore, there is no material science laboratory for understanding the degradation of PV technology. This shows the status of SEC in terms of scientific knowledge production. It limited its role only to testing and evaluation of technologies that created negative impact on the development and production of technological innovation. The scientific mediation from the test bed to a scientific laboratory is so weak that it affected the development of new improved technologies for the Indian context. This shows the weak interactions between the two stages of technological innovations: one is the stage of knowledge production and another is converting the knowledge into a product. There should be a continuous interaction for a technological innovation, which is missing at the SEC. Over all, the R&D scenario shows the nature of vision and policy intervention in the area of solar energy in India. The role of SEC is also located at the end stage of production and not at the core R&D works that involve basic and applied science. In one of the discussions, we shared common points on the following lines: I also suggested that there should be a separate unit for R&D and the scientific manpower needs to be based on the specialization in various aspects of PV technology. Other infrastructure facilities such as accommodation, food and Doctoral and post doctoral fellows need to be incorporated into the R&D activities. Providing opportunities to retired Professors from various Universities to guide the R&D activities in PV, fosters technological innovations. Funding is not the main problem right now as we get a lot of funding from MNRE and other collaborations from foreign research institutions. There is no knowledge production at the level of core R&D but we do performance based research such as experimenting the technology to suit Indian climate conditions. We need various training programme to handle R&D activities at various level of PV technology development. Industry based laboratory structure needs to be incorporated into the systems of knowledge production in India so that our system of economic production reaches the global level.

Shortage of Scientific and Technical Manpower:

Adding the lack of infrastructural facilities is the scarcity of well trained scientific and technical manpower in India. One could see this scarcity ranging from academic institutions to in-house R&D and Public Research Laboratories. Out of the 40 scientists interviewed, the study shows three categories of SPV scientists in India: the first category of scientists directly belong to the area of SPV and largely fall in the age group of 50-60; the second category of scientists indirectly belonging to the area of SPV and falling in the age group of 40-50; and the third category of scientists not directly related to the area of SPV but largely falling under the age group of 30-40. The picture indicates two things: one, the solar research community is emerging; and two, the growth in further SPV scientific manpower and knowledge production has become stagnant at the level of doctorate research (reasons having been discussed in the previous chapter). This is clearly reflected in various scientific and academic institutions like the SEC which has only two scientists for PV technology testing and two others have joined newly without a Ph.D. There is no material scientist employed in the process of testing and evaluation.

Furthermore, due to the lack of scientific manpower, the in-house R&D in the PSU provides training to the newly recruited scientific staff. The senior most scientist trains the junior staff in the area of SPV. To address the issues of scarcity, the corporate R&D has become the training centre for new scientific and technical manpower. One of the in-house R&D scientists said:

> Since, the investments in PV industrial R&D was lagging behind, it also affected the development of scientific and non-scientific manpower in India. Where do we train people, if we do not have space for R&D? Corporate R&D becomes the training centre for the scientific manpower. Since, the research on SPV in academia declined, we started training people to meet BHEL requirement of human resources. We teach from the scratch like what is a solar cell? What are the components? How much current does it generate? What are the precautions one needs to take? How does one handle wafers in

> production? SPV research requires knowledge of Physics, Chemistry, Engineering, etc. No institute trains people in such a way that he/she fits into the industrial research. In this R&D unit, we address the issues by training people in various technological activities.

One of the major reasons as to why the SEC started training and teaching is the decline in academic research and teaching programmes on SPV in academic institutions. Except IITs and other leading CSIR laboratories, there is no engineering college that offers a course on solar and renewable energy in India. The academic curriculum neglects the importance of providing training to scientific manpower in the area of industrial R&D relating to solar energy in India[81]. Majority of the scientists accept that programmes on developing scientific and technological capabilities are necessary because the number of PhD scholars trained in the area of SPV is relatively less at present. On the other hand, the majority of doctoral fellows move abroad for a post-doctoral career, and it produces brain drain locally. In India, Industrial and academic opportunities are yet to develop and hence researchers move to foreign countries for better employment and career opportunities. A few academic institutions, in India, provide training in solar industrial R&D. Solar Energy is part of the academic curriculum in Centre for Energy Studies at IIT Delhi and does not have a separate programme at the level of B. Tech and M. Tech. programmes. It needs a lot of scientific manpower and advanced scientific laboratory to train students in basic material science and PV technology. It is an important issue that needs to be addressed. The academic curriculum should consist of required technologies, material research, and scientific manpower to train the students. The culture of research practice and teaching in solar energy is not well established across the research institutions. To bridge this gap,

[81] However, at present various universities are incorporating Departments and Schools for Science Studies in Solar and renewable Energy technologies, for instance, School of Solar Energy (Teaching and Research in Solar Technologies) at Pandit Deendyal Petroleum University, Gandhi Nagar, Gujarat and TERI University offers M. Tech Programme in Renewable Energy and Engineering Management.

NCPRE, the research and teaching initiatives organized at IIT Bombay funded by MNRE, are to bridge the gap between industry and academia in terms of knowledge requirements. However, some of the scientists claim that now the market for PV technology is emerging so IIT Delhi may introduce specialization in renewable energy-cum-solar PV technologies. Subsequently, the market determines the course and education work in India. One of the Scientists from IIT Delhi hinted out that:

> But now we find the difficult to get access to those persons. Now, institutions are in the process of reinventing the group/s. it may take some time to catch up with real time. Most of them left India, due to non-availability of opportunity in PV technology. Slowly, the research practice and developing resources personnel are reorienting the government intervention through solar energy policies such as NSM.

Politics of Solar Energy Funding:

There are several public and private institutions which fund solar energy research such as MNRE, DST, CSIR, NTPC, ONGC, BHEL, CEL, Moser Bear and Tata BP. Out of these the DST, CSIR and MNRE are the largest funding bodies for solar energy research and teaching programmes in various scientific and academic institutions. For instance, now CSIR has started a network project on solar PV technology development, and MNRE initiated NCPRE focused on teaching and training programmes in solar energy. It aims to develop science, technology and industry research as a coherent system to foster the innovations in SPV. However, these initiatives are now at the rudimentary stage and also scientists claim that things are happening though in a slow pace.

Despite these initiatives, PV technology relating to solar energy R&D is one of the larger areas of energy research in India. For instance, the proposed R&D initiatives for the 11th Five Year Plan for the period of 2007-2013 attempt to invest in various energy technologies and resources such as fossil fuels, renewable energy, hydrogen, shale and oil, biofuels, development of new materials, etc. Out of Rs. 5300 crores, the R&D investments in photovoltaic stand at Rs. 1200 crores, which nearly comes around 22.6 per cent and a total share of 85 per cent in the category of renewable energy (Kempener, 2010). It shows that other technologies and resources get higher priority in energy based R&D, compared to higher investments in photovoltaic as a recent phenomenon. To substantiate this point, S&T financing under the MNRE programmes, the solar photovoltaic got the least priority in terms of funding for the period of 2003 to 2008 (NISTADS report, 2008: 62). Likewise, the Department of Atomic Energy consumes 12. 2 per cent of R&D expenditure compared to the non conventional, and renewable energy source consumes 15 per cent of the total central government expenditure on S&T, which also includes other areas such as biotechnology, information and communication technology, and ocean development (NISTADS Report, 2008: 44). Overall, the renewable energy sector is one of the least priorities of the science policies in terms of funding and research, out of which solar photovoltaic gets the most inadequate treatment. Majority of the scientists claimed that, though solar energy has future viability in terms of market potentials, the development of science and technology in energy intensive areas such as fuel cells, hydrogen and nuclear fission make scientists to perceive solar energy as less potential, if these energy technologies become cost-effective and commercially viable. However, the government funds all the areas of energy R&D since energy has become one of the national-security programmes, which feed development and growth of a particular country. But, it makes the scientific community to experience that the government is still not open to solar energy research. Therefore, some of the scientists perceive funding SPV may be reduced if other renewable technologies would develop faster than PV technology. For instance, the second generation scientific community, at NPL, has submitted six different projects to MNRE.

These projects focus on material research to increase the efficiency of solar cells. The target is to achieve stability and efficiency of 10 percent and to reduce the rate of wear and tear in PV technology. It is also focused on increasing the size of the PV cell-one foot by one foot. Initially, the funding was allotted for seven years and later MNRE reduced it to 4 years. Consequently, the scientific community also reduced the goals of technology development and industrial research in SPV. One of the scientists from second generation solar group in NPL mentioned:

> Now the government provides a new version of solar mission plan with the change in the name from Rajiv Gandhi to Jawaharlal Nehru Mission plan. At present, six different projects have been submitted to MNRE. We expect funds to come within a short period of time. We will start our projects once the funds are released. This time we focus on material research to increase the efficiency of a solar cell. The target is to achieve 10 percent efficiency in solar cells by increasing the size of the same. To accomplish this task, initially, the funding was allotted for a period of seven years and later they revised it to 4 years. Thereby, we reduced the scope of our research goals.

In spite of NSM long term programmes on PV technology implementation, the programme on technology development and techno-scientific research in SPV is highly short term based. It shows the nature of projects that are sanctioned and funded by these institutions. For instance, one of the scientists in NPL claims that MNRE funds small project on technology development and industrial research. He further criticizes that MNRE is a micro lending bank and now it is converted into an institution. It is a ‘bucket’ where scientists get small petty loans rather than a bank where they get loans for big dream projects on solar energy. Solar energy research has become a neglected science in India like neglected diseases such as malaria, TB, etc. There are no priorities in project funding and selection of projects. This reflects the miniscule role that MNRE plays in the larger energy research and development scenario in the country often controlled by bureaucracy and policy makers. The allocation of funding to MNRE is vey less when we consider the larger allocation of funding to energy related research and development in nuclear or fossil fuel based energy research. It restricts the production of scientific knowledge and also the nature of research. Therefore, India's scientific knowledge production and technology development is indirectly governed by the politics of policy making and bureaucracy. One of the scientists from IIT Delhi stated this:

> MNRE has become a bucket where you can get small petty loans rather than a bank where you can use for repaying big debts or get loans for big dream projects. It has become a subject of pity things. For instance, it provides funding for small projects such as bio-diesel production, demonstration projects, etc. There were no priorities in selection of projects and funding. These days MNRE has shifted its focus to the development of solar technology, which should have been done before in 1980s. Apart from DST and CSIR, MNRE is the largest funding agency for solar energy research. They have also established their own R&D centers. It was a micro lending bank and now it has transformed into an institution. At the same time, the government system is also not very open in providing funds to solar energy research. They have distributed the funds for the same form of research and development in various energy researches.

A similar experience is reflected by the BHEL in-house R&D in India. One of the corporate scientists from BHEL in-house R&D claims that the total investments on R&D in energy sector stands at Rs. 827 crores but the amount dedicated to solar energy research is relatively low, compared to other forms of electrical and electronic devices. The moment the corporate head office releases the funds it forces the scientists to develop the technology or it evaluates about the how much efficiency the scientific group achieves. Such evaluation constructs pressure and increases the accountability of the scientist with the funding from the corporate head office of BHEL. However, it also reveals that in-house R&D gets funding from various Ministries but these programmes are at the rudimentary level at the time of the present study. One of the scientists from in-house R&D mentioned:

> Yes. The allocation of funding to solar energy research is comparatively low when you consider the larger allocation of funding to other energy R&D investments. The moment we ask for R&D investment in solar, they start predicting the economic results of scientific knowledge production. First, the corporate head office enquires about how much efficiency the R&D unit will increase. They don't think about anything expect the profit of the scientific results. If you don't agree they don't fund your project. First of all,

we need material research to increase the efficiency of a cell, and therefore we need manpower, etc. All these things are never taken into accounts. It puts high pressure on scientist when they allocate money. Ultimately, the funding is the major hurdle but right now we have also applied for the DST projects and those have been sanctioned, but still we are yet to receive the funds.

Concluding Remarks:

In this chapter, I discussed about the factors contributing to the revivalism of solar energy industrial R&D and reflections of the solar energy research community on technology development. The energy securitization, new sector growth and influence of approach developed in other countries (especially Western science) influence the Indian scientific knowledge production and technology development. Though the study indicates the emergence of transdisciplinary approach to knowledge production and the formation of hybrid community, it has several limitations such as existing norms regarding credit sharing which affects the synergy in public research institutes. Likewise, the academic scientists are limited to the disciplinary cultures and there is noticeable shift from first generation to second and third generation of PV technologies, which emphasizes on publication with some consideration for patents. At the same time, academia-industry interactions are incorporated from the very beginning of the R&D in various mission oriented projects. However, the real issue is the practice of reverse engineering that is more focused on applied research and imitation of what is happening in other parts of the world. In the midst of this, the scientific and academic institutions are in the process of rebuilding the laboratories and training of scientific and technical manpower to produce new knowledge. However, these activities are at the rudimentary level, due to the delay in the process of funding. The scientists are also pessimistic about the future of SPV R&D in India, if other energy technologies succeed in the market. The projects are short term oriented. These factors indicate the continuity of the same practice which was witnessed in the previous period of time though a change is evident. There is an urge among the members of solar energy research community to produce new knowledge.

Nature and Structure of Indian SPV Industry: The Case of Technological Dependency

Introduction:

This chapter attempts to look at the two objectives: 1) to know the nature and structure of the Indian SPV industry; and 2) to understand the factors that determine\curtail the development of Indian SPV industry. This is to understand how Indian SPV industry is located in the globalised production and innovation of photovoltaic technology and why there is no linkage between industry and academia. Based on these objectives, the study discusses the nature and structure of Indian SPV industry and exposes the factors which contribute to socially and technologically locked in position. Second, it helps to understand the reasons for the joint ventures and technological tie-ups with foreign firms and explores the nature of the same. Third, the study identifies the issues of lack of skilled laborers and the position of experimental R&D in Indian SPV firms. These three factors explain the nature of the problems faced by the Indian SPV industry. Further, it reveals the reasons for the disconnectedness between the industry and academia in the SPV industry.

Nature and Structure of Indian PV Industry: Local to Global and Global to Local

Locked in Technological Base of Indian PV Industry

The study witnessed that, before 2005, SPV firms found it very difficult to get process and product technologies and other raw materials from international markets. This is because the demand for SPV technology was minimal and also the foreign firms were reluctant to provide new technologies and projects to the Indian SPV firms. Consequently, the development of Indian SPV industry, in terms of production capacity, was limited and also located at the last stage of production such as the module production and suppliers of SPV technological systems. However, the new institutional mechanisms such as Kyoto Protocols and international dialogues on climate change have increased market demand for sustainable source of energy productions in which solar energy technologies play a vital role. Now, the foreign firms, especially the Europeans, offer turnkey projects such as implementation of solar power plants and production of solar cells and modules to meet the local and global demand. This has created the joint ventures and collaborations in the Indian context. Most of the new Indian SPV firms have been established at this juncture or have attempted to increase their production capacities to meet the local and external market demand. This is clearly evidenced from the organizational profiles of the SPV firms that are located at Hyderabad. In 2004 to 2010, there are four out of nine SPV module manufacturers which have started their operations and mainly focused their activities on the external market. This also could largely be correlated with India's announcement of new institutional framework on solar energy in 2008-2009. These factors have resulted in the increase of investments in the process of production and also the export of SPV technology in India.

For instance, Table No: 7. 1 shows the Nature of Manufacturers, Production Capacities and Technological base of Indian PV firms. In the study, out of nine SPV firms only one large scale firm has invested in the production of 170 MW in PV cells and 180 MW in SPV modules and another firm has increased its capacities from 50 MW to 110 MW to meet the domestic and external market demands. In the study, only one firm is engaged in the process of producing second generation thin film SPV technologies such as Amorphous Silicon and Cadmium Telluride. In India, the technological production based on second generation solar cells and modules has recently started and the market concentration on thin film technology is less than 10 percent (Indian Semiconductor Association, 2008).

(Table No: 7:1)

Names of firms	Year	Nature of the Firm	Production Capacity			Technological Base	
			Wafers	**Cells**	**Modules**	**First Generation Technologies**	**Second Generation Technologies**
XL Telecom LTD	1985 (1994) solar operation	Limited	Nil	120 (newly started)	24 to 210	Mono/Multi-Crystalline Silicon	
Titan Energy LTD	1992	Limited	NIL	NIL	50 to 110	Mono/Multi-Crystalline Silicon	Produce CIGS & Amorphous Silicon Modules
Photon Energy LTD	1996	Limited	NIL	NIL	50	Mono/Multi-Crystalline Silicon	
Access Solar LTD	2005	Limited	NIL	NIL	10	Mono/Multi-Crystalline Silicon	
Ecosol	2009	Private Limited	NIL	NIL	10	Mono/Multi-Crystalline Silicon	
Sungrace	1999	Private Limited	NIL	NIL	10	Mono/Multi-Crystalline Silicon	
NEST	2004	Private Limited	NIL	NIL	15	Mono/Multi-Crystalline Silicon	
Solar Nights	2010	Private Limited	NIL	40	40	Mono/Multi-Crystalline Silicon	

Complied by author, Source through field work

Likewise, the investments and production in modules outweigh those in SPV cells, wafers and ingots in India. SPV firms are reluctant to invest and involve in the manufacturing of PV wafers and ingot productions. All the SPV firms in the study which are predominantly located in module manufacturing mainly function as assembling firms. These firms integrate SPV cells into SPV modules and produce SPV technological systems such as SPV water pumps, solar lantern, street lights, etc. The technological base of Indian SPV industry is predominantly located at the first generation of solar modules such as mono and multi-crystalline silicon technologies followed by crystalline silicon solar cells. Most of the PV firms export modules followed by cells and subsequently, end up in low-labour and technology intensive works. The large and medium scale firms focus on the export market compared to that of the small scale firms which concentrate more on domestic market rather than the export market. The export market requires huge investments in international technological certification from foreign scientific laboratories for which it requires more than INR 45, 00, 000 lakhs. This limits the small scale firms to focus on the Indian domestic market.

One of the small scale entrepreneurs said as follows:

> The international certification is important to participate in the global production process. In India, there are no such international standard scientific labs to certify the Indian PV modules and cells. There are some new scientific labs coming up in Bengaluru and Hyderabad such as UL, TUV Rhine field and DuPont. These scientific labs belonged to foreign firms but are setting up operations in India. Every Indian PV firm pays nearly Rs. 45, 00, 000 for the purpose of getting a certificate. This makes the small-scale firms to concentrate more on the local market.

The solar market conditions are highly fluctuating since the geo-political discourse on climate change (in other words politics of climate change) and subsidy-based demand largely shape the production and commercialisation of SPV technology. In the study, most of the PV firms claim that exporting and contracted manufacturing of SPV modules and SPV cells may be affected, if the respective governments stop or change the incentive structure for solar energy as per the new cost of SPV technology. It has several implications in the Indian context. First, it unfolds that Europe contributes to 80 percent of the global SPV market and it is one of the hot spots for solar exports. The European Feed in Tariff (FIT) has helped to establish the Asian firms as the leading module manufacturers in global PV industry. Now the low cost Asian module manufacturers dominate the 82 billion dollars global SPV market. It is clearly evidenced from the study that most of the PV manufacturers accept that there are three factors which attract projects, orders and collaborations from foreign countries; (1) cheap labour power, (2) the low cost of modules and module production and (3) state-driven policies favouring China and India as the hot destinations for module productions and exports. These factors play a major role in increasing the mass production that finally brought down the economies of scale and increased the global competition in SPV industry. The Indian PV industry is basically a part of this structure of globalised SPV production that mainly survives on cheap labour power and dependency on export and foreign markets. However, in the study, the PV firms accept that Indian manufacturers are less competitive than other Asian foreign firms such as China and Taiwan. The basic problem is that the weak domestic market for solar energy technologies and dependency on foreign technologies and raw materials make the Indian PV firms less competitive in this globalised SPV production. For instance, China and Taiwan have the strong local markets, easy accessibility to raw materials and complete value chain of PV productions. So the SPV firms in these countries survive easily in the global competition. This is actually missing in the Indian context. Consequently, the Indian PV firms concentrate more on export market and technologies.

One of the Vice Presidents of a large scale firm mentioned:

> The Indian PV industry is yet another industry driven by external market rather than by the internal market. Since 1990s, the domestic demand has been very less in the Indian context. The Indian PV industry is not a high-tech industry because we are located at the end stage of manufacturing - integration of all PV cells and modules. The basic infrastructure for further development of PV industry is missing in India. However, India is not the only country which produces PV modules and cells. For example, China, Taiwan, Korea and Japan manufacture all the materials, which are required for the production of PV technology. The low cost of production, less production time (for instance, producing one MW within four days), and cheap labor power make the Indian PV industry to compete in the international market. This enables the Indian PV industry to participate effectively in the global process of production. We attract more projects from other outsourcing countries, especially European countries compared to India. However, China's exports are more compared to those of India. Their domestic market is helpful to establish the export market. For instance, internally driven demand is met out by the local production unit. It saves the cost of production and time. Their industry is far advanced than Indian industry in terms of technology and production capacity.

One of the directors of a large scale firm said:

> The Indian PV industry incurs the additional rate of interest (additional cost) due to the gap between production and selling of PV modules and cells. For instance, to produce 4 MW, it costs around 10 crores. To get the investment back, it takes nearly three months for which we pay interest rate. It affects the production of PV technology. We produce, if

> there is any requirement. Otherwise, we reduce the quantum of production. This is not the case of other countries where they gain easy accessibility to local market, other materials and parts which makes them to survive easily. In the Indian context, the local domestic market demand is less, which makes the production relatively in favour of external market. Within a matter of days the production will be over. The entire process is missing in India. The export of PV technology takes more time and money. For instance, we need to get containers, storing in warehouses, taking insurance, and so on. These all make Indian manufactures less competitive than Chinese manufactures. Indian manufacturing firms try to overcome those positions by focusing on the quality of the PV technology. The money is not the problem in India. For instance, Mukesh Ambani can set up a plant to manufacture A to Z of the PV technology. The dependence on a single product market makes return on investments doubtful. The manufacturers expect 70 per cent domestic market and 30 percent export market. In reality, the domestic market is relatively weak. The production capacities are under-utilized at present, due to the economic crisis in Europe.

At present, Europe is facing an economic crisis and most of the countries have decided to cut down the deficit spending in green economy. For instance, Spain, Greece and U.S are the best examples in the recent times that have withdrawn subsidies on renewable energy such as solar, wind and bio-fuel. This has created the policy uncertainty which is affecting the installation of solar energy technologies at present.: 'Spain halted subsidies for renewable energy projects to help curb its budget deficit and rein in power-system borrowings backed by the state that reached 24 billion euros ($31 billion) at the end of 2011…The government passed a decree today stopping subsidies for new wind, solar, co-generation or waste incineration plants' (quoted by Sills, 2012). The Indian SPV manufacturers believe that this factor largely influences the PV industry at present. The SPV firms are unable to operate the production continuously in this context. As a result, most of the firms involve in production if there is sufficient external demand. Otherwise the firms reduce the rate of production to avoid externalities due to unpredictable external market conditions.

Socio-Economic and Political Conditions of the Domestic Market:

India has vast opportunities to diffuse and adopt the technological innovations of solar energy. The potential market space is huge in terms of energy supply. Solar energy technologies are viable options to meet the India's energy demands due to several other factors: (1) Indian electricity infrastructural system is not well connected into the remote areas; (2) connecting those remote areas need additional power plants that require huge investments and manpower in the near future; (3) transmission and distribution loss create inherent energy deficit and increase the economic burden; (4) finally, government especially ends up with total loss in their balance sheet. On the other hand, the demand for PV technology in India has been still at the sub-optimum level so the commercialisation depends on the market gap in energy production and supply. This assumption is based on two factors that act as social constraints for the adoption of PV technological innovations in Indian conditions: (1) Socio-Economic Factors; and (2) Policy and Political factors.

Social and Economic Factors:

One of the main comments of the entrepreneurs point out that the Indian urban class structure is dominated by middle class configuration and rural class structure is dominated by agricultural based production that play predominant a role in the social acceptance of SPV technological innovations in the Indian context. At present, the majority of consumers belong to the categories of private and government sectors, NGOs and upper class groups. Medium and low classes in the urban social space are located at the level of solar lantern and individual home lighting systems and local PV firms maintain its low profile in the rural areas. Most of the PV firms find difficulties in penetrating into the rural areas. It mostly happens through government and NGO sponsored programmes. Although the market space is limited, most of the entrepreneurs use other strategies to diffuse PV technological innovations to rural and urban markets. At the urban space, the entrepreneurs consider the frequent power shortage as a major opportunity to sell stand alone systems based on off-gird systems such as mini-power plant, home lighting system and solar lantern. For instance, the intermittent power supply and increase in the electricity tariff to Rs 10-12 for a commercial complex building provide an opportunity to adopt the SPV technology in the urban space. Some of the entrepreneurs who are also manufacturers cum traders target this small portion of market space. The manufacturers create new avenues like NGO-firms inter-linkages to commercialize the technologies in the rural markets. For instance, Access Solar Energy and Sungrace have commercial collaborations with a NGO based in Anantapur to commercialize the PV technology among the horticulture farmers. Therefore, the Indian PV market potentials are only 5- 10 percent. Although it is a socially known fact that cost of the technological innovations is higher, there are other factors which curtail the diffusion and adoption of PV technologies such as long term insurance policy for solar technology, social acceptance of SPV technology, lack of collaboration with construction industry, etc. The director of the Titan Energy pointed out:

> Out of 100 consumers the potential consumers are only 5 – 7 but there are nearly 30-40 suppliers are there, hence the competition is high. The firm/organization has to find the gap in the market which is just like an air-tight bottle. The market is so weak in nature because technology is weak in terms of cost-efficiency and technological efficiency. The consumption rates of PV technology are low and production rates of PV technology are high hence economies of scale could not be achieved. The entrepreneur uses the daily power cut as an opportunity to sell the stand-alone systems (which could be affordable to the middle class). According to him, there are four thermal manufacturers and 12-13 PV module manufacturers. These PV module manufacturers use imported second/third-rate quality PV cells for producing PV modules.

Case One: PV Water Pumping System

The pilot study was conducted in the Anantapur district to know the consumer aspects of PV water pumping technology. Providing renewable based technologies is part of the sustainable energy programme in the TRD (Pseudonym) NGO. PV water pumping system is mostly used by large scale farmers than the medium and small-scale ones. A major hurdle is the affordability of the technological cost. At present, the returns on investments in agricultural productions are lesser than the cost of investments. Farmers consider SPV technology as an additional cost to the process of production. The cost of the PV water pumps varies with the technological capacities and design. The non economic viability of farmers is another major hurdle. However, it proves suitable for horticultural cultivation such as mango, critic fruits, and is mainly used for drip irrigations. Other forms of agricultural cultivations such as rice, maize, sugarcane and wheat are excluded due to low potential capacity in terms of water output per unit of energy in-take. The technological capacity is not equal to those of the diesel and electricity water pumps. Further, it has time limitation, that is, the technology can be used between 9 and 4 PM and battery would add to the cost of the technology. Hence, the usability is highly limited for specific agricultural productions. Apart from this, the other subsidy programmes such as free and subsidized electricity and well connected local irrigation facilities prevent the adoption of technology. At present, this technology is only applicable to the place where the cultivation is totally disconnected from the mainstream electricity and irrigation facilities.

Case Two: Mini-off gird PV System for Urban Consumer

It seems that the above upper and above middle classes are the people who can afford the mini-off grid power plants which come under the category of standalone system. At present, in the Indian context, it is difficult for the stand alone system based on mini off-grid power plant to penetrate into the market. There are several factors responsible for it. It is not merely the cost that plays a crucial role in determining the adoption of technology. There are other factors such as energy requirement of a family and the middle class mind set (needs quality goods at the cheapest price) which affect social acceptance of technology. For instance, adopting the SPV technology instead of conventional energy seems to be uneconomical for a nuclear family in the urban social space. Even with the advent of apartments, the task of fixing and maintenance of the technology is highly impractical due to the fragile nature of technology. Though the PV investment is for life time and some of the large scale firms provide 15 years warranty for module failures, still consumers are reluctant to purchase the technology by doubting the very existence of those firms in the future. Therefore, the technology is highly constrained to be adopted at the level of consumer market, since the future predictability of technological market constrains the diffusion. At the same time, there are no legal arrangements existing between firms and consumers and lack of such legal arrangements adds to the problem. Even the government subsidies cannot match the cost of the technology and getting finance from the government or private banks is very difficult since there is no return on investments. One of the Vice Presidents from Titan Energy System reflected:

> The rich and upper middle classes are the people who can afford the solar energy, as a standalone system. For instance, independent villa in Banjara or Jubilee hills consumes nearly 10 kW. For which we need to install a system with minimum power generation of 7 to 8 kW. Today’s cost per watt is Rs. 100 then 7 kilo Watt is 7000 Watts which would cost around Rs. 7, 00, 000. These seven lakhs are the total investment cost to convert from conventional electricity to non – conventional mode. The cost of investment will also increase, if there is any additional investment such as battery. The battery cost would come around Rs. 30000 to Rs. 1, 00, 000 lakh. It depends upon the consumer's choice. Every two to three years he/she has to change the battery. The total cost of the PV system comes around Rs. 15, 00, 000 to Rs. 20, 00, 000 lakhs for 10 kW. The interest rate on first investment on PV system nearly comes around Rs.8, 000 per month. The consumers

> total energy cost would come around Rs. 3000 to Rs.4000. With the additional investment on solar would reduce the electricity bill to Rs. 2000 to Rs. 2, 500. The consumer gets only Rs. 1,500 per Rs. 8, 00, 000 lakhs. The remaining 6,500 is a loss to the consumer. The consumer gets Rs. 4, 50, 000 out of Rs. 8, 00, 000 lakhs. Hence the solar is not viable to the individual consumer since the return on investment is very low. The solar lanterns are economically viable compared to a mini individual power plant. The business model does not match the exact requirement of the individual consumer. On the other hand, grid connected solar power plant is also economically viable compared to other modes of energy production. In India, it is very difficult to penetrate an off-grid or standalone system. The business model won't support the system. The grid solar power and mixed renewable energy resources could drastically reduce the cost and demand for energy. The government should work out a policy on these lines which helps photovoltaic to penetrate into the society.

Institutional Dependencies of Indian SPV Industry: The Policy and Political Factors

The implementation of National Solar Mission (NSM) has several implications for Indian PV firms and consumers: first, the implementation of solar energy power productions increase the existing cost of electricity in India as it is also evidenced from other countries such as Germany, Italy, etc. This transfers the economic burden of climate change to middle and lower income classes who are the dominant proportions in population composition in India[82]. One of the Vice Presidents from Assess Solar Energy observed that,

> The Indian society is dominated by middle and low classes. Our consumption rate is dictated by the production rate and not vice versa. The energy has to be produced according to the requirement/demand. The basic consumption rate is maintained in certain parts of the region. For instance, the urban energy demands are met at the cost of rural energy demand. The per capita consumption rate is less compared to other developed countries. Likewise, India is not over consuming like western society in terms of energy. The energy inequality exists in the Indian society. On the other hand, the massive industrialization process and rise of new middle class/upper classes stimulate further energy demand. Can India meet the additional power demand with the existing infrastructure? It is difficult to provide energy for further development. Environment and economic burdens are borne more and more by the Indian middle class. The distribution companies incur a massive loss in various states. On the one hand, poor class is exempted from paying electricity bills and also often fails to pay the electricity charges as it is

[82] The similar sorts of experiences are gained from Germany, UK and other European countries. The non-solar power producers pay extra charges on the consumption of electricity due to the implementation of solar energy programmes. There is only one exception that Spain employs the policy instrument of deficit spending to reduce the consumer's burden. However, the present crisis made them to withdraw its deficit spending at slow phase.

> mentioned in the bills. On the other hand, high class consumes more energy but pays as equal as other classes. In this case, the middle class takes the burden of the increased tariff because neither, they have the economic-political power nor dadagiri.

On the other hand, based on the factors such as decrease in the cost of PV technology and technological innovations, the continuous revival of Feed in Tariff for power purchasing agreement creates certain skepticism among the manufacturers about the political commitment and will in implementing the solar energy since the power production contract is for 25 years in India. At present, the entrepreneurs feel that considering several factors such as state government losses, T&D losses, the government attempts to reconsider the CAP fixing for solar energy and things are yet to be finalized. Still, there is no commitment and enforcement of Renewable Energy Purchasing Obligation (RPO) from majority of the state governments though they are obliged by law. Furthermore, any political change may affect the solar energy plan and consequently affect the Indian PV industry. So, there is an unpredictability that exists about the whole framework of NSM and other renewable energy policies in India.

One of the Vice Presidents of a large scale firm pointed out the policy lacunae in NSM:

> Recently, the Government of India has recognized the solar potentials and other renewable energies, which were absent for nearly 30 years. The demand has started recently, in India, through plans and policies such as National Solar Mission Plan and integrated energy policies. In future, we may expect high green investment, in India. On the other hand, the initial euphoria which was established at the launch of solar mission is less at present. The main reasons are a continuous revival of tariff rates, and the functions of systems are not properly defined like the difference in commitment to solar energy and renewable energy. For instance, the hydro power is much cheaper than the solar energy. The states which are abundant in hydro power may sell their power to other states and utilize the same power to achieve the target. The solar energy is one of the options in renewable-energy production but not the enforcement. There is no specific policy on solar-energy production within the renewable energy. The unified or integrated policies and clarity are missing in the Indian context. India has abundant solar radiation throughout the year which is yet to convert into resources. We need to rectify the policy obstacles for solar-energy penetration into society. The differences in state electricity boards are found in different states. The clear understandings between state electricity board and central power purchasing agreements are yet to take a form in the areas of energy productions. The lifetime of PV technology is twenty-five years. The good tariff

> amount draws attention of many investors into the field of solar energy. On the other hand, the continuous change in the policies is witnessed and considered as a threat to the investors and entrepreneurs. At present, the investors are skeptical about the solar-energy power plants. No investors are ready to invest money on behalf of state government. The production of PV modules depends on the created demand. Any change in the policy framework directly affects the demand which is created. Consequently, it affects the PV industry.

Second, NSM actually hampers the creation of mass market since the centralized source of solar power production gets higher importance than the off-grid systems. It has two implications for the Indian PV firms: first, though NSM enforces the solar power producers to employ indigenously produced solar cells and modules in power project, majority of the power producers may prefer to deploy foreign modules since these are cost effective and have high efficiency. On the other hand, first generation silicon technology is highly prone to technological defects due to low intensity of silicon to absorb heat. This has become the vantage point for power project producers to import second generation solar cells. This would eventually destroy the local industry base which is dominated by the first generation silicon technology. The solar energy policy is not clear about this position at present, which has serious repercussion in the development of the Indian SPV sector. One of the Directors of a large Scale firm criticized as follows:

> Right now, the government policies enforce that indigenously produced PV modules should be utilized in the power plants, and this is limited to first-generation technologies but not to the second generation PV technologies. This may become an advantage to the power plant producers to import second generation technologies, which affect the industry development since the PV industry is based on first-generation technologies.

Furthermore, majority of the investors seem to be attempting to locate as the power producers rather than the PV manufacturers since it provides continuous profit for 25 years. Subsequently, there is tough competition to get solar power project and thus provide an opportunity for irregularities in allotment of projects to private parties. This may stop the entrepreneurs from being in the last stage of production and further backward integration may also yield little efforts in the Indian PV industry. It may also lead to the technological dependency on the Chinese or any other market which provides cheap technologies. It may curtail the indigenous industry and technology development.

One of the Directors from the PV industry pointed out that,

> The firm was started four years back. Now our annual turnover is six crores. Political connections are highly important in this sector. Presently, I am to get the Industry Representative Position in the government, on behalf of the industry. It will be helpful in getting government bids, if I get through. The political power of the entrepreneur mediates commercialization of the technology. Most of the entrepreneurs have political backgrounds, for example, Photons Energy Ltd, Chairman is presently an MLA; likewise, Lanco and Solar SemiConductor also has from the political and business backgrounds. These social profiles are highly important for government procurement of technology from private firms and also to get solar power plant projects. PV/thermal is not consumer goods rather public goods, the entrepreneurs and power project developers depend on the government projects such as NSM and Rural electrification programmes. Initially, we had thought of starting a PV cell plant but we dropped the idea since it is easier to purchase technologies from outside rather than starting our own plant.

One of the Vice Presidents from a large scale PV firms mentioned,

> The political background is relatively important to get the government tenders/bids, since the present market demand is driven by the state intervention. To be honest, the concerned minster asks how much you will pay, if I allot the bids to you. On the other hand, there are a lot of bureaucratic processes involved in sanctioning the solar-energy projects. An economic bargain takes place in this politically influenced situation. In the process, the implementation gets delayed along with the production. The total system becomes dysfunctional due to the political process of economic action. There are a lot of dysfunction existing in the Indian political and bureaucratic systems but still the system functions without any stoppage. The ethics is missing and everybody turns out to be opportunistic in the present context. In this situation, how can we expect every individual to be morally correct? The legitimization of crime has become the ethics of the present world. This reflects the functioning of the system in which we live.

The demand for solar energy would be very less till 2025 since the centralised power production dominates and so, may play a negligible role in the consumer market in India. If that is the case, the consumer demand for solar energy will be at the sub-optimal level. The demand based on off-grid systems would create the mass market which could bring down the cost of PV technology in India. For which, manufacturers consider an integration in various government programmes such as Rajiv Gandhi Rural Electrification

Programmes and NSM-off-grid systems. These need unification under one scheme so that the bureaucratic process will be reduced and will encourage decentralized and distributed energy production systems. Most of the firms claim that subsidy is an instrument for solar energy but that is not sufficient to create the mass market demand.

> The demand market would be very less till 2025 since the NSM creates centralized power production. It is based on power plants projects. At present, penetrating off-grid system is very difficult since the major part of demand is satisfied with conventional energy source in urban areas. If the mass market picks up, the cost would come down drastically. We need to have some integration in various programmes such as RGEP and NSM. This along with subsidy will help to penetrate solar energy technologies.

Another entrepreneur mentioned that subsidy is not required to penetrate the solar energy technology but the effective market mechanism through pricing control needs to be reformed in India.

> NSM provides importance to centralized power production and the off-grid gets less importance. We need to regulate the tariff structure and also reduce the subsidy on kerosene, diesel and electricity to make solar energy penetrate into Indian society. This is much more important than providing subsidies.

The market mechanism needs effective control that is possible only through the intervention of government policy. For instance, the central and state government control the energy source, production and distribution that determine the energy supply and demand. This structure has been curtailing the adoption of PV technology in India. This creates the dilemmas of policy framework on energy production and its composition in India. The present institutional framework on energy production and distribution bestows higher importance on conventional and nuclear energy sources compared to the solar PV and thermal ones. The recent integrated energy policy suggests that India requires 8, 00, 000 MW power production in 2030 to meet the daily requirements of the consumption. At the same time, NSM sets the demand from solar energy as 22 GW in 2022. This would come to approximately 2.5 % of energy production from solar energy. This demand provides larger scope to centralized power production which stands at 20, 000 MW and rest of the 2000 MW is based on rooftop and standalone system. This shows a disproportionate demand creation existing in the policy framework. One of the major reasons it that the large scale PSU (corporate) and private firms are involved in the process of energy production and distribution. In the present context, it is less possible to restructure the Indian electricity system. For instance, the various public sectors such as National Thermal Power Production (NTPC) and Nuclear Corporation of India Limited (NCIL) control the production of power in India. The state-owned business enterprises are controlled by different Ministries in India such as Ministry of Coal, Ministry of Petroleum and Natural Gas, and Ministry of Power. These ministries get higher priorities in Five Year Plans that allocate subsidies through their individual government programmes. It seems to be that MNRE gets one tenth of the public sectors investments that are very less and minimizes the impacts of renewable energy programmes in Indian society. One of the entrepreneurs reflected that the recent PV manufacturers and government interaction has circulated on these lines of allocating central funds from other Ministries to MNRE. It also encouraged to reduce the subsidy rates for other energy based consumable products such as kerosene and diesel. Likewise, a scientist from SEC commented that the allocation of funds for renewable energy is minimal compared to other sources of energy. This would encourage penetration of solar energy in India. However, this approach is missing in the present context and government maintains both systems together which the manufacturers consider as political rationality failure and also consider NSM as energy securitization process.

One of the scientists from the Solar Energy Centre (SEC) -MNRE acknowledging the view points of entrepreneurs as follows,

> It is the mindset of the people that made solar energy technology as less useful one. For instance, one litre of diesel is Rs. 40 and how much the quantum of the energy produced through diesel generator? Do you know how many units will be produced for one litre? It depends on the capacity of the generator. Nobody have one kilowatt Diesel generator and minimum of 30 KW Diesel generator. It takes Rs 15-16 per unit on diesel generator, if it works for one hour with good load efficiency. This is subsidised rate of electricity per unit of production otherwise the cost would come around Rs. 60 for a unit of electricity. The government is ready to fund these technology based energy production. It is the right place to explore the possibilities of creating solar energy technology as economic myth. This is how bureaucracy and political factors come to play a major role in fostering the technology. Today, if we are looking at the biding of NVVN, we have offered reverse bidding Rs 1000 for per kilowatt. There are people who are taken that bidding. Even Rs. 12 is wrong thing but people are ready to take. However, we are paying Rs. 15-17. By budget is Rs 1000 crore, if one kilowatt per hour is Rs. 15. Every year government of India is paying Rs. 20000 crore on Diesel subsidy. It is less than 5 per cent of subsidy. Most of them have been asking for five per cent of subsidized cost of diesel for solar power. Still, it is not implemented.

Over all, the unreliable market, socio-economic factors and unfavourable political and policy conditions constraint the development of the Indian PV industry. In this context, most of the PV firms are unwilling to invest money on backward integration. On the other hand, the firms require high capital and labour-intensive technologies to move up in the ladders of vertical integration that may be considered as uneconomical. Furthermore, the vertical integration needs applied and experimental research at the level of cell and wafers productions and requires R&D backups, manpower and continuous power supply which is less available at present. This limits the Indian PV industry at the last stage of production in the value chain of PV technological productions. To some extent, it also depends on the future growth of the PV industry in India.

One of the scientists from the SEC – MNRE mentioned;

> The second is the lack of infrastructural facility, which could link the various activities of PV industry. The foreign firms have R&D back up and university linkages to provide immediate solutions to industrial problems. In the Indian context, there are cell

> manufacturers, but still they import wafers from other countries such as Germany, U.S.A and China. There are only three reputed wafers manufacturers in the whole world. This does not exist in Indian PV firms. If that is the case, how can we expect to set up vertical integration in PV industry? The setting up of the vertical integration all together needs different infrastructure development, which also includes effective policy implementation and market development. This will take some more time in the Indian context.

Most of the firms have preferred to be within the end stage of technological production in India. This also shows the concentration of technological production in the value chain of Indian PV industry. Therefore, the Indian PV industry is not only technologically but also socially locked in its present position.

Technological Dependency of Indian SPV Industry: Technological Tie-ups and Joint Ventures

At present, the oligopolistic nature of world SPV industry controls technological innovations and productions that create two forms of dependencies in India: technology and knowledge. In the study, most of the PV firms depend on the collaborations with foreign firms which are created by two factors: First, the recent years have been witnessing the increase in PV technological innovations from global giants such as Solarium, Solarrex, etc and also increase in mass production of PV technology across the countries. The foreign firms, through technological innovations, control the cost of PV technology. Consequently global PV industry witnesses an unpredictable fall in PV technology prices. This is one of the recent factors which influence the economies of scale vis-à-vis change in the government stand on fixing the Feed in Tariff (FIT) as per the new prices of PV technology. This creates a social condition that the firm which maintains the cost and develops new technology will survive in the global competition or else it will perish. One of the executive directors from a large scale organization mentioned:

> Indian PV industry is fully controlled by the global market in terms of technology, innovation, raw materials and market. The foreign corporate giants, such as DuPont, Premier, have access to money, knowledge, advanced laboratory facilities and market. The affordability to R&D investments makes them to provide the products at competitive

> prices. The global giants control the PV industry. This is the present condition of global PV industry. It is true that the Indian PV industry purchases technology and gets knowledge expertise from other countries to produce the product. It follows two standardized practices: one, is doing reverse engineering and the other is purchasing new technology from foreign firms. This is reflected in the Indian PV industry. This is to remain competitive in the highly fluctuating Indian market.

One of the Vice Presidents from a large scale PV firm elaborated the conditions of PV industry:

> Till 2009, the cost of solar PV modules was higher compared to the present. The market price has come down, for solar modules, with the increase in the demand and supply internationally. On the other hand, the solar cell manufacturing and supply has increased globally rather compared to the previous years. For instance, the cost of solar cells has come down from 2.7 dollars to 1.2 dollars. We are expecting that there will be a rise in price of solar cells but it will not reach the extreme end. We cannot predict anything on the price fluctuations of solar cells and modules. With the rate of 1.2 dollars per watt, there is decrease of 30 to 40 percent on solar module prices leading to decrease in investment cost on solar power plant project from 22 crores to 15 crores at an average. This may vary from firm to firm. Since the module prices have gone down, the state wants to reduce the tariff rates on solar power plants to ensure larger participation from the entrepreneurs. Likewise, the payback time is also reduced to 7 years compared to the earlier 15 years. These factors attracted the large entrepreneurial community by creating opportunities for setting up solar power plants in general. In this context, the firm which produces low cost PV technology will survive or it will be eliminated in the fierce competition based on innovation.

This position renders Indian firms as highly vulnerable to frequent price and technological change at any given point of time. It also exposes the Indian PV firms to bankruptcy as it was the case with other foreign firms such as Solyndra in the US and Solon in Germany. The sudden decrease in the solar PV prices, with increase in mass production and technological innovations, drove some of the global PV firms to bankruptcy. The similar sort of experience was evidenced from the present study. As one of the scientists from the SEC reflected that the frequent fluctuation in solar technology prices has severely affected one of the Indian PV firms. The particular firm BM (**Pseudonym**) had heavily invested in cell and module production and had entered into an agreement with a German firm for purchasing wafers. It was four times higher than the actual cost of the production of PV wafers. The sudden decrease in the cost of cell lesser than the wafers technology pushed the firm into debt-crisis situation. Finally, the person who was responsible for the action was fired out of the firm. Due to fierce global competition, the PV firms maintain certain strategic relations with foreign PV firms. One of the scientists from the SEC-MNRE commented on the nature of PV industry:

> The joint venture ruined the MB. MB had entered into MOU with a German company for purchasing wafers. The agreement was four times higher than the real cost and suddenly the cost of wafers came down. The total economic burden came to MB. They have sold the cells lesser than the wafers cost.

Second, in late 1970s & early 1980s, Indian S&T policy emphasized technological self-reliance as a path to attain economic development. At that point of time, importing technologies from foreign countries were restricted with the imposition of high customs duty under the regime of import substitution policy. It hampered transfer of technologies through joint ventures and technological tie-ups. The foremost priorities on energy based R&Ds have been predominantly located within public sectors of industry and research, such as CEL, BHEL, and BEL and R&D laboratories such as NPL, DAE, and DRDO. The indigenous and imported technologies on process and product were limited only to these public sector units that focused on PV cells and modules research and productions. Most of the scientific collaborations happened within the government sectors that limited the vertical and horizontal integration and also technological innovations. The private firms were severely affected by this course of policy restrictions. The non-availability of technologies (process and product) and investments limited the development of entrepreneurial capabilities and located the firms at the last stage of production. It pushed Indian PV entrepreneurs predominantly as traders, at the initial stage, to sell PV technological systems to government and also there were no government initiatives to train the industrial labours and entrepreneurs. Subsequently, two phenomena emerged though the policy relaxation and incentives have been available to the Indian PV industry since late 1990s: one, technological learning was curtailed; and subsequently, the development of technological capabilities and innovations came to a state of pause; and two, it also affected the development and transition of Indian PV industry. There is little technological breakthrough that has happened at the level of process and product of PV technologies in India since the Indian R&D on new PV technological development has been one of the neglected areas of Indian science and technology. It hampered the trajectory of technological innovations and industrial development in India. Subsequently, the basic infrastructural facilities and production lines such as ingot, coke reductions, silicon purifications and wafers are highly limited in the Indian context since the cost of investments on the vertical integration is higher. The value chain of SPV technological production is lagging in India. Indian PV firms consider this as a failure of the innovation system in the PV sector that could not create the value chain of SPV technological productions in India. This produced anomalies in constructing the industrial knowledge base and curtailed the development of indigenous technological innovations. The director from a large scale firm revealed:

> Indigenous technological developments in solar PV are less in India compared to other foreign countries. The firms import process and product technologies from other countries through collaboration, joint ventures and buying patent from foreign countries. Some of the machineries are foreign-made and some are from India. One of the basic reasons for such dependency is that the government ignored to develop this industry. Within this, the public sector unit got primary importance than private firms. Consequently, most of PV firms are located at the end stage of production and there is no technological learning process that has happened in these years. We often compete with public sector units which have made them to import technologies which are relatively cheap in international market.

Low technological innovations and weak technological manufacturing capabilities at the local level lead to the collaborations (technological tie-ups and joint ventures) with foreign firms basically located in Europe, China, Taiwan and Japan. The non-availability of cost-effective and efficient technologies makes PV firms to purchase technologies and raw materials from foreign firms. This keeps the Indian PV firms in the global order of PV technological production and innovation. The PV firms consider importing technologies and contracted manufacturing provide access to market, raw materials but also construct technological capabilities that help to reduce the cost of PV technological productions in India. It adopts the process technologies such as technologies on production lines and product technologies such as wafers, cells, modules and PV technological systems. However, the study finds little collaboration on new technology development between Indian and foreign PV firms. The inter-firm collaborations is based on MOU or legal agreement that exists between Indian and foreign firms. The nature of MOU varies from firm to firm and not all the firms in the study unfolded the relevant information on the nature of agreements that deal with purchasing the technologies (process and product). However, the study identifies certain patterns of agreement that exist in the Indian PV industry. The trade arrangements on technology transfer unfold two aspects; transfer of technologies based on the agreement that Indian PV firms produce cost effective PV cells or modules for the foreign firms and also purchases the technology rights through license, royalties to export PV cells and PV modules to foreign countries. For instance, one of the large scale firms has trade agreement with Schott Solar to produce PV modules for which the foreign firm sends PV cells. Likewise, the manufacturing equipments are purchased predominantly from various foreign firms such as Komax USA, Mondragon Assembly, Spire Solar, Pasan, etc and some equipment from Indian firms such as HHVC that produce vacuum technology. In the second context, the Indian PV firms purchase the technological knowhow through trade agreements with foreign firms, especially, located in European countries. For instance, one of the large scale firms has recently purchased the technologies of "Roth and Rau" for multicrystalline solar silicon cell production and employs licensed know how process from ECN Netherlands. In both the contexts, the Indian PV firms incur the cost of investments in technological productions and the responsibilities of foreign firms is just to provide technologies, expertise, and projects.

However, the joint ventures or trade agreements always favour the western firms who look at Third World country as technological dumping ground, since, most of the entrepreneurs and directors are from management or other industry and not the technocrats. This position has clearly evidenced from the study that two entrepreneurs are from solar energy background and rest of them are from other fields. Likewise, Indian PV entrepreneurs are not as trained as the scientists in the laboratory. Most of the entrepreneurs know little about the technological knowledge of photovoltaics such as efficiency and device structure, and how to calculate the cell performance in the long run, etc. This also provides room for adopting the technologies which are technologically obsolete and low graded in technological capacity and efficiency. It is very difficult to determine the technological efficiency in the first two years and later the technological performance degrades at a faster rate. The market is flooded with cheap imports of second and third graded qualities of PV modules and other balance of system from the East Asian countries such as China and Taiwan. This is to remain competitive in the constrained market space of 5-10 percent and to cater needs and meet the mindset of the Indian consumer. One of the scientists from the Solar Energy Centre revealed the conditions of Indian PV industry and entrepreneurs knowledge base:

> Our Indian manufacturers do not even know how to select the particular things. Very few entrepreneurs have the in-depth knowledge of solar PV. All the joint ventures or collaborations are non-sense. This is the reason for the loss of MB. All the employees are daily wage labors who have completed just ITI or Diploma. There are no engineers and scientists. The rest of the people is from management who cannot handle technical aspects. For instance, RK (IIM-A) from MB gave dhokha to the firm. This is not a joke but it is a true. He was thrown out of the MB. Later fellow is RV and he is a technocrat. He admitted that I could not handle the problem and went way. Now MB is red. They started with big expectations but everything came down. This is due to lack of field knowledge in PV. Entrepreneur cannot run the firm without the science background in PV. We require scientists and technocrats and not the MBAs. Most of the scientists in this area have gone out. For instance, RV went to the US and he was from IIT Kanpur.

Furthermore, he mentioned,

> The large scale private firms bring the technology from outside. This is in collaboration with some x, y, or z firms. Other PV firms are operators. Still, Indian manufacturers are unaware of the technologies that they are handling. Chinese and Japanese direct them in handling the projects from erection to production. This is the fact of our Indian PV industry. For instance, the Maruti firm is still in collaboration with Japan. We get some technologies from abroad. Still, our Indian firms are virtually slaves to those foreign firms. In the case of PV industry, the entrepreneurs have little knowledge on the technology. For instance, you ask them whether it is PRN or NRP they get confused. This is one of the reasons that the Indian entrepreneurs' knowledge base on PV technology is weak. Now, it has become a trend that kapada, Dobi and Geyser walla are entering the business of solar energy. This indicates the knowledge base of the PV Indian industry.

One of the entrepreneurs addresses reason to this kind of practice in the Indian context. It seems the government agency requires cost effective technology which also includes their commission and entrepreneurs always expect immediate returns or high profit that ultimately resulted in importing second and third quality PV cells from other countries such as China and Taiwan which ruin the market potentials in India. This discourages the technological adoption in Indian society. Such strategies have resulted in the technological inefficiency that creates a negative impact on the consumer markets. To prove this point further, most of the farmers agreed that the capacity of the PV water pumping technology is not efficient as diesel or electrical water pumping. The efficiency of a technology reduces after two or three years of installation. In most of the cases, either efficiency of a module decreases or other balance of system gets defect. Likewise, some of the government programmes were stopped in the middle due to the technological failures. For instance, in 2002-2004, NEDCAP, in Andhra Pradesh has dropped the programme on providing solar water pumping system at subsidized price to farmers due to frequent technological failures in terms of efficiency and defects in the balance of system. Likewise, the other programme on solar energy lantern has become a failure due to technological defects in the balance of system and sometimes in modules. This has created a social belief that the solar energy technologies are ineffective and has created the conditions of impossibilities for the penetration of technology into the society. The technological inefficiency has severely affected social acceptance of the technology, that ultimately curtailing the growth of the PV industry in India. On the other side, there were no initiatives from the government to understand the technological failures of solar energy. The effective communication between the potential users and R&D institutions was not mediated by the Indian scientific institutions such as Solar Energy Centres.

Lack of Skilled Labour and the Picture of Experimental R&D:

At present, the reduction of cost and innovation of technologies will be the key to success in withstanding in the fierce global competition. However, all the PV firms collectively agree that the reduction of cost depends on the basic and applied research in material science and needs new applications in the technological front. Such scientific knowledge production reduces the cost and improves the efficiency of PV technology. The scientific research is presently focused on the two aspects of R&D in PV technology: (1) the thrust of scientific research is on improving the existing technologies by focusing on efficiency and reducing the number of steps in the process of PV cells and modules to reduce the cost; and (2) the scientific research is also focused on new material developments, especially located at the third generation of solar cells. All the firms in the study agree that they are not part of the above mentioned categories of research and development. The new knowledge production is scientifically possible at the level of cells, wafers and not at the modules. The PV cell is the final product that determines the technological efficiency which requires basic and applied research. Module production requires less scientific solutions and technological capabilities, since the work is based on simple engineering and soldering. It is a process of lamination to get a final outcome of the technology. Subsequently, this eliminates the R&D process which focuses on new material research and enhances the technological efficiency of a PV cell. In addition, the participation of private firms, in new technology development and academia-industry interactions is highly limited in the Indian context. One of the vice presidents from Titan Energy System mentioned:

> We don't have innovation at all in the Indian context. Neither firm driven R&D nor government sponsored R&D though university & institutions focused on the issues of technological innovations of PV technology. The initiatives of PV technology have started in the early 1980s through government initiatives but did not materialize. There are several reasons for the undevelopment of PV technology in Indian context. In Indian PV industry as such there is no innovation at all. The industry is basically driven by low technology compared to other industries such as IT and Bio-Tech. The search for new material results in technological progress of PV. The R&D units are focused on reducing the cost of technology and increasing the efficiency of the cell. The Indian PV industry is neither focused on innovation of the new material, nor it can reduce the cost of the PV technology. Since the Indian PV industry is at the end of the production unit. The module production does not require deeper scientific knowledge production. So, the process is purchasing all the materials from different manufacturers and assembling it. The manufacturing process could be organized by two or three senior technical persons. Hence, the Indian context does not have any in built R&D process.

In the study, most of the PV firms believe that, at present, huge investments in R&D laboratories and new technology developments are only affordable for public sector units such as CEL, BHEL and BEL since, the R&D investments in photovoltaic research are highly unpredictable and uncertain. In this case, the externalities are more due to the unreliable conditions of knowledge productions and conditions of market that exist in photovoltaic industry. For instance, one of the executive directors in a large scale firm reasoned that to increase one percent technological efficiency requires huge investments in terms of basic and applied research in material science. It takes more than a year to produce a scientific result that has the economic viability in terms of industrial applications and takes another a year to commercialise the outcome of the research. By that time, foreign firms may come up with new technology or increase the efficiency of the existing technology. It affects the Indian knowledge production and technology development. In the study, this practice of R&D has become less affordable to the Indian SPV firms, and consequently they prefer to import technology from foreign firms which is much easier than developing. This has become much easier with the advent of globalisation of technology and production. Therefore, the availability of foreign technologies is considered as a viable option for the present market conditions that are available due to subsidized market conditions. The executive director from XL Telecom mentioned:

> It is very difficult to get the economic results from scientific achievements. We cannot afford the R&D investments in PV technology since majority of foreign firms are in the advanced stage of technological innovation. So it will be difficult for an Indian PV firm to start R&D at present. It is better to get the technologies from outside and produce it here.

Nonetheless, some of the PV firms have started their business recently and foreign firms provide the process and product technologies and knowledge that reduce the chance to start the R&D at the very beginning of the business. Most of the firms are less interested in R&D due to the huge cost of initial investments in business and are looking for an immediate return on investments. Therefore, the Indian PV industry is focused more on production rather than on new technology development. This shows that the Indian PV firms may take some more time to catch up with the present technological conditions and innovations that are available in developed countries.

This study also witnesses that only one PV firm has a separate R&D division. It recently started and focuses on experimental R&D. The rest of the PV firms involve in the same experimental R&D without R&D division. The large and medium scale firms focus on two main areas of experimental R&D: one is process knowhow and the other is product development. The small scale firms are much focused on the product development and less concerned about process know-how. Over all, the R&D activities, in the study, involve two faces: First, the experimental R&D at the level of process in the module production; and second, the firms focus on to train the workers to learn, adopt and absorb the technological knowledge. First, the experimental R&D is based on trial and error method. It attempts to know various ways to reduce the process and raw material consumption in the process of production so that the cost of the technology would be reduced without compromising technological efficiency and energy output. It involves various activities such as minimizing the wastage of solar cells, reducing the consumption of the solar cells and space of the module. Any defect in the module affects the technological efficiency, in turn, reduce the energy output and decreases the lifetime. In the study, PV firms believe that experimental R&D would increase the quality of PV technologies and consider as the international and local competitive strategies to survive in the global competition and to get turnkey projects from foreign countries. For instance, large and medium scale firms develop solar power plants for foreign countries and local domestic markets. These firms employ their modules to develop the solar farms. Any defects in terms of technological efficiency and minimal module efficiency would reduce the energy output in the long run.

Finally, it affects the reputation of the firms locally and internationally. So, the firms are more concerned about the quality of the modules being produced. The director of Access Solar mentioned:

> The attainment of quality involves a lot of processes such as inception facilities, requirement of technical labour, training to the employees and labours, advanced production facilities, etc. At present, more manual works are involved in the process of production. For instance, the modules require soldering which are mostly done manually, not by automated machinery. The automation provides consistency in quality achievement, but not the manual work. The Indian PV firms provide cheap labour force for the external market. The firms do integration works rather than anything of manufacturing. Consequently, there is no scope for innovation because we are at the end process of the technology production. For instance, there is no defined research and development as such to improve the quality of the module but the firm does a little experimentation to reduce the cost and wastage of the modules. There are no employees recruited under the heads of R&D but the firm possesses three technicians who completed B. Tech in electrical and electronics. The CS (pseudonym), Vice President of the firm, heads the team in experimentation process. The firm does not have a single patent. The production processes are standardized and integration oriented, therefore, there is no scope for R&D process. Even, the industry-university linkages are minimal, due to the nature of PV industry. At present, the firm has little R&D facilities but is planning to expand its R&D activities in future. The present facilities are not enough to do R&D which needs huge investments and favourable government policies towards innovation. At present, the firm is producing modules which are used for the lantern, street light, and PV pumping systems. Neither India's labour market supply scientific labor to the PV industry nor the industry has R&D facilities to foster the rate of innovation. PV industry has established itself in 1980s, but is still at the nascent stage.

The lack of professionalism hampers the experimental R&D which can connect process and product output. This pushes the large scale firms into the second stage of adopting the strategies of know-why R&D. Large scale firms consider quality as process and product oriented that involves number of steps such as inception of new methodology and instrumentation facilities, to handle the advanced equipment labs and testing and evaluation. It requires two kinds of workers: engineers and technicians. Most of the PV firms agree that there is shortage of skilled labour in Indian PV industry. First, the scientific and skilled manpower is low and the unskilled workforce is employed in the process of module production and product development. Most of the engineers are from other areas such as electrical and electronic, mechanical, etc., and the technicians are from the level of ITI, diploma and higher secondary education. Despite the fact that the requirement of technical knowledge is low at the level of module production, still the firms believe that technical background in the process of production and implementation is necessary. For instance, the PV cells need to be handled with care and any damage in the PV cell could lead to technological inefficiency at the module level. So, the workers are trained to learn the basic knowledge of PV cell and also how to handle the process of production such as conducting PV cell test and sort, PV cell string assembly, module lamination and framing, etc. On the other hand, there is a need for training manpower in solar power plant implementation, which is the need of the hour. Very few people know the construction of scientific and technological properties in PV technology. The low level of technological capabilities in terms of scientific and technical manpower is clearly witnessed when I asked the top management to provide access to the workers for interview. The majority of the firms rejected the idea by saying that the workers come from intermediate educational background and they have little knowledge of PV technology. This shows that the workforce structure is not from specialized engineering studies such as B.Tech and M.Tech. On the other side, the literature on the Indian PV industry lacks data on the socio-economic aspects of PV industrial labour in India. This position would throw light on the education and class background of the employees which could be useful to understand the nature of PV industrial labour' s social configuration in India. Unfortunately such studies are missing in the Indian context. One of the directors from SGE pointed out:

> The Indian PV firms should be focused on the increase of the capabilities and potentials to meet global requirements to sustain in the global market. For this, the trained

> manpower is required at the level of experiment and designing. The large scale firms have favourable capital structure but it is not available with small scale firms. Large scale firms train employees in the process of production but it is very difficult for the small scale firm since it involves huge investments. It will be helpful to the PV firms, if government takes initiatives to train manpower.

To avoid such labour shortage, the large and medium scale firms train employees in the process of production, implementation and the development of solar products. In the study, firms consider that first generation solar cells and modules is one of the most well researched areas in PV science and technology. Any information that is required for the process of production is easily available in various journals, books, and internets. Senior employees such as Vice presidents and engineers attempt to train the workforce to adopt the process and product technologies which are imported from foreign or utilizing the outdated patents for production. This is to address the issue of low technological and innovative capabilities in firms. One of the SEC scientists mentioned:

> At the same time, industry is recruiting labourers based on the experience in scientific laboratories such as SEC, NPL, institutions, etc. It is also indirectly transferring technologies (& knowledge) to the industry. It is because of the underdevelopment of scientific manpower in solar energy. The research and teaching is very limited to particular institutions such as NPL, IITs and some universities. In the case of universities, the primary focus of solar energy is at the level of research and it is meant only for knowledge production. It is nothing related with conversion of knowledge into technologies. Training the labour force requires particular social settings equipped with technologies which is lagging in most of the scientific institutions. The transfer of knowledge from academia to industry through labour force is affected.

On the one side, sometimes the firms recruit workers, who previously worked as project fellows in leading scientific institutions such as Solar Energy Centre and National Physical Laboratory. The firms consider this as knowledge transfer from academia to industry in the form of human resources. However, the small scale firms are reluctant to invest money on training the labours since the cost of training the workers is higher. The need for technicians and skilled labourers has led to the higher attrition rate so the firms are experiencing difficulties in attracting skilled labourers. An Assistant Director from Photon Energy Limited mentioned:

> At present, attrition rates of employees and technocrats are higher in the firm. The PV industry requires more technicians, engineers and workforce to achieve the targets of National Mission Plan and meet international market demands. At present, the quality and the content of workforce is not up to the international standards. One of the major reasons for this is engineering studies on PV technology in particular, and solar energy in general is quite lagging in the field of engineering education in India. The current policies need to address these lacunae to meet the global demands of PV technology and to establish the Indian PV industry on par with industries like pharmaceuticals and IT in India.

On the other hand, except IITs, there are no other engineering colleges which offer courses at the level of B. Tech and M. Tech on solar energy engineering studies. There are no proper courses and specializations in solar energy (PV & thermal) which are offered in the local engineering college of science and technology. This factor severely affects the process of production, experimental R&D and product development at the level of firms. This is one of the biggest lacunae affecting the development of Indian PV industry.

Conclusion:

From what is presented above, it is clearly evidenced that the Indian PV industry is technologically and institutionally dependent. To move up in the value chain, the industry needs to improve its technological capabilities and knowledge-intensive human resources. However, development and transition depend on how Indian PV industry will be nurtured in the future for which effective policies are needed. Though the NSM is at the nascent stage but it can be more effective by improving the Indian laboratory for testing and evaluating to international standards. This would reduce the burden of manufacturers depending upon foreign labs for testing and evaluation. At the same time, the sample firms in the study composed of small and medium firms which have established after 2005.

These firms were emerged to meet the domestic demand rather than foreign market. In this context, Indian NSM policy needs to encourage more off-grid system. As a result of it, the mass market for solar PV technology may emerge in the future and also government should invest money on building technological capabilities and human resources of this industry. Otherwise, industry would be in same like 1980s. This also narrates unlike Western countries, why Indian firms could not effectively engage with academia in new knowledge production. There are two reasons one could emphasize: one is the culture of import; and the other is low capabilities in terms of technology, organisation skills and capital. This locates the Indian SPV industry at the low stage production.

Summary and Conclusion

Through the analysis done in the previous chapters, the study attempted to addresses its research objectives: 1) to know the social practice of solar photovoltaic techno-scientific knowledge production at the level of academic and scientific laboratories in India; 2) to understand the role of government and industry in transfer and innovations in SPV technology; 3) to know the present conditions/status of Indian PV industry and factors that promote or constrain the development of Indian SPV industry; 4) to study how the Indian system of S&T functions in relations to knowledge production, transfer and innovation and What policy interventions are required to facilitate the PV technological innovation in India. To explore the above research objectives, the study employed Mode 2 Knowledge Production as a conceptual framework. To recollect, the Mode 2 Knowledge Production rests on three important assumptions: one, knowledge production is contextualized; two, participation and interaction of heterogeneity of social actors such as industry, academia and scientific laboratories, and government in new knowledge production. It emphasizes on a transdisciplinary mode of knowledge production in which people from different institutions and disciplines interact with one another. Three, policy environment facilitates new knowledge production that provides importance to Mission mode R&D to achieve industrial, consumer and socio-political goals at large. However, the scientific and technological initiatives may come from any of these social actors - academia, industry, government or consumer. In the case of SPV technology in India, majority of the technological programmes have been initiated by the Government of India, which has publically funded R&D programmes, since its inception. The role of industry in funding R&D programmes in SPV technology is negligible. In this context, the study took the basic question of how the Indian system of S&T functions in relation to knowledge production, transfer and innovation in SPV technology.

Innovation is defined as a successful conversion of scientific ideas into a viable economic product/process. It is a process of translation of ideas from one social setting to wider social context. The study illuminates that transfer and innovations in SPV technology to society at large are completely absent and the techno-scientific knowledge production is continued to only at the laboratory level. One can see a larger gap between invention and innovation in solar photovoltaic technology. This creates a disjunction between transfer and translation of ideas from one subsystem to the other. This addresses the important question of why Indian S&T system is not conducive to innovations. With the empirical evidence in SPV technology, the study attempted to articulate factors that play an important role in shaping the technological innovation: 1) context of knowledge production; 2) practice of science; 3) bureaucratisation of science; 4) culture of reward system; 5) culture of import and technological dependency; and 6) policy and politicization of science.

Context of Knowledge Production:

The study indicates that at present, there are two main factors that rejuvenate the development of SPV science and technology in India. One, SPV technology is perceived as an important instrument in mitigating climate change and also contributes to the process of energy securitization. This creates opportunities for the emergence of new sectors such as semiconductor and SPV in recent times. For which, National Solar Mission and Semiconductor policies influence R&D investments, industry and market development programmes, since the global demand for these technologies have been constantly increasing. The policies attempt to encourage Mission Mode R&D to achieve the large socio-political goals of energy independence and securitisation. This is the 'context of application' that stimulates the social condition for new knowledge production in SPV technology.

Unlike the 1980s, this brings the multiplicity of actors such as public research laboratories NPL and NCL, academic institutions IIT Delhi and IIT Bombay, in-house R&D, and private firms like MoserBaer. The participation of heterogeneous social actors leads to the emergence of hybrid community and a transdisciplinary nature of knowledge production in SPV. This shows the changing structure of SPV science and technology in Indian context. However, one needs to understand that SPV is influenced by the West. There are other examples such as Biotechnology, ICT, atomic energy, telecommunication and pharmaceutical that are influenced by the development of Western science. It has become a culture that our science develops when market demand and knowledge production increases in the West. In the case of SPV technology, the neo-liberal agenda associated with climate change protocols influences the developing countries science and technology development. Thus, it increases its global technology development, the rate of techno-scientific collaborations, inter-firm relations, and technology production in the area of SPV science and technology. Hence, the changing structure of science is influenced by global technological collaborations and knowledge production. For instance, various countries in East Asia, the USA, Japan, Germany, etc., have proved the technological viability in photovoltaic. This leads to an increase in technological efficiency and reduction of cost, which made to reinitiate solar energy research in the Indian context. However, it is just a supplementary reason for the reemergence of photovoltaic research; the real context is influenced by the development of other sciences (especially Western) in India. This is influenced by the emergence of new sciences such as Nanoscience and Nanotechnology, a combination of Organic and Inorganic sciences, Quantum Physics, etc. The growth of new sciences and its application encourages Indian SPV scientific community to rethink about the possibility of doing SPV science. In this context, the SPV research is perceived as an emerging area of science in India. Despite these, the scientific community's fear of being disconnected from the global new knowledge production made to consider them as inferior to the practice of science in general. Indian scientists engage with the scientific problem when the particular science gains importance in the global knowledge production. Subsequently, the knowledge production in SPV is shaped by the intellectual and social demands already mentioned here.

The Practice of Science in IITs and Industrial Laboratories:

The technology development started in both generations of technologies in different social settings such as academic institutions IIT Delhi and IIT Bombay, and public research laboratory like NPL. However, the nature of scientific practice varied from academic to public research laboratories. Though IIT Delhi is one of the core institutions for the second generations of amorphous silicon technology, knowledge production is highly limited to publication of papers and training scientific manpower. As it is the same case with IIT Bombay. One has to look within the academic scientific practice of technoscience. To meet the technological and commercial feasibility, synergy between pure science, applied science and technology is required. Majority the scientists are focused on the academic dimensions rather than on the practical dimensions of SPV technoscience. In this regard, rationalized links between pure science, applied science and technology is disconnected.

One of the main reasons is that the disciplinary approach to technological problems was followed rather than the multidisciplinary mode of research. It denotes that the orientation of scientists is highly focused on pursuit of knowledge excellence for its own sake rather than on technology development. Hence, knowledge production is primarily driven by cognitive context and shows the absence of industry-academia collaboration, corporatization of academic research, and scientist-entrepreneur relations in SPV techno-scientific knowledge production. There are two reasons one could articulate. One is that the disciplinary approach to scientific practice was historically nurtured since colonial context, where university is considered the ground for the knowledge production in pure science. Subsequently, the knowledge production in Indian technical institutions is highly limited to laboratory scale and has sidelined the approach focused on converting the technological feasibility into commercial feasibility. However, such knowledge production follows the same methods and problems that prevail in Western journals and markets. The NISTADS report suggests that low quality of publications and poor citation rate in solar photovoltaic knowledge production in India. Second, within this disciplinary approach, limited funding and credit sharing stopped collaborations with other scientists and institutions. It made solar energy a socially isolated form of research that produced the phenomenon of individualism against collective representation of knowledge production in India. Hence, the study observes Mode 1 Knowledge Production as a predominant form of research practice compared to Mode 2 Knowledge Production in India.

On the other hand, NPL focused its attention on technology development as the main objective. The practice of scientific research is driven by the adoption of technology from the West to develop further and use it at the local level as the prime means of technology development. This model of science follows incremental innovation rather than radical innovations. For instance, the real concern is the practice of reverse engineering. Subsequently, it shows that the imitation of others' ideas exist in the Indian scientific practice. To elaborate, the scientists focused on HIT type of solar cells, or developing one square feet modules are the ideas taken from east and west. Though some of the scientists talk about radical innovations in SPV, majority of the scientists focuses on applied science and reverse engineering. In this scenario, new material research, new knowledge and technology development is limited to the incremental innovations in product and process. Majority of the scientists are reluctant to take on new ideas since they believe that it is not an appropriate time to start new ideas in technology development. So the scientists attempted to be within the applied science to meet the market needs. The practice of science is influenced by developing generic scientific and technological knowledge rather than end to end technological products. For instance, technologies were highly limited to specific purpose of applications such as space, telecommunications, remote village electricity programmes, etc. rather than mass commercial applications. This basically determined the nature of knowledge production in public research laboratories. In the due course of time, it developed new technologies in the first and second generations of photovoltaic. Though the achievements of technological efficiencies in both generations of technologies were considered to be of international standard at that point of time, the commercial success was very limited. The real problem was the cost of the technology, and subsequently the research seems to be hindered further. It is mainly the new economic rationality that focused on the law of efficiency, economics of scope, possible ideas for development, etc., which curtailed the further development of knowledge and transfer of knowledge from laboratory to industry. Though the scientists attempt to rectify the further problems in technologies, due to technological defects, it was not carried forward. The optimization of the technology in terms of difference between laboratory and industrial efficiency was considered as commercially unviable. One of the reasons for the failure of technologies at the level of industry is the use of low quality of raw materials to attract the consumer market, which ultimately failed to yield results at the level of commercial applications. Since the cost of the technology is more, it is difficult to reap profits within a short period of time. This practice largely affected the social acceptance of the technology. At the same time, this constructed the notion that commercialization of SPV scientific knowledge as unviable.

Bureaucratisation of SPV Science:

The commercial failures of SPV technology introduced the language of social accountability into research practice. It largely affected the scientific interest on techno-scientific knowledge production in the area of SPV. Subsequently, the authority of SPV scientific community is lost within this paradigm. At this juncture, majority of scientists in academic laboratories have lost curiosity in knowledge production, and in the case of industrial laboratory, scientists were asked to shift to other areas of research such as photo dynamics, safety razors, need based automobiles, etc. This experience provides great insights into social accountability and lack of autonomy of scientists within the industrial laboratory. In majority of the cases, scientists, at the higher order, determine the area and the nature of knowledge production. It is then clubbed with hierarchy of rules in public research laboratory which takes away the individual liberty to pursue one’s ideas. The bureaucratic form of research practice affects the autonomy of scientist and synergy in collaborative research in public research laboratory. For instance, in the 1990s, a majority of the directors at NPL negated the ideas of solar energy as a viable option, since the market demand was less at that point of time. Public R&D expenditure on SPV was substantially reduced which slowed down the efforts of research at IITs and public research laboratories since 1990s.

This has various repercussions in the Indian scenario. Firstly, it witnessed the disintegration of the solar research scientific community and doctoral research came down as well. With this, the advancement in material science research and development of new techniques in production came to the state of rest. The two aspects are clearly witnessed with this social context of science: upgrading the infrastructure and laboratory facilities in industrial R&D was also thwarted; and two, the social production of scientific and technical manpower in industrial R&D was curtailed. For instance, many of the scientists' experience about their doctoral research unfold that how the epistemic culture of science existed in the 1980s and 1990s. This could be witnessed through inadequate laboratory and infrastructural facilities, repeating the same experiments and lack of new knowledge production. Moreover, majority of the students shifted to other areas of science and also went abroad for career development. These all are the main aspects that stopped the development of a solar photovoltaic specialty in India. It literally stopped the social reproduction of culture of knowledge relating to solar energy. Finally the scientific knowledge production and technology development came to a state of rest. Subsequently, the solar energy research became stagnant in India. This phenomenon is largely referred to as a crisis of science and scientists in India by Jairath (1984) and at the Gramicisian ceasarian crisis by Parathasarthy (2011). These aspects attempt to reveal that knowledge production in photovoltaic exist at the same level as they were in 1980s. On the whole, an understanding of the scientists' accounts and experience expose that the new knowledge production in photovoltaic is at the exploratory level and it may take some time to catch up with the international standards.

Culture of Reward Structure System:

There are two factors that make the scientific community prefer publishing papers over technology development: one is the reward structure; and the other is the import culture. Majority of the scientists in the study focused on publishing papers rather than on technology development. It is not only in the academic settings but also in CSIR laboratory such as NPL and NCL. The career development of the scientist depends on the number of publications, which determines the mobility of a scientist in the social hierarchy within the industrial laboratory as well as the academic institution. This creates a social tension, especially in industrial laboratory since the objective of the institution is to develop and transfer technology. However, majority of the scientists are nurtured with the culture of university based knowledge production, which ultimately shapes the research practice. For instance, with the advent of NSM, the recent scientific and technological programmes consider second, third and fourth generations as thrust areas of SPV technology. It is also evident that majority of the scientists from academics and industrial laboratory located their research in the second and third generations. One of the major reasons is that opportunities for publishing papers are higher in new areas of science compared to the former generation of SPV technology. This makes the scientific community engage with the later generations of SPV, though the present reward structure emphasizes patent as a criteria for evaluation. It exposes how a scientist is identified within the area of knowledge production in India. However, there are certain exceptions which prevail in IITs and public research laboratories. Some of the scientists focused on development of new techniques and have also patented them. But these techniques and technologies were hardly transferred to industry since majority of the inventions were process technologies. For instance, scientists Chetan Singh and Anil Thotanthariyal from IIT Bombay produced patents in the areas of SPV technology, but these are not transferred to the industry. On the other hand, from NPL, the first generation group has transferred SPV cell technologies to the public sector unit – Central Electronics Limited, but cases are very sparse. This is primarily because the culture of import stops transformation and translation of technologies. This seriously limits the research at the SPV cell and wafers technologies, since very few firms (except public sector firms) exist at this level in India. Likewise, majority of the research focused on cell rather than on modules and SPV technological system for which there is no firms to take those technologies.

Technology Import Policies, Import Culture and Technological Dependency: Reasons for the Limited Academia-Industry Interactions

One of the important reasons for the lack of linkages between laboratory and industry is that units in SPV industry are located at the end stage of production as module and system integrators. Basically, the entrepreneurs of Indian SPV industry are traders in the market, which predominantly depends on the import technologies from East Asian countries to meet the domestic and export demand. Due to the lack of a domestic market, a majority of the SPV module firms focused on external market, especially Europe for which these firms function as cheap modules producers. Only a few firms exist at the level of polysilicon, ingot, wafers and cells. Subsequently, very few PV firms are involved in end-to-end production chain in photovoltaic industry, which increases the cost of the SPV technologies in the local market. This creates a technological dependency in India. Consequently, this social condition (as it seems to be) results in joint ventures and technological tie-ups with foreign firms. However, the nature of tie-ups and trade agreements are underexplored in this study. Simply put, the globalisation of technology provided room to dump cheap PV technologies in the Indian market which not only destroys the PV market and but also creates a low social acceptance of PV technology. For instance, concession to import PV cells and modules from foreign countries limited the industrial participation at the last stage of production rather than encouraging it. That the Indian manufactures recently attempted to give voice against this dumping practice is noteworthy to mention in the conclusion.

On the other hand, the technological dependency creates vulnerability to frequent changes in the prices of SPV technologies such as Wafers and cells. It reveals the oligopolistic control of world PV industry since a very small number of large corporations holds the patents (Patent Report, 2008) and productions of solar technologies. For instance, the development and transfer of new technologies were also affected by the two factors: firstly, the patent procedures delayed the acceptance of invention that ultimately ruined the economic potentials of PV technology; and secondly, the dynamic international competition in terms of technological innovation crashed Indian technology development in public sector. Subsequently, the corporate head office have asked the R&D management to reduce the R&D efforts after the technological innovation crashed in international market and thereby stopped the research. Therefore, importing technologies is considered the best option. For this, the patent system acted as a hindrance to indigenous R&D efforts. It is not that industrial R&D efforts are unsuccessful in producing economically viable technologies. Because of the above mentioned reasons the mass production failed to take off in the Indian context.

Since the 1990s, liberalization of technology import policy has engendered a culture of imports which affected the private firms' collaboration with academia in knowledge production. However, earlier there were many instances that prove the development of technologies and the transfer of the same. But this was limited to first generation of technologies compared to the second generation, since none of the PV firms (public and private) started production in second generation of technologies then. So the developed technologies remained within the laboratory. Subsequently, majority of scientists felt that the availability of very few firms and the limited market would not encourage the efforts of technology development in academic and public research laboratory. In this context, industry funding academic research in photovoltaic is almost limited to the public sector units such as CEL and BHEL. It has become a strategy where demand decides the nature of knowledge required in solar energy. This is one of the foremost reasons that thwarted the industrial R&D and the subsequent transfer of technologies to industry. However, BHEL and Moser Bear are a part of the technology development programme initiative in Indo-US solar PV technology development, there are very few initiatives happening at the level of first generation PV. As a result, the knowledge production, at the level of first generation as well as doctoral research, is on the decline in India. It has two implications: one, this further widens the gap in interaction between Indian SPV Industry and academia; and two, there is a shift in the knowledge production and technology development from first to second and third generations.

Lack of Quality Human Resources:

Likewise, majority of entrepreneurs and directors are from non-PV technological background. In that case, the knowledge base of SPV industry is highly limited and technological capabilities such as technical skills, knowledge and management/organizational skills are at the nascent stage. An unskilled workforce employed in the industrial production of photovoltaic at the modules level. Due to weak labour and technological backwardness, the PV industry faces a huge competition from China and other East Asian countries. It shows that the lack of training and teaching programmes in photovoltaic, lead to the low level of technical and scientific manpower in India. Now it is one of the major lacunae in the process of experimental R&D in PV firms. While the large scale firms are ready to invest money in training the labour power, the small scale firms are unable to invest money in labour training programmes. Though Indian PV firms are relatively backward in terms of technological capability and capacities, the large scale firms are highly focused on the aspects of quality to ensure the survival in the global competition. But most firms are reluctant to invest money in training since it increases the cost of production. Without innovations and technological capability, Indian PV industry is focused on the export market. Moreover, import technologies reveal the present social condition in which the industry exists. All these factors show the nature and the factors that curtail development and the growth of Indian PV industry in India. Overall, the scenario of the science and industry development affected the technological innovation in photovoltaic in India. These are things which affected the translation and transformation of ideas from the laboratory to the industry. The industry and the academia act separately in Indian context, which is evident from the present study. However, the study revealed a need based R&D collaboration between academia and industry. Mostly, it was to get consultation services, training labors and testing modules were provided importance rather than new technology development.

Policy and Politicisation of SPV Science in India:

The political construction of SPV technology unfolds the other side of the reasons for the retarded development of SPV technology in India. The oil crisis has been a predominant factor for political commitment and for political decision on the solar photovoltaic. It has determined the practice of science and has reduced the consciousness of technology development once crisis was overcome. One could say that the political choices and decision are shaped by the external factors of "compulsion" and an internal factor of "urgency" in the form of energy needs. Thus, "compulsion and urgency" becomes the politics of policy in SPV technology in India. This leads to the discontinuity of scientific practice, technology development and funding in photovoltaic. There are three ways in which one could see how the choice of political decision and policy for SPV was affected, which made SPV as a "neglected science" in India.

First, science policies provided more importance to atomic energy and fossil fuel energy compared to renewable energy. Though Technology Policy Statement (1983) and Science and Technology Policy (2003) provided importance to energy efficient technologies and renewable energy, there is no specific approach provided to SPV industry and technology development unlike the IT industry in India. By considering the argument from Dr. Homibhaba and Dr. Kosambi, the study reopens the new avenues of science debate between "Nuclear Technology and Silicon Technology" in India. The science-politics nexus provided much importance to Nuclear technology compared to Silicon technology.

This shows how Indian innovation system is shaped by the historical forces of intellectual arguments of elite scientists and politicians in India. These contributed to the politicization of SPV technology in India. Unlike East Asian Countries such as Taiwan, Korea and Japan, India failed to understand the strategic importance of silicon technology in particular and photovoltaic in general and as a consequence failed to focus in this area. There is no effective S&T policy to link these two sectors (semiconductor and photovoltaic) of one technology called Silicon. There are two factors emerged: a) the underdevelopment of semiconductor and micro-electronic industry; and b) the backward integration of raw material productions in polysilicon and the R&D investments are particularly affected. The economic cost of the SPV technology would have reduced, if mass production was organised from silicon processing to SPV technology system in India. Thus, we are in the stage of technological dependency in SPV technology. At this juncture, the study raises an important question of how can technological dependency in solar photovoltaic contribute to energy securitization programmes in India. The dependency and securitization never go hand in hand. What is happening right now is import of technology which will make India as an energy surplus country. This is almost equal to the import of fossil fuel to meet the energy needs of the country and hence, energy dependency still persists in India. The study emphasizes that the technological self reliance is essential for energy independency and securitization, without which, claiming India's energy independence shows the National Solar Mission Plan's political rhetoric.

Finally, the developmental objectives of the Indian S&T policy are to take science to the public– but the Indian scientific institutions did little in the area of energy independence and securitization. The source of power production is relatively low and we still depend on foreign technologies in solar and nuclear energy. Sagar (2004) argues that the industrial and technological capabilities of the Indian energy sector are in an underdeveloped state. Despite the energy R&D since independence, the contributions of Indian R&D to the energy sector have been negligible in addressing the various technological issues of the Indian electricity system such as T&D losses, energy efficient technologies, etc. At present, these issues are highlighted in the discourse on energy crisis in India. This indicates the lack of consensus among science, technology and innovation policies on how to nurture indigenous technology and industry development, hampered the translation and transformation of ideas from laboratory to industry.

One can see the repercussions of these lacunae at various stages of SPV technology development. One witnesses inadequate infrastructure and laboratory facilities in photovoltaic and semiconductor in India. For instance, a few international standard laboratories for testing and evaluating SPV technology exist, though Solar Energy Centre only functions as a testing laboratory for photovoltaic. Further, the weak scientific and technical manpower lay a constraint on providing value added services and also provides an ineffective link between R&D and industry. This problem further culminated with public policies on teaching and training programmes in photovoltaic. Unlike IT, Biotechnology and Pharmaceuticals, India failed to develop human manpower in the area of solar energy in particular and renewable energy in general. As mentioned above, there is a shortage of scientific and technical manpower at present. However, the recent initiatives such as NCPRE in IIT Bombay, new Training programmes in SEC, and Centre for Excellence in Solar Energy at IIT Jaipur are limited to certain parts of the country.

Second, the civil society's appropriate technology movement opposed the idea of solar photovoltaic in energy programmes. Earlier in India, SPV technology was considered as elitist and Western, since, it comes under the market paradigm and the control of technology exists with industry. For which, huge investments and enormous energy consumption are required to start mass production from the silicon processing, which could lead more exploitation of natural resources or would encourage the import of technology from the West. Both these considerations in terms of social and cultural values contradict the concept of intermediate technology and nature-culture interaction. This produces the argument that in the name of restoring ecological system, one cannot reap economic benefits and commercial gains. In this context, new solar power plants projects are opposed by civil society movements, since these create twin subsidy programmes and also the middle class became the victim of National Solar Mission Plan. The photovoltaic technology is perceived as a market good as opposed to public good. This attitude of civil society organisations affected the social acceptability of knowledge production in solar photovoltaic and demand for technology also substantially reduced. So, the role of civic movements played a minimum role in fostering technology development in photovoltaic (Barabara *et al.*, 2009) and much of the focus was given to biomass, solar thermal, and wind technologies. Subsequently, SPV technology did not get social and political consideration in India. In this regard, the role of sociologist and the civil society's approach is limited to a particular problem we encounter in our daily life. They did not think about the broader idea of how a particular technology like silicon and photovoltaic could contribute to the larger political economy of a country like India, which suffers from dependency. Unlike India, in Germany, the green movements and political parties like the

Social Democrat nexus enforced various laws in favour of renewable energy and led to the formation of Eurosolar. These factors encouraged policies in favour of Solar and Wind energies and introduced various laws such as Feed in Tariff and Renewable Energy Sources Act in 2000. Like Germany, various programmes, in Japan based on subsidy, were effectively adopted by the consumers. For this, the construction industry and solar PV industry came up with tie-ups in fostering solar energy technology at the grassroot level. With the mass production, the cost of the technology is also reduced and slowly paved the way for the diffusion of SPV technology. This has successfully reduced the fuel dependencies. However, the success stories of SPV in India at the grassroot level are very few like SELCO and Aryavartt.

Third, the energy sector is dominated by giant public sector units and subsidy based programmes undermined the diffusion of technologies at the grass root level. For instance, Renewable Energy Purchase Obligation (RPO) and National Tariff Policy are yet to be implemented effectively in various states in India. Under this larger technological system, the solar energy is eliminated from being a part and parcel of scientific culture and society. As a result, India is at a state where it lost its predominant position in the area of mono-crystalline technology. In this context, once again SPV scientific knowledge production and technology development becomes one of the hot areas of science in India. It has been kept outside of the ambit of energy policies since independence. However, the real problem is the nature of funding. Like the previous context, solar energy is just a part of the larger energy programmes in India. Since energy securitization is considered as a part of the economic development process, so the government invests in all forms of R&D in energy technologies. A considerable skepticism prevails over the development of other cost-effective clean energy technologies. In that case, the SPV technology would be an option, if other technologies develop faster than solar. On the other hand, some scientists claim that MNRE has reduced the duration of funding from seven to four years, hence the scientific community has also reduced the research targets simultaneously. A similar sort of experience is witnessed in in-house R&D in India.

Lacunae of National Solar Mission Plan:

At present, NSM provides more importance to grid connected SPV power project compared to the off-grid market. At the same time, the SPV firms find it difficult in phased manner of encouraging grid connected SPV power projects. Along with this, the other subsidy programmes on diesel, kerosene and electricity affect the growth of the SPV industry. In this regard, the study reassures Barabara's *et al*., (2009) argument that focused on the state as regulator and also a participant in the programme on solar energy technology development. It shows the market as a social structure and how such a structure is controlled by state monopoly.

On the basis of analysis of relevant data, the study concludes that Indian energy sector is controlled by large-scale public sector units (PSUs) and private firms dominate the energy market backed by the public policy. Absence of equal emphasis on solar energy, led to resistance against extensive adoption of solar-energy technologies by households (off-grid systems). A narrow market base is confined to elite social groups in urban areas and NGO based in rural spaces and which, affects the emergence of a domestic mass market in India. Further, public policy on the energy sector tended to favour conventional and other sources of energy such as nuclear, discourages local firms from further investments in the development of wafers, cells and module productions. In this context, the demand created by National Solar Mission is considerably low and more oriented towards a centralised mode of power production. It undermines attempts to create mass market in India. Due to unreliable external market and policy conditions, the manufacturers, especially small scale manufacturers depend on the local market. The constraint imposed by local market may hamper the development of small PV module manufacturers. As a consequence of negligible up—stream R&D and vertical integration, Indian PV firms confine themselves at the end-stage of the module production. This socially and technologically locked-in position has two implications for the Indian context: one, it undermines the growth and development of infrastructural inter-linkages between various stages of production. This makes Indian SPV firms dependent on foreign firms for raw materials and technologies forever; and two, it may curtail indigenous technological development and capabilities that ultimately affect the transition and growth of the Indian PV industry. Subordination of Indian PV industry to foreign firms in the area of knowledge production and technology development would affect India's quest for technological self-reliance. On the other hand, this dependency creates debt-crisis situation for Indian PV firms since the technological innovations are moving at a faster phase globally. The Indian PV firms' competitive strategy depends on the cost advantage and is not based on the innovation capabilities. So it is necessary to upgrade the technological competence to meet the international competition. In this context, the small scale firms are unable to invest money in training workforce at different levels and feel that the vertical integration is uneconomical. These act as constraints for the development of technological capabilities in Indian PV industry. It is clearly evident that the validity and success of Indian PV industry depends on the demand in the domestic market based on off-grid and on-gird systems. The current scenario, dominated by non-renewable energy producing actors, has to be regulated in terms of minimizing subsidies and investments in conventional sources of energy production; to reemphasize that substantial investments have to be made in creating scientific and technical manpower and R&D laboratories to develop solar energy technologies indigenously. Second, there is need for integration of all the government programmes under one head to create the mass market for solar energy products. Otherwise, the new institutional intervention on the solar-energy programme in India will become a mere political rhetoric without a goal-orientation towards mitigating effects of climate change through sustainable development. In this sense, the sustainable development is once again constructed under the politics of crisis – politics of compulsion and economic urgency. At present that, solar energy is as an appropriate technology is part of the language game in the politics of crisis management (oil crisis and climate change). In the context of adhocism of the policies, it is very difficult to institutionalize the notion of sustainability and inclusive development. Thus, one could see the large gap between science-society relations in India.

Elements of Mode 2 Knowledge Production in India:

- There are elements of Mode 2 Knowledge Production but one can see variations in terms of knowledge production and scientific practice in India. For instance, though the recent scientific and technological initiatives provide importance to transdisciplinary mode of knowledge production, the grass root evidence proves the individualization in research practice. It is purely driven by cognitive context and disciplinary in nature. In short, individualistic ways of working, dispersed intellectual resources and slower pace of collective scientific advancement are reflected in the area of SPV technology. As a result, the heterogeneity of actors participation in production of new knowledge is very low in the Indian context.

- Knowledge for excellence gets due importance rather than knowledge for application. The curiosity oriented knowledge production fetches social recognition and esteem among the scientific community. This social interest determines a research agenda. At the same time, career growth of a scientist depends on the number of publication rather than on patents. This institutional norm governs the practice of science in India, though there are feeble changes witnessed in terms of including patents in promotion.
- With regard to the context of knowledge production in SPV, the contexts (oil crisis and climate change) of application predominantly played a vital role in setting research priorities and goals. But such initiative gets diluted once the crisis reaches the normalcy. In the sense, the market mechanism determined the demand and choice of a particular technology rather than the notion of energy independence. The study reassures the notion that the viability of science is influenced by the notion of commodification of science. This is irrespective of the space (West or East). Hence, the market mechanism and commodification of science influence the national character of science and technology. This affects the grass root innovations and the demand for a technology from rural areas in India. The SPV technology could have been a developmental tool in terms of production of decentralized energy. However, SPV technology as a national advantage and commercial gain undermined with the discontinuous knowledge production.
- The study clearly evidenced that irrespective of academic and industrial laboratory scientists are socially accountable for the research practice. This accountability is enhanced

with the aspect of quality control in terms of efficiency, cost and return on investments. These aspects act as a social control over scientist and his or her knowledge production.

- Given the dependence on import of technology, indigenous Mode 2 Knowledge Production does not seem to emerge as the policy on import of technology has been liberalized over time. Subsequently, the SPV industry participation in production of new knowledge is being affected in the Indian context. However, there are no appropriate policies that facilitate industry-academia interaction in SPV technology. The weak institutional setup and infrastructure push Indian SPV industry to look outside for technology. The ability to engage in research and utilize the existing knowledge is slowed down, and Indian SPV firms literally have little abilities to participate in the international production and innovation. With the advent of globalisation of technology, Indian SPV industry and knowledge production has become the victim of such a process. Thus, inequality exists in the Indian national system of innovation.
- With regard to science-society relations, the social dispersed knowledge in the form of civil society organisations just oppose the idea of taking SPV technology to the public, since it reproduces market relations, in the name of restoring the ecological system. At this juncture, the entire framework of National Action Plan on Climate Change is being criticized for biased articulation and emphasis only on energy rather than understanding what is the real problem of the Indian society. Here, the manifest gap among science, state and society are clearly evidenced.
- Finally, the study concludes that Indian knowledge production exists in Mode 1 with the little shades of Mode 2 Knowledge Production. This national character of science

represents distinct identity compared to the experience of European science and technology.

Policy Suggestions for Photovoltaic Technological Innovation:

1. The need for effective policies is required to stop importing PV models, cells and PV systems from foreign countries. It stops the industry from developing indigenous capabilities and the local industry and technology development will come to a standstill, once the imported regime takes the market positions.
2. To develop indigenous Indian PV industry, there should be a clear policy regarding the extent to which the first and second generations of PV technologies in power project have to be employed. However, this is not enough. The policy should clearly indicate that second generation technologies are allowed to import necessary components when there is scarcity at local, but it encourages monopoly in Indian PV industry since very few firms are located in thin film technologies. Equal emphasis to start thin film production needs immediate actions. Along with this, there should be market limitations for thin film technologies.
3. Government should encourage backward integration of PV technological production for which one need to take PV and semiconductor sectors as more complementary rather than separate areas. They have to be integrated so that the cost of the technologies would come down when there is end to end production chain. It also encourages the semiconductor industry in India since it failed to take off with the semiconductor policy since 2007. The new National Electronic policy needs to incorporate the complementarities.
4. More R&D interactions and collaborations between industry and academia are required at various stages such as polysilicon, wafers, cells, modules and PV systems. One needs to

have different mechanisms for interactions at different levels so that the complete chain of PV technological production will be integrated in into the frame of academia-industry collaborations. It benefits all the manufacturers in the value chain.

5. The immediate upgradation of scientific laboratories and infrastructure is the need of the hour. The Government should take immediate steps to build scientific laboratories for testing and evaluation according to international standards. Converting SEC into Centre for Excellence partly satisfies the task but training scientific manpower, introducing doctoral research programmes, and recruiting retried eminent professors in the area of photovoltaic makes the culture of research vibrant.
6. Market is a social structure which needs to be regulated through price mechanism so that a particular product can penetrate easily. There is a need to reduce the rate of subsidy and consumption of imported fuels so that the PV technology would easily penetrate into the rural areas. It is highly important to diffuse the technology at grass root levels which is possible only by limiting the centralized distribution system.
7. The greater emphasis should be given to the decentralized solar energy distribution rather than centralized version of distribution. It effectively encourages mass market.
8. Teaching and training programmes needs to be diffused across all level of technical education ITI, Diploma and engineering studies at the national and regional levels so that the number of scientific and technical manpower will be increased to provide adequate human resources.

Limitations of the Study:

I was unable to collect data on the nature of funding and duration of scientific projects funded to academic and public research laboratories. When I enquired about the status of funding in MNRE, the administrators declined to provide the same due to reasons best known to them. This could be an authentic source of facts in R&D investments relating to R&D energy sector in India. Moreover, most of the patents were not transferred to industry since majority of the firms exist at the end stage of production. So, the present study unable to analyze the nature of technological patents that scientists in the sample of the present study invented and also transferred to industry, if any. Likewise, I also attempted to collect the information on in experimental R&D but none of the firms gave the actual cost incurred so the study dropped the idea of including cost of experimental R&D in firms. Consequently, the study assumes that very few firms attempt to invest on R&D, except large scale firms, which invest in the technological adoption process.

Future Implications of the Study:

Solar photovoltaic is one of the emerging areas of research in sciences and social sciences. Unlike Western society, in India knowledge production in the area of solar science and social studies of science in photovoltaic is relatively minimum at present. One needs to consider various aspects of solar energy technologies such as thermal, CSP which receive minimal attention. Future studies must have interdisciplinary orientation involving social studies of science, technology and innovation to bring out the significance of solar energy for achieving self reliance in energy production, energy securitization, empowerment of marginalized group and gender equality. The innovation system in solar energy must be participatory in nature involving all stakeholders. Even though, the present study attempted throw light on these aspects, but it just explored the surface. We need scholarly attention to these emerging areas from social studies of science, technology and innovation studies.

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INNOVATIONS IN SOLAR PHOTOVOLTAIC (SPV) TECHNOLOGY IN INDIA: THE MODE 2 KNOWLEDGE PRODUCTION PERSPECTIVE

SYNOPSIS

DOCTOR OF PHILOSOPHY

IN

SOCIOLOGY

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Innovations in Solar Photovoltaic (SPV) Technology in India: The Mode 2 Knowledge Production Perspective

Synopsis

Introduction:

The present study attempts to explore the factors impeded the production of techno-scientific knowledge and subsequent transfer of technology to industry. India's major challenge is how to take science to public / science to industry. This undermines the interface between science and industry, irrespective of various scientific and technological initiatives taken by Government of India. One of the major reasons is that majority of the scientists in India focus only on knowledge aspect of technology or attempt to engage within knowledge for excellence. For instance, NISTADS report suggests that the nature of funding to extramural R&D is located at the thematic and academic level compared to innovations (Abrol *et al*., 2008: 52). In fact, such engagement neither put us on the top of the world of science nor produced innovations, when we compare the ranking orders of publication, citation rate, achievements in the diverse field of science and innovations with other developed and developing countries. Though this reflection should be taken as an insight before exploring the field of science and technology in India, it is an important vantage point to engage with the question of what factors hamper the idea of taking science to public / industry. The present study attempts to answer this question specially, though many studies commented, criticized and exposed the nature of relationship that exists between science studies and science policy in India. However, this study takes similar point of entry to explore the unexplored area of emerging technology called solar photovoltaic in India. With the climate change and resources constraint, under the institutional framework on National Action Plan on Climate Change (NAPCC) – National Solar Mission (NSM) nurtures solar energy technologies in which solar photovoltaic plays a predominant role. Subsequently, solar energy as an alternative energy resource is employed as an instrument to mitigate climate change and resource constraint. From this backdrop, there are three different points through which one should approach the area of solar photovoltaic in India: *one*, the context which makes India to take initiatives on SPV technology; *two*, tracing the trajectory different phases of the SPV technology in India; and *three*, problems associated with academia-industry interactions in India. Based on these points, the study has described the story of solar photovoltaic in India by employing the Mode 2 Knowledge Production perspective.

Exploring the Literature:

The *first chapter* of my thesis explores the literatures in two areas: *one* deals with the social studies of science and technology in energy in India; and *two*, the study understands the conceptual framework of Mode 2 Knowledge Production and how it applicable in the Indian context. *First review* attempts to locate energy studies in India from sociology of science and technology perspective. Such attempt exposes that the contributions from sociologists of science and technology to the area of solar energy is minimal. However, the study tried to collect the literature pertaining to solar energy by employing the method of content analysis in various Indian and international journals for which, the key words of solar and renewable energy in India were used. The study organized social studies of energy studies under three main sub-headings: *firstly*, energy as a technocratic project; *secondly*, public engagement of science in energy falls within two categories; *a)* is about the emergence of new energy movements; and *b)* is about questioning the appropriate technology. These two categories of public engagement of science describe the nature of struggle persist against the state development programmes on energy and how civil society wants to change the energy sector by incorporating renewable energy into the mainstream paradigm of development. *Thirdly*, it talks about the emergence of new epistemic community and interest group, which encourage solar energy as an appropriate technology. Unlike 1980s and 1990s, the scientific community and industry association are coming forward to enforce the government to take initiatives on solar energy. With this review of literature, the study understands that there are very few studies focused on examining the social practice of techno-scientific knowledge production and subsequent transfer of knowledge and technology to industry relating to SPV technology. This study is an attempt to do the same.

The *second review* understands the Mode 2 Knowledge Production perspective (Gibbons *et al*., 1994; and Nowotony *et al*., 2001 and 2003), to explore the issues associated with new knowledge production and subsequent transfer of knowledge and technology to industry. As a conceptual framework, it examines the context in which different social actors come forward to produce new knowledge and attempt to show the changing nature of knowledge production. Subsequently, it talks about the transdisciplinary, hybrid community and socially dispersed forms of knowledge production in which innovation occurs simultaneously rather than in isolation. Though, this framework was constructed with the experience of Western (especially European) science, still is appropriate to employ it in the Indian context by considering three aspects: *a)* context of knowledge production; *b)* policy environment; and *c)* commodification of science. Overall, Mode 2 Knowledge Production perspective is located at the intersection of science studies and science policy studies (Harding, 2008: 76). Further, the study also reviews the pertinent issues involved in techno-scientific innovations in India. As a result, it explores three areas in an in-depth manner: *1)* academic practice in Indian scientific knowledge production; *2)* Indian S&T policy and its socio-political critiques; and *3)* industry-market interactions. Understanding these areas unfolds that there are minimal interactions between academia and industry in fostering technological innovations. There are three reasons one could articulate for low level of interaction in techno-scientific innovations: *first*, is about isolated knowledge production in Indian academia and scientific laboratories; *second*, import of technology from abroad by industry and collapse of local technology development programme; and *third*, lacunae in government policy to bring different social actors together in new knowledge production. Through this understanding, one can explore the science-society relationship and also strengthen the argument for Mode 2 knowledge production from developing country's science and technology point of view. Unlike Western countries, the new knowledge production is weakly rather than strongly contextualized in India.

Locating the Problem and Methodology:

The *second chapter* attempts to know the successive generations of SPV technology and industry structure to locate the problem of the study and methodology. This shows that the Indian SPV industry is located at the end stage of production: as modules and system integrator. Vertical integration in SPV industry lacks in India. This creates technological dependency and subsequently, encourages the culture of import. Exploring the reasons for the culture of import reveals four intersecting points: *a)* lack of technology development; *b)* lack of industry development; *c)* failure of market development programmes; and *d)* political factors and policy lacunae. In Indian context, none of the studies attempts to explore the reasons behind the lack of technology development and, subsequent, transfer of knowledge and technology to industry. From the Mode 2 Knowledge Production perspective, the study is an unpretentious attempt to answer the following research questions.

- *How the techno-scientific knowledge relating to solar photovoltaic is socially produced and practiced in academic and scientific laboratories in India?*
- *How Indian SPV scientific community understands the role of government and industry in promoting techno scientific innovations– technology generation, transfer and commercial production of SPV technology?*
- *What is the present status of Indian SPV industry in relating to technology generation? What are the internal and external factors that promote /constrain the development of technology in Indian SPV industry?*
- *To what extent we can use the case of SPV technology to understand Indian system of S&T functions in relation to knowledge production, transfer and innovation? What policy interventions are required to facilitate SPV technological innovation in India?*

Objectives of the Study:

- *To review the literature associated with the issues of technological innovation in India to gain a comprehensive understanding and a holistic perspective of how Indian SPV techno-scientific knowledge production and SPV industry is embedded in the present context of globalised production and innovation.*
- *To examine the context/s in which the debates on solar energy have been taking place to know the factors stimulate scientific and technological initiatives in solar photovoltaic in India.*
- *To understand trajectory of SPV technology development in India by focusing on the relations among S&T policy, entrepreneurial development, SPV techno-science and adoption of SPV technology.*
- *To know the factors that govern the techno-scientific knowledge productions related to solar photovoltaic (SPV) technology in India in an attempt to explore how do (or did) these factors curtail/curtailed the technology development and transfer of technology from laboratory to industry.*
- *To understand the SPV industry structure, functions and its relations to SPV technological innovation and to examine the factors curtailing the productions of PV technology.*

Argument of the Thesis:

The present study attempts to explore the factors that curtailed the techno-scientific knowledge production relating to SPV technology, to argue that there is intense relationship exist between science studies and science policy studies. With this insight, the study exposes the politics of techno-scientific knowledge production that are largely shaped by the context and has made SPV science as "*neglected science*" on the name of cost.

Methodology:

For this purpose, the study selected the academic and scientific laboratories which are involved in techno-scientific knowledge production. The study eliminated University as a social setting that focuses only on knowledge aspect of technology and the development of human resources (Joseph and Abraham, 2009). Consequently, the study has collected data from 40 respondents under four different social actors: First, public R&D institutions such as National Physical Laboratory (NPL), Delhi and National Chemical Laboratory (NCL), Pune; second, technical educational institutions such as IIT Delhi and IIT Bombay; and third, the in-house corporate R&D (BHEL), Gurgaon; and government controlled R&D Solar Energy Centre (SEC), Gurgaon. Except NCL, the rest of the R&D and academic institutions have been dealing with development of solar photovoltaic technological innovations in India since 1980s and 1990s. This would bring continuity and discontinuity in techno-scientific knowledge practice in SPV, but also attempt to understand the emerging of new structure of innovation. Apart from this, the study also collected data from 12 respondents in various SPV firms located at Hyderabad to know the Industry perspective on SPV technology and also factors constraining industry development. As part of this process, the study also included the consumer category to know the performance and efficacy of SPV technology that are produced in India. Likewise, the study interviewed two government officials one of whom has office at MNRE and another in NEDCAP, Andhra Pradesh. Further, the study interviewed two NGO activists who are engaged in the area of energy. Hence, the study manifestly employed the technique of triangulation to increase the credibility of the study. Multi-dimensional views strengthen the reliability of this study. Finally, the study employed discourse analysis to know the themes and meanings associated with the practice of techno-scientific knowledge production in solar energy. This unfolds the continuity and discontinuity in the practice of solar science and technology that curtailed the development of technological innovations in India.

Contextualising Solar Energy in India: A Critical Understanding

The *third chapter* of my thesis explores the socio-political contexts which led to the emergence of SPV technology initiatives in India: one is oil crisis and the other is climate change. Such understanding of the contexts reveal how science, energy and development are related to one another in India; and how SPV technology has always been influenced by the external force of compulsion (oil crisis and climate change) and internal force of urgency (energy securitization). Thus, "***compulsion and urgency***" become part of the SPV technology development programmes. One can see two phenomena are clearly evidenced from this: one, as part of the energy securitization programme, solar energy is incorporated into various scientific and technological initiatives like other energy programmes such as nuclear, coal and hydro. Two, unlike 1980s and 1990s, innovations in solar energy technologies become an instrumental means to achieve the larger agenda of developmental needs. At present, this brings the different social actors into the process of new knowledge production in India through the new scientific and technological initiatives on National Solar Mission Plan.

Tracing the Trajectory of SPV Technology Development:

To locate the study in a historical context, the fourth chapter of this study attempts to understand the trajectory of SPV technology in India. This provides solid background to know how solar initiatives were emerged and how it is sidelined in the process of development. Although India has a long standing history on the development of solar energy technologies the production capacities and market penetrations are relatively low since the beginning. So, the objective of this chapter attempts to understand how scientific, technological, social, economic and political factors influenced and shaped the development of SPV technology in India. The issues unfolded by different phases of photovoltaic technology development are as follows: first, science-politics nexus in shaping photovoltaic industrial R&D and energy approaches (1947-1970); second, socio-political context of oil crisis led to the formulation of new technological programmes, initiatives, as well as the factors that disintegrated the solar energy programmes (1970-1991); and third, how the era of economic reforms and globalisation of technology undermined the development of photovoltaic science, created culture of import, and also provide reasons for the failure of market development programmes in photovoltaic (1991-2007). Consequently, India is in a stage where it virtually lost the technology development in photovoltaic. Fourth phase, with the regime of climate change and resource constraint, India reformulated the massive National Solar Mission Plan (NSM), under the National Action Plan on Climate Change (NAPCC) (after 2007). The chapter, then, discusses some of the issues emerging with the implementation of NSM and how it shapes the indigenous technology development in photovoltaic. Finally, the chapter concludes that the understanding of technology development in solar photovoltaic unfolds two intervening factors: one is the "***continuity of resistance***"; and two, is the "***resistance to continuity***". The "*continuity of resistance"* indicates the factors which prevent the development of the SPV technology whereas the "*resistance to continuity*" indicates breaking the resistance against the SPV technology and attempting to develop and use it. Though it made technology development in photovoltaic as continuous discontinuity, but it largely reflects the different facets of SPV technology. With this socio-historical account, the study empirically understands the social practice of techno-scientific knowledge production in SPV and subsequent problems in transfer of knowledge to industry.

Major Findings of the Study:

The study attempted to connect the historical context with the scientists' social practice of techno-scientific knowledge production in SPV. Consequently, from the actors' point of view, the fifth chapter attempts to discuss the rise and decline of solar photovoltaic techno-scientific knowledge production and technology development in India. It gives emphasis to the period from 1980s -the implementation of various technological initiatives and research programmes in solar energy to the period of announcement of National Solar Mission plan in 2008. It illuminates the light on how techno-scientific knowledge production is socially practiced in academic and scientific institutions, and what happened to the techno-scientific knowledge production in the area of solar photovoltaic. It rests on five factors that are narrated by the SPV scientific community in India: 1) economics of knowledge production explains the close relationship between science studies and science policy in SPV technology; 2) study reflects the culture of knowledge production in terms of disciplinary approach, publication and persistence of individualism in research, and culture of import and limited funding led to the shift in knowledge production to other areas and also provide reasons for the decline of new specialization. In that sense, how disciplinary form of knowledge production limited the knowledge development in SPV technology; 3) low level of academia-industry interactions expose the lack of new technology development initiatives; 4) the patent regime destroying the indigenous technology development in in-house R&D; and 5) the political construction of PV technology reveals that energy crisis played a vital role in fostering PV technological research but ultimately it also stopped the knowledge production once the crisis attained the state of normalcy. On the other side, the science and technology policy provided little importance to the development of solar energy technologies. In the sense, unlike, ICT and Biotechnology, Indian science policy socially neglected the growth of SPV technology sector.

At this juncture, several factors contribute to the revivalism and reemergence of SPV techno-scientific knowledge production in India. It explains that climate change and influence of Western science and technology development in SPV contribute to the revival of techno-scientific research in India. This is actually an urgency to be part of the international knowledge production process in SPV; otherwise India will be socially and scientifically disconnected from the emerging discipline of solar photovoltaic science and technology. Under these social conditions, various new scientific and technological initiatives have emerged in SPV. However, the study shows that the thrust areas of SPV are shifted from first to third and fourth generations of technologies. The development of science in these areas is new and encourages young scientists to venture into these areas due to a lot of opportunities in terms of publications and patent. Subsequently, majority of the scientists are located in third and fourth generations of technology. However, the study points out that inadequate laboratory facilities and lack of scientific and technical manpower constrain the present techno-scientific knowledge production in SPV in India. In the midst of this, the scientific and academic institutions are in the process of rebuilding the laboratories, scientific manpower and training. But, these activities are at the rudimentary level due to delay in the process and nature of funding. The scientists are also pessimistic about the future of SPV R&D in India, if other energy technologies get success in the commercial market. As a result, the SPV scientific and technological projects are short term in nature. These factors expose the continuity of same practice which was witnessed in the previous period of time though few changes are evidenced. Finally, the study highlights the issues of how SPV science is governed by the political and bureaucratic structure. This kind of understanding attempts to expose the continuity and discontinuity in techno-scientific research and technology development in SPV. Overall, this chapter attempts to connect with the previous chapter by focusing on the new issues underlying the SPV research and exposes that the scientific research still exist at the exploratory level.

On the other hand, the seventh chapter attempts to look at two objectives: 1) to know the nature and structure of Indian PV industry; and 2) to understand the factors that determine\curtail the development of Indian PV industry. This is to understand how Indian PV industry is located in the globalised production and innovation of photovoltaic technology and why there is no linkage between industry and academia. Based on these objectives, the study discusses the nature and structure of Indian PV industry and exposes the factors which contribute to socially and technologically locked-in position in SPV technology. Second, it helps to understand the reasons for the joint ventures and technological tie-ups with foreign firms and explores the nature of the same. Third, the study points out at the lack of skilled laborers and the position of experimental R&D in Indian PV firms. These three factors explain the nature of problems faced by the Indian PV industry.

Conclusion:

Through the analysis is done in the chapters, the study attempted to know the factors that affected the process of techno-scientific knowledge production and subsequent transfer of knowledge to industry. Innovation is defined as a successful conversion of scientific ideas from one social setting to wider social context. The study concludes that transfer and innovations in SPV technology is completely absent and the techno-scientific knowledge production rests only at the laboratory level. The study witnesses the larger gap between invention and innovation in SPV technology. The study articulates the reasons for this gap: 1) context of knowledge production; 2) practice of science in IITs and industrial laboratory; 3) bureaucratisation of science; 4) culture of reward system; 5) technological dependency and import culture; and 6) policy and politicisation of SPV science – provide the reasons for SPV as a "***neglected science***" in India due to three aspects: a) political preference of science policy in India; b) the question of appropriate technology and solar photovoltaic; and c) government control on energy production and distribution. Finally, the study discusses the lacunae of National Solar Mission Plan and how such lacunae may affect local technology development and R&D programmes in future. To reduce such affect, the study makes several policy suggestions to improve the conditions of Indian SPV industry in India. Finally, the study shows the elements of Mode 2 knowledge production in Indian context, but such elements are slightly emerging with the network form of knowledge production that leads to the formation of hybrid community in India. However, the isolated forms of knowledge practice and import culture, very few interactions among government, industry and academia undermine Mode 2 Knowledge production framework in the Indian context. Though this reflects the third world science practice, it also exposes how our practice of science is still stuck within the Western paradigm of knowledge production. Hence, our autonomy in science is still a dream project.