GREEN GROWTH AND DEVELOPMENT: EVALUATING SUSTAINABILITY IMPACTS OF SOLAR ENERGY TRANSITIONS IN INDIA

Ph.D. Thesis

By
SURABHI JOSHI

DISCIPLINE OF ECONOMICS
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GREEN GROWTH AND DEVELOPMENT: EVALUATING SUSTAINABILITY IMPACTS OF SOLAR ENERGY TRANSITIONS IN INDIA

THESIS

Submitted in partial fulfillment of the
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DISCIPLINE OF ECONOMICS
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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **GREEN GROWTH AND DEVELOPMENT: EVALUATING SUSTAINABILITY IMPACTS OF SOLAR ENERGY TRANSITIONS IN INDIA** in the partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **DISCIPLINE OF ECONOMICS, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from July, 2011 to June, 2017 under the supervision of Dr. Pritee Sharma , Associate Professor, Indian Institute of Technology Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

Signature of the student with date
SURABHI JOSHI
(NAME OF THE CANDIDATE)

This is to certify that the above statement made by the candidate is correct to the best of my/our knowledge.

Signature of Thesis Supervisor #1 with date | Signature of Thesis Supervisor #2 with date

(Dr. Pritee Sharma) | **(NAME OF THESIS SUPERVISOR)**

SURABHI JOSHI has successfully given his/her Ph.D. Oral Examination held on - ________________

Signature(s) of Thesis Supervisor(s) | Convener, DPGC
Date: | Date:

Signature of PSPC Member #1 | Signature of PSPC Member #1 | Signature of External Examiner
Date: | Date: | Date:

Dedicated to Amma & Kaka

For Suriti

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October, 2018 **Surabhi Joshi**

SYNOPSIS

Green Growth and Development: Evaluating Sustainability Impacts of Solar Energy Transitions in India

1. Introduction

This thesis locates itself within the emerging Green Growth-Sustainability paradox and its implications for India as an emerging economy. Last decade has witnessed an unprecedented transformation in dynamics of renewable promotion, facilitated by drastic reduction in production costs of various renewable energy technologies (RETs). A sharp decline in the costs of solar photovoltaic panels (> 80% between 2007-15) prompted Indian policy makers to leverage the untapped solar generation potential in the country. A target has been set to add hundred Gigawatts (GW) of grid connected solar generation capacity by 2022 under the flagship of National Solar Mission (MNRE,2010). Following that this study argues that the policy decision aiming at energy transition of such magnitude implies concomitant lock-in of substantial capital and material resources across the deployment process. Thereby potently influencing the trajectory of existing developmental pathways for India necessitating further evaluation.

Renewable energy sector has been singled out to play a pivotal role in orchestrating global green growth. Policy-makers widely acknowledge the existence of important trade-offs between investing towards sustainable development and adequately supporting economic growth (Mercure et al, 2016). A topical predicament relates to articulating effective green growth policies in developing economies. This would entail innovations for not only minimizing environmental impacts of the growth process, but also techno-economic innovations for ensuring long run economic growth with cleaner technologies (Hallegate, 2011). In the case of developing economies, it also hem-in developmental concerns like inclusive growth, equitable wellbeing and alleviation of resource scarcities. Further, global expectations of greater role in sustainability transitions by "leap frogging" to cleaner technologies also need to be accommodated effectively.

Taking an exploratory route, the initial chapters (2-3) elucidate the critical links between energy, technology and sustainable development. Further, technology innovation system for Indian solar deployment is analyzed by compiling ecosystems for solar deployment and solar manufacturing. The study further develops a quantitative framework for mapping expansive impacts of investments in solar sector from sustainability perspective. Systems research framework-based Input-Output (I-O) analysis, Social Accounting Matrix (SAM) and Environmentally Extended Multiregional Input-Output (MRIO) analysis is performed to evaluate economic, social and environmental impacts (estimated in terms of embodied GHG emissions) of ground mounted grid connected solar photo voltaic (PV)[1] deployment process.

The thesis further analyses dilemma of designing a balanced domestic industrial policy that allows leveraging solar mediated local green growth possibilities without obliterating WTO obligations is analyzed. This is done by integrating comparative study on direct and indirect impacts of attaching domestic content requirement (DCR) criteria in Indian solar policy within the framework of analysis (Oliver, 2013). This comparison also forms the basis of evaluating technology localization impacts in the process of solar transition. Triple bottom line impacts (economic, social and environment) associated with solar deployment process (chapter 4-6) involved deployment category differentiated[2] impact assessment with following objectives:

i) Estimation of direct & indirect macroeconomic impacts associated with solar deployment process using input-output analysis to understand a) The process of solar deployment under DCR & open category leads to demand generation across economic sectors, b) Direct and indirect GDP and employment generation impacts of

[1] Grid connected ground mounted solar PV presently constitutes 98% of total solar deployment capacity in India

[2] National Solar Mission (2010) provided differentiated incentives for solar deployment projects using domestically manufactured (DCR projects) solar panels from those using imported (open projects) C-Si solar panels

deployment process, c) Labor compensation distribution profile across low, medium and high skill labor categories for solar deployment.

ii) Meso-economic evaluation of solar deployment process is used to evaluate social impact in terms of a) Income generation effects *via* deployment effects on sector, production factors and consumption pattern b) Distributive efficiency of solar scale up induced economic growth with respect to impacts on poor c) Determination of direct, cross-sectional and feedback impacts on Indian economy.

iii) Estimation of environmental impacts by estimating embodied GHG emissions and distributive efficiency of labor generation across multiregional boundaries to understand a) Embodied GHG emissions profile, within and across national boundaries, into major exporter countries to the solar sector b) Estimating GHG emissions per unit of employment generation within and across economies along with the qualitative mapping of compensation generation. The analysis structure integrates a comparison between DCR & open deployment for each of the above objectives. Under this backdrop **Box 1** provides organizational structure of the thesis.

2 Model Selection & Research Design

This section details model selection criteria and research design for the work. Systems analysis framework was used to develop a sufficiently representative model. This involved structuring in impacts of solar deployment process and connecting it with regional growth and development perspective. This model could effectively analyze social, economic, technological and environmental impacts thus fitting in well with in the triple bottom line of sustainability frame.

Box 1: Organizational Structure of the Thesis

1	**Introduction**	• Background • Research landscape
2	**Sustainability – Technology – Energy Inter linkages**	• Sustainability-Technology interlinkages • Sustainability-Energy interlinkages • **Sustainability inquiry for the study**
3	**Green Energy Internalization**	• Clean Technology Innovation System • Indian Solar Innovation System I. Solar policy II. Solar manufacturing ecosystem III. Solar deployment ecosystem • **Technology inquiry for the study**
Estimation of Sustainability Impacts of Solar Deployment Process in India		
4	**Macroeconomic Impacts**	• Domestic content requirement in RET policies • Construction of solar block and IOT integration as a new sector • Input-Output Analysis for multiplier matrix • Estimation of GDP, employment, skill-based labor generation in solar deployment
5	**Meso Economic Impacts**	• Inclusive growth • Constructing Social Accounting Matrix (SAM) • Output, income and consumption Multipliers • Direct, cross sectional and circular Impact • Household income generation and distribution
6	**Environmental Impacts**	• Barriers to technology transfer in developing economies • Multiregional solar block • Estimation of multipliers & emission coefficients across economies • Embodied emission per unit of deployment
7	**Conclusions**	• Contributions & Synthesis • Limitations

Estimation of economic impacts involved Input-Output (IO) based analysis. The methodology was based on the work of Caldes (2009) involving estimation of solar thermal installations impacts for Spain. India-specific solar block was compiled for integration of solar deployment as a new sector in existing national IO table in lines with Kulistic et al (2006) methodology involving compilation of biodiesel production block for Croatian economy. The solar block was constructed for both DCR based deployment where crystalline silicon (C-Si) solar panel manufacturing occurs within economy & Open category where solar panel is imported and manufacturing is an exogenous activity. Employment impacts and compensation distribution across the labor category were estimated using socio-economic satellite accounts in world input output database (WIOD, Dietzenbacke, 2012).

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Social impacts were modeled by the construction of a Social Accounting Matrix (SAM) in order to i) Link changes in value adding income to final demand through income-consumption effect ii) Study impacts of solar deployment across nine heterogeneous house hold categories for India[3], leading to poverty alleviation impacts of solar deployment iii) Decomposition of multiplier matrix to estimate sector wise direct, cross sectional and feedback effects of solar deployment with respect to income and GDP multipliers.

A discussion is made on the environmental impacts in the study by developing environmentally extended multiregional input output model (EE-MRIO). The model simulates impacts of solar deployment process both within India and across the main exporter countries (China & Germany) providing inputs to Indian solar sector. The analysis involved estimation of embodied GHG emissions associated with such deployments (Andrew, 2009) inclusive of trade. The estimation is augmented with topical debate on existing barriers for clean energy technology transfer to developing economies along with synergies emerging from rapidly growing global solar sector thus connecting it to sustainability discourse.

3 Data Description:

Data was compiled from three categories of databases to construct representative and homogenized models involving: i) Technology specific data, ii) Balanced and homogenized macroeconomic data bases iii) Economy specific micro data bases. The data details are delineated in **Table 1**.

[3] HH1: Self employed in agriculture (R), HH2:Self employed in non agriculture (R), HH3:Agricultural labor (R), HH4: Casual labor(R), HH5 Regular wages + others (R), HH6: Self employed (U), HH7:Regular wages/ salaries(U), HH8:Casual labour(U), HH9:Other HH(U)

R-rural households U-urban households

Table 1: Data Compilation

Type of Data	Sources
Technology Specific Data	MNRE Reports on Solar PV deployment incentives (2010-2015) NREL PV C-Si panel manufacturing cost curves Input quantity estimation Tons/ MW using standard construction manual estimations Input cost estimation prevailing market price & solar deployment reports
Macro Databases	World Input output database, European Commission 35 sector National I-O Table (2011) 35 sector national socio-economic account (2011) 35 sector national emission accounts (2011)
Micro Databases	CSO- National Sample Survey Report 68th Round Household Consumption and Expenditure 68th Round Education and Occupational Statistics

The quantity and value of inputs required for a unit of solar deployment sector was compiled from current market and specific project deployment reports. This covered thirteen key inputs of deployment process i.e. quantity of metal, panels, balance of system inputs, electrical and electronic equipment, transportation, concrete, labor and maintenance, human capital required for a Mega Watt (MW) of solar deployment. The desegregated value of component cost for C-Si manufacturing was integrated with the help of National Renewable Energy Laboratory (NREL) technology cost graphs (Goodrich, 2011)

The data was compiled in monetary terms in a solar block and homogenized to be integrated with macroeconomic databases in the form of Input output tables (IOTs). The national IO tables, satellite accounts including socio-economic accounts and energy & emissions accounts were compiled using World Input Output Database (WIOD). The country specific micro data were obtained from National Sample Survey Organization (NSSO) 68th round reports for energy consumption and use, Household consumption and expenditure along with rural and urban education and occupational statistics. The matrices were solved using MATLAB (2015).

4 Results & Discussion

The results of the three modelling exercises detailed above were compared to understand impacts of technology localization through domestic content requirements in Indian solar policy. The first objective involved input-output analysis-based mapping of economy wide demand generation when a Megawatt (MW) of solar generation capacity is deployed. The analysis involved construction of a solar block and integrating it as a new sector in the IO tables for both DCR and open category deployment. The direct and indirect GDP, employment generation and distribution of labor compensation across high, medium and low skill categories.

The analysis (**Figure1, a-c)** reveals that DCR based deployment has superior backward linkages in the economy leading to 24.74 % higher GDP generation when estimated in terms of direct and indirect value added. Further, DCR deployments generate 36.64 % more employment. The estimates of labor compensation distribution profile indicate generation of more medium skill (38.8 % & 40.1 %) compensation followed by high skill (31.1 & 35.5 %). DCR deployments however generates 35.4 % higher labor compensation. These results provide a qualitative insight into the known positive employment effects (Hillebrantdt, 2007) of solar deployment. The results indicate that localization of technology by using endogenously manufactured solar panels leads to higher GDP and employment generation up the value chain, a discernable positive trend for India’s developmental trajectory.

Chapter 5 constructed a Social Accounting Matrix (SAM) by linking production sectors of the IO analysis to household income and consumption matrix. The analysis led to i) Identification of high impact sectors with respect to production, household income generation and associated consumption ii) Profile for household income distribution across nine occupational category iii) Direct, cross sectional and circular multiplier impacts of solar deployment with respect to income and GDP generation. **Table 2** details the key results of multiplier dissociation for the two categories.

Figure:1 Comparative Solar Deployment profile for a) GDP b) skill based compensation c) employment in DCR & Open deployment

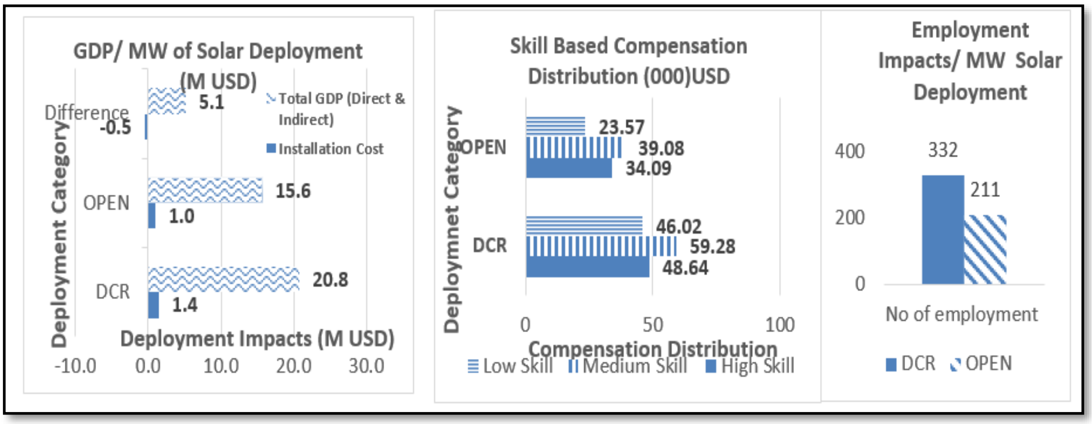
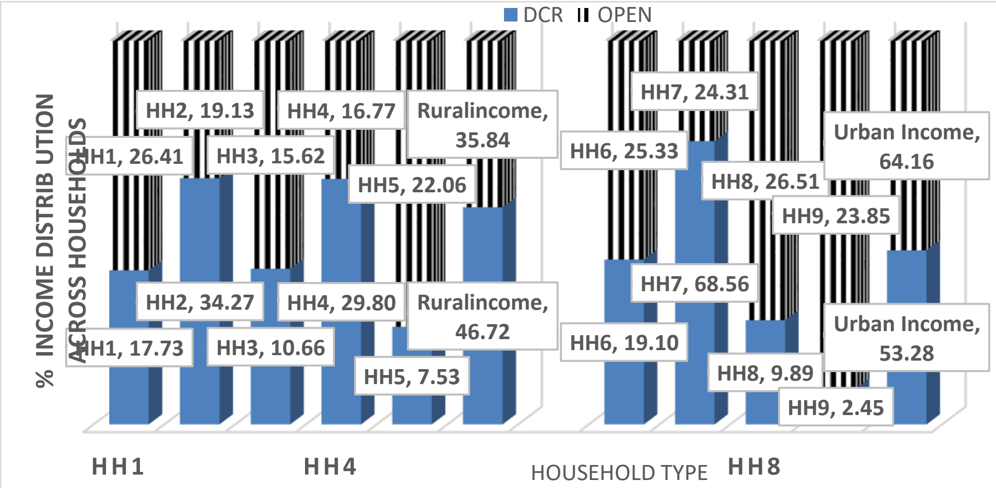


Figure a **Figure b** **Figure c**

The income distribution across the nine-household categories for the DCR & open deployments was estimated with the help of income multipliers from SAM. The technology localization by DCR leads to 35.84 % greater income generation across house hold. The income distribution is skewed towards urban households (53.2 %; 64.16%) in both the deployment categories though DCR generates greater rural income.

The analysis with respect to income distribution across household categories reveals that technology localization by DCR based deployment triggers greater income generation the self-employed in non-agriculture (H2,37.27%,) and casual labor (H4, 29.80 %) categories in case of rural households. Higher income is generated for self-employed in agriculture (H1,26.4%) & regular wages categories (H5, 22.01%) for open category. In the case of urban household, income generation is highest under regular wages (H7, 68.56%) followed by self-employed (H6, 19.1%) for DCR. The household income distribution trend is more uniform for urban households in case of open category (23.85% - 26.51% across all the four households). This was followed by multiplier decomposition to segregate direct, cross-sectional and circular impacts of the solar deployment for the two categories (**Table 2)**. Results reveal that direct impacts of open category deployments (M1) is marginally higher than the DCR category. However, cross sector effects (M2) are predominantly under DCR with sectors like textile, paper & pulp, leather and footwear, water transport and private household sectors as the main beneficiaries.

Figure 2: Income distribution among households for Solar Deployment Categories



The circular effects were detected in both the categories. Community, social services and agriculture showed highest circular effects in DCR, while sectors like electricity and whole sale trade were highest in case of open category. Income multiplier's direct effects (M1) are equal for both deployments, cross effect multipliers (M2) are largely in DCR for various household categories (**Table 2).** The results indicate a good backward integration of DCR deployment in the Indian economy not only at sectoral level but also in house hold income and consumption accounts. The M3 or the circular impacts are mixed for DCR and Open categories.

Our analysis reveals that distributive efficiency of income effects for solar deployment is better under DCR projects with greater income generation for rural households. Further, highest income generation is indicated for households under self-employed in non-agriculture and casual labor category. The income quintile data reveal that 68.8 % of the casual labor falls in the lower two income classes, thus affirming that DCR based solar deployments provides greater integration in the local economy and better penetration efficiencies in lower income deciles indicative of better poverty alleviation impacts.

The chapter 6 involves mapping environmental impacts of solar deployment process in India. The total embodied carbon dioxide emissions inclusive of emissions from imported inputs in the solar sector was estimated. The imports which was exogenously treated in previous chapters was modelled into the solar sector. This included modelling the process of solar panel manufacturing in China and inverter manufacturing in Germany along with the process of solar deployment in India. An environmentally extended multiregional input-output (EE-MRIO) analysis was performed. The analysis estimated GDP, employment and environmental impacts of a unit of Indian solar deployment into economies of India, China and Germany.

Table 1: Summary of Direct (M1), Cross(M2) and circular impacts (M3)

Sector	DCR	Open	No of Sectors	High Impact Sectors
M1	present	present	36, 36	
M2	present	Not Detected	36,0	Textile, paper & pulp, leather, transport,
M3	present	present	18, 18	
Income			High Impact House Holds	
M1	present	present	9,9	
M2	present	Not detected	RH4, UH6, RH5, UH9	
M3	present	present	UH9, RH5, UH8	RH4, UH7

Figure 3 (a) illustrates country wide GDP generated per MW of solar deployment, the results indicate that open category deployments generate greater GDP flows across Chinese economy when compared with those in DCR category as panel manufacturing is primarily located in china. GHG emission per MW of solar deployment **Figure 3(b)** is 58 % higher for DCR category indicating an overall inefficiency of production processes in India. The emission coefficient estimates in terms of GDP generated/ KTon of CO_2 emission is 49% lower in case of DCR deployments but overall employment generation is 21%

higher. The results showcases the predicament of trade offs in green growth . It is indicative that without facilitation of appropriate clean technology transfer for developing countries like India either economic or environmental benefits would have to be compromised.

Figure 3 a) GDP b) emission cofficient c) employment generation in multiregional model

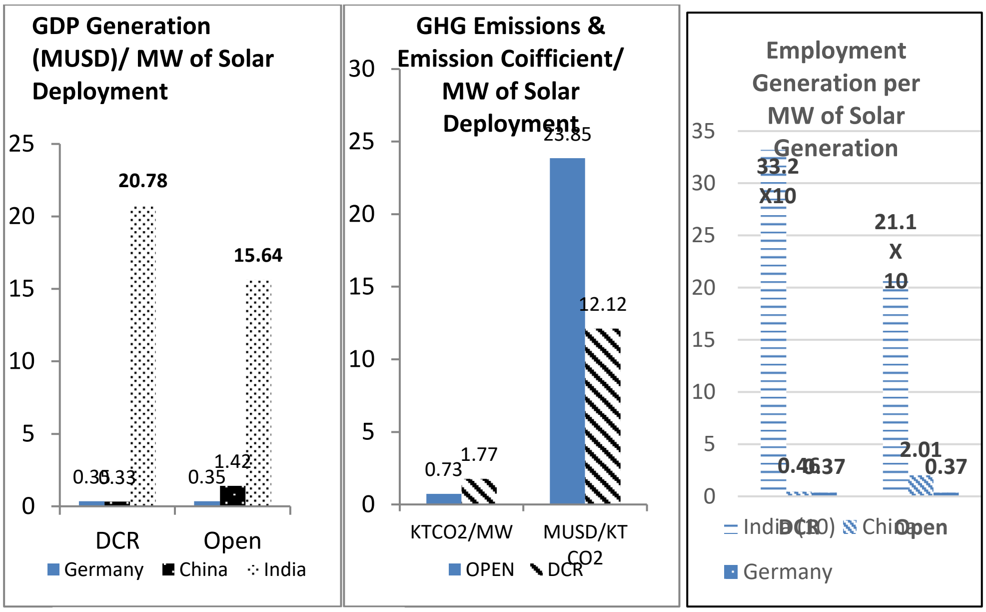


Figure a

Figure b

Figure c

5 Contributions of the Work

The Green Growth – Sustainability paradox associated with Indian solar promotion was explored in this interdecipliniary study. The study developed an empirical framework to evaluate solar transitions underway in India intending to go beyond the prevalent industrial policy based discourse (Sahu & Shreemali, 2015) to relevant developmental perspective associated with process of renewable promotion .The study reveals that harnessing green growth potential of the solar scale up in India would be more effective if domestic localisation of technology manufacturing can be maintained. The greater benefits in terms of GDP , quantity and quality of employment generation occurs when solar panel manufacturing occurs within India, as indicated by estimates of domestic content requirement based solar deployment.

Technology localization through DCR based deployments also has superior backward linkages integrating well in Indian economy. Further, there are substantial cross and circular linkages benefitting economy. Household incremental income generation is higher, estimated distributive impacts of the income generation reveal greater spread into low income households for DCR categories. Thus, incentives for establishing the solar manufacturing in India has greater positive effect with respect to poverty alleviation and inclusive growth synergizing well with sustainable development goals.

The study also reveals that in-house solar manufacturing has higher environmental impacts in terms of embodied emission in manufacturing process, but it has the potential to generate more jobs per unit emissions for deployment. The results once again highlight the paradox between green growth and sustainability. The mechanisms of technology transfer for renewables into late mover economies largely focus on learning by using strategy circumventing a learning by doing curve which is known to create positive spill overs in terms of cleaner technology transfers and has a potential for economy wide improvement in process efficiency.

Ensuring sustainable supply of energy is a critical challenge for an emerging economy like India posed with conditions of energy poverty, greater climate change vulnerabilities and high population growth rates. Thus, policies formulated for renewable energy scale up and deployment have to be scrutinized for their efficiency to meet multiple developmental goals. Therefore, evaluation of solar transitions in Indian economy should transcend the existing framework of conventional industrial policy strategy and free trade obligations to bring in perspectives of developmental strategy fine-tuned for alleviating intrinsic climate change vulnerabilities and aspired developmental goals.

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LIST OF PUBLICTAIONS

A Publications from PhD thesis work

A1. In refereed Journals

1. Joshi, S., Sharma, P., (2018). Energy, Economic Growth and Energy Transitions: Exploring the interlinkages for Indian Economy, *Journal of Emerging Technologies and Innovative Research*, Vol 5(8).

2. Joshi, S., Sharma, P., (2018) Green growth & Trade restrictions: Assessing socio economic impacts of local content requirements in Indian solar policy, *Journal of Developing Areas (Accepted).*

3. Joshi, S., Sharma, P., (2014). Browning the Green Agenda: Understanding Indian Solar Policy through Local Sustainability Perspective, *Journal of Studies in Dynamics & Change*, Vol 1, No 2, 76-79.

A2. In refereed conferences

4. Joshi, S., Sharma, P., (2017) Employment and GHG Emission effects of grid connected solar PV deployment in India: A multiregional Input Output (MRIO) based analysis, Conference Proceeding 25th International input output Conference, 19-23 rd June, 2017, Atlantic City , New Jersey, USA, URL: https://www.iioa.org/conferences/25th/papers/files/3099_20170516071_MRIO25IIOA.pdf.

5. Joshi, S., Sharma, P. (2015). Estimating economic impacts of introducing domestic content requirement in Indian Solar Policy using input output analysis, Conference Proceedings 23 rd International input output Conference, 21-25 June 2015, Mexico city, Mexico, URL: https://www.iioa.org/conferences/23rd/papers/files/2144.pdf.

A3. Book Chapters

6. Joshi, S., Sharma, P., (2018). Mapping meso-economic impacts of grid connected solar PV deployments in India: A Social Accounting Matrix Approach In K. Mukhopadhyay Ed. *Applications of the Input-Output Framework*, Publisher Springer Nature, Singapore, ISBN: ISBN:978-981-13-1506-0 (In Press).

(B) Other publications during PhD:

B1. In refereed Journals

7. Kumar, A., Sharma, P., Joshi, S., (2016).Estimating climate change impacts on agricultural productivity in India: A panel data analysis, *Journal of agricultural science and technology*, Vol 18, 1-13.

8. Kumar, A., Sharma, P., Joshi, S., (2015). Effects of climatic factors on agricultural productivity in India: A state-wise panel data analysis, *International Journal of basic and life sciences*, Vol3(1), 48-57.

LIST OF CONFERENCE PRESENTATIONS

Presented

1. Joshi, S., Sharma, P. (2017). Employment and GHG Emission effects of grid connected solar PV deployment in India: A multiregional Input Output (MRIO) based analysis, 25th International input output Conference, 19-23 rd June, 2017, Atlantic City , New Jersey, USA.

2. Joshi, S., Sharma, P. (2016). Green energy & local economic development: Mapping impacts of solar scale up on Indian economy, 24th International input output Conference, 4-8 July 2016, Seoul, South Korea

3. Joshi, S., Sharma, P. (2014). Estimating economic impacts on introducing domestic content requirement in Indian Solar Policy using input output analysis, 23 rd International input output Conference, 21-25 June 2015, Mexico City, Mexico. **(Received IIOA graduate fellowship for the travel)**

4. Joshi, S., Sharma, P. (2013). Measuring sustainability of solar based energy transitions: Framework and Methodology, International Conference on Economic and Social Sustainability 2013, Tokyo, September 30, 2013 (online Presentation).

5. Joshi, S., Sharma, P. (2012). Novel framework for valuing forest degradation associated with coal mining, ACES and Ecosystem markets 2012, Dec 10-14, 2012, Ft. Lauderdale, Florida, USA ***Received recognition and ACES graduate fellowship for the work**

Poster Presentation

6. Joshi, S., Sharma, P. (2013). Deforestation due to coal mining and Climate Change: Estimating indirect costs and future liabilities, 1st Climate Science Policy Workshop (CSPW), The Victor Menezes Convention Centre, Indian Institute of Technology Bombay, Mumbai, 6-7 March 2014.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

KW	Kilo watt
MW	Mega watt
GW	Giga watt
KWh	Kilo watt hour
ASEAN	Association of South East Asian Nation
CEA	Central Electricity Authority
CEEW	Council on energy environment and Water
C-Si	Crystalline Silicon
DCR	Domestic content requirement
EE-MRIO	Environmentally extended multiregional input output model
GAIN	Global Adaptation Index
GEA	Global energy agency
IEA	International energy agency
IPP	Independent Power producer
IPCC	International panel on climate change
WTO	World trade organisation
GHG	Greenhouse gases
GWEC	Global wind energy council
INDC	Intended Nationally Determined Contribution
LCR	Local content requirements
MDGs	Millennium development goals
MNRE	Ministry for new and renewable energy
MoP	Ministry of power
NAPCC	National action plan on climate change
NEP	National energy policy
NSM	National solar mission
NTPC	National Thermal Power Coop oration
NVVN	NTPC Vidyut Vyapar Nigam Limited
IREDA	Indian Renewable Energy Development Authority
OECD	Organization for Economic Cooperation and Development
PV	Photo Voltaic

PPA	Power Purchase Agreement
REC	Renewable energy certificate
REN21	Renewable energy network for 21st century
RETs	Renewable energy technologies
RPO	Renewable Purchase Obligation
SAM	Social Accounting Matrix
SREDA	State Renewable Energy Development Authority
UNCSTD	United nations
UNFCCC	United nations
WEC	World energy Council
WIOD	World input output database
I-O	Input-Output

Chapter 1

Introduction

This thesis explores the emerging Green Growth – Sustainability paradox and its implications for developing economies. Dynamics of renewable energy technology (RET) deployment has witnessed an unprecedented transformation in last decade following a sharp decline in production costs of various renewable energy technologies. This has led to six-fold growth in renewable energy installations (from 85 GW to 657 GW between 2005-2015), with over 164 countries establishing renewable energy capacity targets (REN21,2016). A policy shift towards renewable energy base is also transforming the Indian energy mix as total renewable installed capacities has increased from roughly 4000 MW in 2002 to over 50000 MW in 2016, accounting for almost 16 % of the country's total generation capacities (CEA,2017).

The solar scale-up of this magnitude implies concomitant lock in of substantial material and capital resources across the deployment trajectory. The green growth imperative for solar promotion in India thus needs a scrutiny with respect to not only inherent developmental concerns of inclusive and equitable growth but also alleviation of resource scarcity in the country. Public policies for renewable promotion thus often endorse multiple performance expectations. This would include strategies for climate change mitigation and adaption and security of energy supply. Further, RET promotion also lead to local growth opportunities in the form of development of domestic industry and local employment, expansion of domestic export (Joshi & Sharma, 2014; Allan et. al, 2011; Rio and Burguillo, 2009; Reddy et. al 2007). Although integration of developmental imperatives is rarely discussed explicitly in context of renewable development, this thesis attempts to examine green growth impacts of ongoing solar transitions from a developmental perspective.

This introductory chapter comprises of four sections, the first section delineates context of the research by providing brief description of the research landscape, solar promotion trajectory for India and utility of solar technology in alleviating developmental concerns. This is followed by section two, which details research questions and objectives of the study, followed by a brief overview of methodology and data in section three. The last section of the chapter (section four) provides a brief description of the thesis structures and key findings of the research.

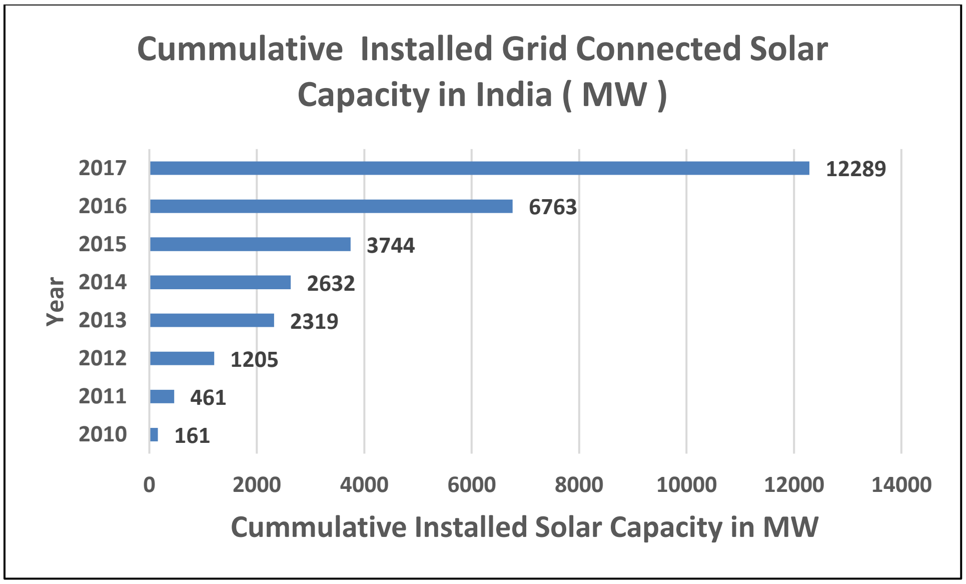
1.1 Background

This dissertation involves a techno-economic evaluation of the impacts associated with solar scale up in India. The green growth regime created systematic policy incentives towards renewable energy scale up and deployment. India being a tropical country has immense potential for solar power generation. The country enjoys over 300 sunny days annually with daily average solar energy incidence of 4 to 7 kWh/m^2 with about 1500–2000 sunshine hours per year (Purohit and Purohit, 2010). The value of solar energy as an alternative for cooking fuel and power has been well recognized by Indian policy makers for last four decades leading to long initiatives for promotion of small standalone installations and solar cookers.

A major turnaround in dynamics of production costs of global solar sector driven largely by ambitious energy transition targets in developed economies like Germany, prompted Indian policy makers to proactively engage in solar transitions to leverage the inherent green growth prospects for the country. This led to launch of an ambitious solar program in the year 2010 under the flagship of national solar mission, focusing on systematic incentives and target oriented solar scale up. A sharp decline in cost of solar PV panels (> 80% between 2005-2017; REN 21, 2015) prompted Indian policy makers to revise the already ambitious solar target of 20 GW grid connected solar deployment under national solar mission to 100 GW by 2022. Policy decision to logarithmically scale up solar generation capacities of this magnitude bring with it strong expectations of not only transforming the energy mix (54.4 % renewable by 2027, NEP, 2016) but also playing a critical role in articulating the targets for Intended Nationally Determined Contribution (INDC) set under UNFCCC Paris agreement for India.

Indian solar sector post NSM has witnessed a logarithmic growth facilitated by solar policies articulated through the National Solar Mission. The program has been able to effectively scale up the grid connected solar deployment capacity for India from less than a 100 MW before 2010 to over 12000 MW by March 2017 (MNRE, 2017). **Figure 1.1** illustrates year on year growth trajectory of solar deployment in India post National Solar Mission (NSM) launch.

Figure 1.1: Trajectory of Indian Solar Deployment under NSM



Source: MNRE, 2017

The National Solar Mission has come up as one of the key initiatives under National Action Plan for Climate Change (NAPCC, 2008) and demonstrates key trends of Indian strategy to leverage green growth. The concept of green growth traditionally encompasses concepts of sustainable preservation of natural capital and technological innovation to minimize environmental impacts along with promotion of techno-economic innovations for creation of long run economic growth with cleaner technologies (Hallegatte et. al., 2011). A distinction in interpretation of green growth is fast emerging with respect to developing countries is emerging (OECD,2012) which emphasize that imperatives of green growth in developing economies should hem-in concerns of inclusive economic growth and equitable wellbeing along with improved environmental management for alleviating resource scarcities and climate change impacts.

Growth in installed solar capacities have been associated with various favorable developmental outcomes. Studies reveal that process of increased solar deployment can have favorable impacts on economies both during deployment and ex-post. Increased deployment contributes to regional development (Lopez et. al, 2007; Mıguez, 2006; Faulin et. al, 2006), enhanced employment opportunity especially in rural areas (Caldes et. al 2009, Heallebrand et. al, 2006, Bergmann et. al, 2006; El Bassam and Maegaard, 2004) along with improved health conditions due to minimized environmental impacts during energy generation. Moreover, energy accessibility potential also has close links with alternative livelihood generation capabilities there by better prospects for adaptation to any climate-genic vulnerabilities.

The implication of largescale solar deployments in India should be scrutinized inclusive of existing developmental concerns. The socio-economic expectations implicit in renewable scale up often warrant use of unique, normatively tailored policy design that fits well with economy specific developmental agenda. A highly criticized but popular strategy amongst policy makers has been to instrument channelization of intermediate goods for renewable energy deployment through local producers or manufacturer by including domestic or local content requirements (DCR/LCRs).

Current Indian solar policy initially differentiated incentives for solar power projects utilizing domestically produced solar panels (DCR) and those using imported solar panels (non DCR). The intention was to protect and incentivise solar panel and BOS manufacturing in India. The policy instrument has come under controversy and has been regarded as violation of free trade agreement by WTO in the year 2017. The situation thus poses a challenge for India to design a balanced domestic industrial policy that allows leveraging solar mediated local green growth possibilities without obliterating WTO obligations. This thesis weaves in comparative study of direct and indirect impacts of attaching domestic content requirement (DCR) criteria in Indian solar policy within the framework of green growth sustainability analysis . This comparison also forms the basis of evaluating technology localization impacts in the process of solar transition. Triple bottom line impacts (economic, social and environment) associated with solar deployment process. Following this research landscape, the next section delineates the research rationale in terms of key research questions and objectives of the thesis

1.2 Key Research Questions & Objectives

This study thus has a two-tiered concern: The first concern relates to positioning of solar transitions within the overarching framework of green growth and its relevance for India as an emerging economy. Second more specifically relates to understanding the technology localization impacts with in a techno-economic framework and discerning the impacts of proposed solar deployments involving evaluation of economic, social and environmental perspectives.

The initial objective of the thesis involves positioning the phenomenon of Indian solar transitions within the existing analytical framework of green growth and sustainability, followed by an analysis of the ongoing solar transitions in terms of solar policy structure and the structure of evolving solar sector in India. The policy commitment towards logarithmic scale up of solar capacity deployment (100 GW by 2022) also pose certain concerns in terms of possible inefficient lock in of capital and resources across the developmental pathway. This renders a systematic analysis of economy wide impacts of solar deployment process critically essential.

These concerns frame the initial rationale for the research work wherein the ongoing solar transitions are studied w.r.t. the Green Growth - Sustainability Paradox. This is followed by a quantitive inquiry dealing with evaluation of triple bottom line impacts (economic, social and environment) associated with solar deployment processes. The five key objectives of the thesis along with associated research questions are presented below:

i) Analyzing the Sustainability, Technology & Energy interlinkages and evaluating how the process of Indian solar transitions derive interlinkages w.r.t. the above-mentioned elements. The key research questions evaluated are

a) What are sustainability – technology linkages?
b) How energy indicators link with sustainability discourse?
c) What are the key differentiators of green growth conceptualization in developing and developed economies?
d) What are the key developmental concerns linked with Indian solar promotion?
e) What are the key indicators to analyze developmental impacts of the process of Indian solar deployment?

ii) Evaluating and analyzing the effective of the Indian solar innovation system towards internalization of renewable technology mediated green growth. The following are the key research questions evaluated are

a) How are clean technology innovations articulated for overcoming the barriers in green growth?

b) What is the structure of growing solar innovation system in India?

c) What are the key characteristics of Indian solar policy w.r.t. elements, structure, incentives mechanisms and implementation mechanisms?

d) How has the Indian solar panel and BOS manufacturing sector responded to the incentives for solar promotion under NSM?

e) What is the structure of growing solar deployment ecosystem in India, developed through effective implementation of NSM?

iii) Estimation of direct & indirect macroeconomic impacts associated with solar deployment process. The following key research questions evaluated are

a) How does the process of solar deployment under DCR & open category lead to demand generation across economic sectors in India?
b) What is the direct and indirect GDP and employment generation impact of solar deployment process?
c) What is the labor compensation distribution profile across low, medium and high skill labor categories for solar deployment?

iv) Meso-economic evaluation of solar deployment process to evaluate social impact with the help of following research questions

a) What are the Income generation effects *via* deployment effects on sectors, production factors and consumption pattern?

b) What is distributive efficiency of solar scale up induced economic growth with respect to impacts on poor?

c) What are the direct, cross-sectional and feedback impacts of solar deployment processes on Indian economy?

v) Estimation of environmental impacts associated solar deployment process in terms of embodied GHG emissions and distributive efficiency of labor generation across multiregional boundaries. The key research questions evaluated are

a) What is the embodied GHG emissions profile, within and across national boundaries, including major exporter countries supplying to the Indian solar sector?

b) What would be the GHG emissions per unit of employment generation within and across economies?

c)What is qualitative profile of compensation generation across economies?

The work takes an exploratory route as the aim is to capture key characteristics of the ongoing process of solar transition in the country. This objective also poses a challenge in terms of absence of any direct term of reference in the existing literature. Therefore, generic and well accepted framework of system's analysis has been used to perform the key estimations of the research work.

1.3 Methodology & Data Compilation

The study develops a quantitative framework for mapping expansive impacts of investments in solar sector from sustainability perspective. Systems research framework-based Input-Output (I-O), Social Accounting Matrix (SAM) and Environmentally Extended Multiregional Input-Output (MRIO) analysis is performed to evaluate economic, social and environmental impacts of ground mounted grid connected solar photo voltaic (PV)[1] deployment process. Further, the existing dilemma of designing a balanced domestic industrial policy that allows leveraging solar mediated local green growth possibilities without obliterating WTO obligations is analyzed. This is done by integrating comparative study on direct and indirect impacts of attaching domestic content requirement (DCR) criteria in Indian solar policy within the framework of analysis.

Systems analysis framework was used to develop a sufficiently representative model. This involved structuring in impacts of solar deployment process and connecting it with regional growth and development perspective. This model has the potential to effectively analyze social, economic, technological and environmental impacts thus fitting in well with in the triple bottom line of sustainability frame.

The study initially constructs a detailed technology specific solar block and integrates it as a new sector in the Indian economy thereby endogenising the impacts of solar scale up which has not been previously explored for India at sectoral level.The analytical framework sticks to grid connected ground mounded solar deployments which has emerged the most predominant form of solar deployment in India.

Estimation of economic impacts involved Input-Output (IO) based analysis. The methodology was based on the work of Caldes (2009) involving estimation of solar thermal installations impacts for Spain. India-specific solar block was compiled for integration of solar deployment as a new sector in existing national IO table in lines

[1] Grid connected ground mounted solar PV presently constitutes 98% of total solar deployment capacity in India

with Kulistic et. al (2006) methodology involving compilation of biodiesel production block for Croatian economy. The solar block was constructed for both DCR based deployment where crystalline silicon (C-Si) solar panel manufacturing occurs within economy and for Open category where solar panel is imported and manufacturing is an exogenous activity. Employment impacts and compensation distribution across the labor category is estimated using socio-economic satellite accounts in world input output database (WIOD, Dietzenbacke, 2012)

Social impacts are modelled by the construction of a Social Accounting Matrix (SAM) in order to i) Link changes in value adding income to final demand through income-consumption effect ii) Study impacts of solar deployment across nine heterogeneous household categories for India[2], leading to poverty alleviation impacts of solar deployment iii) Decomposition of multiplier matrix to estimate sector wise direct, cross sectional and feedback effects of solar deployment with respect to income and GDP multipliers.

Substantial discussion is made on the environmental impacts in the study by developing environmentally extended multiregional input output model (EE-MRIO). The model simulates impacts of solar deployment process both within India and across the main exporter countries (China & Germany) providing inputs to Indian solar sector. The analysis involves estimation of embodied GHG emissions associated with such deployments (Andrew, 2009) inclusive of trade.

The estimation is augmented with topical debate on existing barriers for clean energy technology transfer to developing economies along with synergies emerging from rapidly growing global solar sector thus connecting it to the sustainability discourse. The data for these estimations were compiled from three categories of databases to construct representative and homogenized models involving: i) Technology specific data, ii) Balanced and homogenized macroeconomic data

[2] HH1: Self employed in agriculture (R), HH2:Self employed in non agriculture (R), HH3:Agricultural labor (R), HH4: Casual labor(R), HH5 Regular wages + others (R), HH6: Self employed (U), HH7:Regular wages/ salaries(U), HH8:Casual labour(U), HH9:Other HH(U)

bases iii) Economy specific micro data bases. The data details are given in **Table 1.1.**

The quantity and value of inputs required for a unit of solar deployment sector is compiled from current market and specific project deployment reports. This covers thirteen key inputs of deployment process i.e. quantity of metal, panels, balance of system inputs, electrical and electronic equipment, transportation, concrete, labor & maintenance, human capital required for a Mega Watt (MW) of solar deployment.

Table 1.1: List of data

Type of Data	Sources
Technology Specific Data	MNRE Reports on Solar PV deployment incentives (2010-2015)
	NREL PV C-Si panel manufacturing cost curves
	Input quantity estimation Tons/ MW using standard construction manual estimations
	Input cost estimation prevailing market price & solar deployment reports
Macro Databases	World Input output database, European Commission Directorate General
	35 sector National I-O Table (2011)
	35 sector National socio-economic account (2011)
	35 sector National emission accounts (2011)
Micro Databases	CSO- National Sample Survey Report
	68^{th} round household consumption and expenditure
	68^{th} round Education and occupational statistics

The desegregated value of component cost for C-Si manufacturing was integrated with the help of National Renewable Energy Laboratory (NREL) technology cost graphs (Goodrich, 2011)

The data is compiled in monetary terms in a solar block and homogenized to be integrated with macroeconomic databases in the form of Input output tables (IOTs).

The national IO tables, satellite accounts including socio-economic accounts and energy & emissions accounts are compiled using World Input Output Database (WIOD). The country specific micro data were obtained from National sample survey organization (NSSO) 68^{th} round reports for energy consumption and use, Household consumption and expenditure along with rural and urban education and occupational statistics. The Matrices are solved using MATLAB (2015). The next section **(1.4)** provides a brief snapshot of the organization of the thesis into chapters and their content

1.4 Organization of the Thesis

The thesis includes seven chapters in all. There are five core chapters detailing various aspects of solar transitions in India along with a conclusion and the current chapter dealing with the background of the study and technological landscapes. Chapter 2 explores sustainability – technology & Energy interlinkages. The chapter discusses importance of technology in sustainability discourse, emergence of the concepts of green growth and its implementation through renewable promotion. This is followed by a section dealing with the role of energy for sustainable development, analysis of energy -economy linkages with respect to India while delineating concerns of security of demand and supply in context of renewable growth. This is followed by compiling a framework for evaluating sustainability impacts of solar deployment.

Chapter 3 explores the emerging innovation system for solar technologies in India by discussing the issues in clean innovation systems, exploring the history of solar promotion in India and analyzing existing policy structure and incentives. This is followed by analysis of solar deployment and solar panel and BOS manufacturing ecosystems developing in India. The chapter concludes by setting up boundary for quantitive evaluation of solar deployment processes

Chapter 4 deals with evaluating and estimating economic impacts of solar deployment processes in India. The chapter initially discusses use and relevance of domestic content requirement in renewable energy policy. This is followed by methodological discussion on system analysis frame work involving construction of a solar block and integration in the national IO table as a new sector, IO analysis and results in terms of GDP, employment and qualitative skill-based distribution of labor compensation in the two deployment categories under study.

Chapter 5 deals with evaluating and estimating social impacts of solar deployment. The chapter integrates the relevant developmental concerns of inclusive and equitable economic growth. This is followed by discussion on construction of social accounting matrix, method of multiplier decomposition and multiplier analysis of production, income and consumption accounts. The results estimate distributive efficiency of household income generation, profile of consumption multipliers and the direct, cross and circular impacts associated with DCR and open category deployment.

Chapter 6 deals with estimating emissions embodied in solar deployment inclusive of that embodied in trade. The chapter in the initial section discusses concerns of clean technology transfer in developing economies and the relevance and concerns associated with it. This is followed by a detailed compilation of environmentally extended – Multiregional IO matrix (EE-MRIO) and its use to estimate GHG emissions associated with solar deployment processes across India and its major trading partners in solar deployment. Further profiles of emissions per unit of employment and GDP generation are also evaluated along with the profile of labor composition for trading partners. The chapter discusses and demonstrates the critical dilemma of tradeoffs between minimizing environmental impacts and maximizing economic growth across the developmental path

Chapter 7 is the concluding chapter which includes a summary of the thesis followed by delineation and discussion of relevant findings from the dissertation. The chapter includes relevant findings along with key synthesis of the research work. This is followed by a discussion on contributions and policy recommendations from the work. The chapter finally points at the limitations and scope of future extension of the existing work.

Chapter 2

Sustainability –Technology – Energy Interlinkages

2.1 Introduction

This chapter explores discourses pertaining to sustainability – technology and energy interlinkages and develops a framework for analyzing sustainability impacts of the ongoing solar transitions in India. The initial section study relevance of technology and energy in sustainability discourse. This is followed by section focusing on understanding the concept of green growth and its manifestations in the context of unprecedented growth in global renewable energy sector both in developed and developing economies. The role of energy in sustainability discourse is discussed next where energy as a developmental indicators and existing causality between energy and economic growth for India is explored. The final section of this chapter deals with understanding characteristics and the expected role of grid connected ground mounted solar power deployments for energy transitions in India. The chapter concludes with setting up a boundary and developmental rationale for quantitative analysis performed later in the thesis (Chapters 4-6).

Sustainability analysis commonly involves multidimensional evaluation of an array of developmental parameters. This thesis however, primarily focuses on understanding sustainability impacts of green growth associated with solar transitions in Indian economy. Although a consensus exists on the pivotal role played by appropriate technology towards sustainability transition, the expectations and outcomes of technological transitions strikingly vary for developing and developed economies. Further, as it was realized sustainable development is not possible without transitioning to a more sustainable energy base, clean energy transitions have been globally endorsed as a silver bullet solution for achieving sustainable development.

According to Global Energy Assessment (GEA) 2012, energy for sustainable development must concurrently meet, without compromise, all dimensions of energy service requirements. These include availability, affordability, accessibility, security, health, climate, and environmental protection. The energy options that deliver benefits for many, if not all, of these dimensions and avoid costly lock-in of resources would be the most preferred. Solar based technologies are potentially most unique and versatile for catering to both supply and demand side energy services. However, emerging solar regime in India favors monopolistic supply side transition which has established grid connected ground mounted solar PV deployment as the dominant mode of solar transition for the country.

The main aim of this chapter is to explore sustainability-technology and energy interlinkages and synthesize a framework for evaluating the ongoing solar transitions in India from sustainability perspective. Following this is the section devoted to understanding conceptual frames of the role technology input plays in sustainability discourse. This leads to discussion on emerging concept of green growth and its disparate interpretation for developing and developed economies.

The chapter than takes an analysis of sustainability-energy linkages where energy and development discourse is explored and use of energy linked developmental indicators are discussed. This leads to analysis of causality relations between energy and economic growth for India and discussion on energy security concerns driving renewable transition. The concluding section sets a boundary and background for sustainability inquiry of the thesis. The main intention is to come up with a representative framework which can allow empirical analysis of the impacts associated with grid connected solar PV deployment process in India.

2.2.1 Sustainable Development and Technology

Technology oriented solutions have been the favorites amongst both national and international policy makers for achieving sustainability goals. Brundtland

Commission Report (1987) emphasize introduction of new technology as a 'silver bullet' solution to more sustainable future (Chertow 2001). According to Beder (1997) choice of technology has universal acceptance amongst all stake holders. This makes it suitable to overcome strong reluctance shown by policy makers towards making social and political changes critically necessary to reduce adverse environmental impacts of production and consumption associated with economic growth.

Sustainable development policies thus seek to change the nature of economic growth rather than limit it with the help of technological transitions. According to Faucheux (2000) these policy and technological innovation share an apparent symbiotic linkage as both the major conceptions of sustainability (Strong sustainability and weak sustainability) acknowledge technological change to be the key determinant to improve environment and in a larger framework ensure a sustainable development path (Faucheux and O Connor eds 1998).

The concept of "strong sustainability" (Daly, 1991) emphasize strong degree of complementarities between technical, human and natural capitals. Sustainability growth path is thus envisaged as propositions to implement policies for increased eco-efficiencies through dematerialization of economic activity (Hinterberger, Luks and Schmidt Bleek, 1997). Contrastingly, "weak Sustainability "concepts (Faucheux, Pearce & Proops, 1995) presumes that technological change or progress can automatically alleviate environmental concerns through market mechanisms. Both the sustainability approaches are inextricably linked with technological change but emphasize disparate means.

National and international policy making is thus confronted with an unprecedented predicament of effectively managing complex interaction of economic development, energy systems and environmental change (IPCC, 2014). Policy indecisiveness seem to profligate from an acknowledged lack of understanding for these complex interactions within economy. Although policy-makers often acknowledge existence of important trade-offs between on the one hand, improving the sustainability of the economy and, on the other hand, adequately supporting economic growth (Mercure et. al, 2016), thus pointing to an evident state of conflict between both weak and strong sustainability conceptions.

A topical predicament of the kind can be seen in the fact that although energy related innovations, technologies and practices, throughout industries and between households, have been unanimously endorsed as key solutions for alleviating adverse environmental impacts their diffusion is perceived difficult. This is so because clarity on whether cleaner alternatives would be economically or technically feasible and would be able to support economic development do not exist. Although economic feasibility plays a major role in deciding diffusion trajectories, clean energy transitions for developing countries also have other challenges.

Technology diffusion in developing countries is disparate in the sense that the agenda of scaling up clean technologies is critically interwoven with various critical developmental concerns for these countries. Further, there is a formidable technological knowledge gap that need to be addressed while planning a technological transition in developing countries.

It is well recognized that developing countries are expected to play a vital role in global sustainability transitions as they can "leap frog" or shift over from conventional dirty technologies to cleaner technologies. According to Perkins, (2003) the efforts to leap frog have conventionally centered around five prerequisite conditions i.e. i) A shift to clean production, ii) Immediate action, iii) Technology transfer from developed countries iv) strengthening of incentive regime v) international assistance.

Although, these economies have an opportunity to leap-frog and endorse state of art technologies the channels and mechanisms for technology transfer are very difficult to establish in the existing global scenario prohibiting technology diffusion. For instance, leap-frogging would require not only strong incentives but capability of local firms to respond to incentives in terms of skills and expertise to manage technological change (Dooley et. al,2000). Even the channels of FDIs and transnational companies do not guarantee a positive spill over to local learning (Felipe, 2000). Further, 'Learning by using' which is predominant mode of technology transfer for these economies hold other challenges.

For instance, resorting to policy instruments like domestic content requirement (DCR/LCR) in Indian solar policy, for promoting learning by doing in a sector have been highly criticized based on their trade distorting potential. Recently the WTO's appellate body upheld the earlier ruling that India violated global trade rules by imposing mandatory local content requirements for projects under National Solar Mission (WTO, 2016). Thus, there exists strong barriers both through international mechanisms and in terms of local preparedness for technology transfer and green growth in India.

Understanding in the context of the thesis where scaling up RETs (ground mounted grid connected solar PV) is the focus, process of technology diffusion would involve access, transfer and deployment issues which are predominantly developmental issues rather than technological issues. According to recent framework laid down in issue paper on new and renewable energy for sustainable development (UN CSTD (2010) there at are least three elements in renewable energy transfer and development: (1) the reforms of legal, regulatory and institutional frameworks to increase consistency and coordination in policy and operations of line ministries; (2) massive investment for large scale, systematic and long-term training, capacity-building, and R&D activities and the support of networks of domestic and international research institutions to improve local absorptive capacities, diffusion and deployment; and (3) the promotion of public-private international partnership and collaboration to overcome the major parts of the technical and financial constraints. The next chapter (Ch-3) discusses various elements of Indian solar policy with respect to institutional frameworks and evolving structure of solar sector in India.

The sustainability-Technology interlinkages although well endorsed principally by policy makers for dematerialization of economic growth path in practice are seen to have multiple performance expectations. For instance, policies for RET promotion are formulated to fulfill multiple brown agendas ranging from climate change mitigation to security of energy supply, creation of domestic industry & local employment, expansion of domestic export and climate change adaptation strategy (Joshi & Sharma, 2014; Allan et. al, 2011; Rio and Burguillo, 2009; Reddy et. al 2007). Global evidence indicate that sustainability agenda linked policies have manifested more as “Green Growth” policies shifting their focus from environmental good to economic opportunity and growth expectations both in developing and developed economies. The strategy thus refocuses into sustained economic growth by innovations in clean technologies and leveraging implicit environmental and social wellbeing in the process. The following section discusses the emerging green growth and sustainability paradox with respect to developing economies.

2.2.2. Green Growth in Developing Economies

This section discusses the emerging concept of green growth and its interpretation for developing countries like India. The section attempts to highlight the fact that the global sustainability agenda has translated into policies promoting opportunities for regional growth mediated through clean technology innovations. Thus, implementation of sustainability agenda is intrinsically complex and characteristically different for developing and developed economies.

The concept of green growth is informed by rich background literature in environmental policy (Carvalho, 2015). The transformation to current understanding can be attributed to global economic recession of 2008 (Barbier, 2010; Bowen et. al., 2009). Facing the global crises of economic recessions and climate change, international organizations and national governments have predominantly structured policies to encourage investments in industrial activities that reduce adverse impacts to the environment and lead to economic growth (Ekins, 2014; Robins, Clover, & Singh, 2009). The expectation is that establishing these industries can provide economic growth through the creation of new industries, markets, and associated jobs (Hepburn & Bowen, 2012).

According to Hallegatte et. al., 2011; Jacobs, 2012, Carvalho, 2015 there are three key aspects of green growth:

1. Sustainably preserve natural capital in the process of economic development.

2. Innovate both technologically and organizationally to significantly decrease environmental impacts.

3. Support innovations that can provide long-run economic growth opportunities through improving production efficiencies, whilst creating new industries and markets in domestic economies

This generic discourse emerging mainly from developed economies where alleviating negative environmental impacts associated with past, present and future economic growth form the main contention for endorsing concept of sustainable development. The framework has been intervened in the recent consultation draft of OCED for green growth in developing countries (2012) which emphasizes the fact that for developing or emerging economies the green growth discourse primarily focuses on two key imperatives: the continued inclusive economic growth needed to reduce poverty and improve wellbeing; and improved environmental management needed to tackle resource scarcities and climate change.

Economic and social impacts of environmental degradation are particularly important for developing country like India. More so due to high vulnerability to climate change with severe economic, social and ecological threats from energy, food and water insecurity due to climate change and extreme weather risks. Further, premature deaths due to pollution, poor water quality and health also undermine its development. Although the developing countries historically contributed only minor shares to global greenhouse gas (GHG) emissions compared developed countries, India as an emerging economy today not only contributes to global economic growth but is also seen as a major source of concomitant emissions and guzzler of natural resources. To tackle many of the growth and development challenges mentioned above without compromising future growth and poverty reduction goals, the concept of green growth has emerged as a new approach to reframe the conventional growth model and to re-assess many of the investment decisions in meeting.

2.3 Sustainability – Energy Linkages

This section deals with studying the sustainability – energy linkages. The role of energy in economic growth and development is discussed followed by discussion on use of energy as developmental indicators. The later part of the section deals with the process of energy transition and its manifestations for Indian economy.

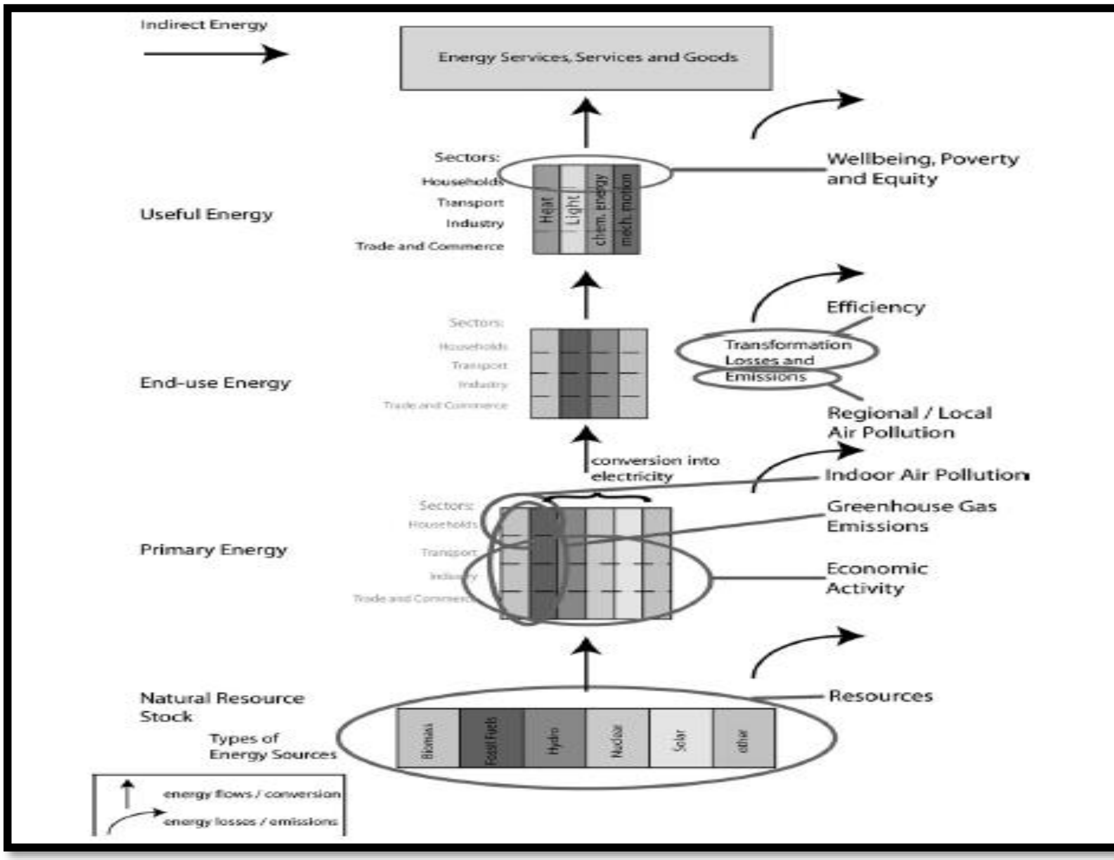
Being an emerging economy, energy discourse from India is inextricably linked with various developmental issues. Although not an explicit goal itself, energy and its access constitute a prerequisite underpinning linked to all Millennium Development Goals (MDGs). Access to electricity and modern energy services contribute to: inter alia, higher yields in agricultural production; increased access to information and telecommunications; improved health and quality of healthcare; and improved standard of living in general. It also contributes significantly to gender equality and education (UN general assembly, 2008). Therefore, the role of energy is recognized as pivotal in articulating sustainable development goals. Furthermore, energy-based indicators have been commonly used for sustainability measurement, the next subsection details use of some of these energy indicators for sustainability measurement.

2.3.1 Energy based Sustainability Measurement

Sustainability measurement requires that an equal consideration and weight to be given to all three key aspects of sustainability i.e. economic, social, and environmental. This means that economic development that disregards environmental and social aspects is likely to be unsustainable, so would be courses of action that focus only on social or environmental aspects while disregarding the economy. This idea assumes a special meaning in developing countries, A focus on fast development to help the economy and alleviate poverty are also contributes to worsening environmental degradation, creating public health-threatening conditions. Alternatively moving to slow development pathways means that poverty remains at an unacceptably high level.

While energy itself is generally not recognized as being one of the basic needs, it is clearly necessary for the delivery and provision of basics like food, clean water, shelter, health and educational services (Toman and Lemelkova, 2003). According to Kemmler & Spreng (2007), since human activities are closely linked to energy use, the energy system is a good candidate for providing a small, manageable list of interlinked lead indicators, with the ability to track sustainability. **Figure 2.1** explores relationship between energy system and the related sustainability dimensions. Sustainability issues relate to the production and use of energy and its possible to estimate future energy flows, demand and distribution with common energy-economic models. Initially use of energy indicators has been limited to environmental and economic issues. For instance, to measure negative effects on the ecosystem (climate change, air pollution) or describe resource stock changes and economic activities. This may satisfy the demand for measuring sustainable development in already ''developed'' countries, where the sustainability discussion is focused on environmental topics.

Figure 2.1: Energy System and related sustainability dimension



Source: Kemmler& Spreng (2007)

However, the situation is different in developing countries, where socio-economic issues like poverty alleviation and fulfillment of basic needs are a priority. Thus, inclusion of a poverty indicator is indispensable in a set of indicators for measuring sustainability in developing countries **(Table 2.1).** Nevertheless, a close relationship between human activities and energy use exists, poverty is linked to energy use, and some aspects of energy consumption can be used to derive an indicator of well-being and poverty .

The framework discussed above primarily deals with demand side treatment of energy for meeting sustainability goals focusing on energy access and use. However, sustainability of energy supply forms another critical concern relating to the developmental trajectory as economic growth leads to greater energy demand, making security of supply critically important. Usually the analysis is done at country level for various policy formulation. An array of indices has been used for assessment of a country's energy security and sustainability concerns. **Table 2.2** provides a detail of some important indices widely used.

Table 2. 1: Energy based matrix for sustainability measurement

	Sustainability Criteria	Indicator
ECONOMY	Economic Activity	Total Primary Energy Consumption (MToe)
	Efficiency	Energy Intensity
	Energy Resource Stock	Ratio of renewable to total energy resource used
ENVIRONMENT	Climate Change	Sum of released CO_2 equivalents due to energy use (MT)
	Local and Regional Air Pollution	Fuel Based Emissions of SO_x and NO_x
	Indoor Air Pollution	Number of people relying on solid fuels for cooking
SOCIETY	Poverty	Access use Matrix Poverty rate
	Equity	Gini Index for access adjusted useful energy

Source: IAEA, 1999

Most of these indices focus on certain specific aspects of energy security; primarily on the economic dimension while neglecting environmental and social aspects; on specific fuels, such as oil and gas, while neglecting energy sources such as renewable energy, nuclear and coal. However, a couple of them such as S/D Index (Scheepers et. al., 2007), Model of Short-term Energy Security (MOSES) (Jewell, 2011) and the index developed by Sreenivas and Iyer (2014), comprehensively attempt to measure major facets of the performance of the energy system. Yao and Chang (2014) have undertaken a quantitative analysis of energy security in China using the 4 A's framework.

Table 2.3 Energy Sustainability Indices

S No	Index	Details
1	Energy Security Index (ESI price & ESI volume)	IEA (2007)
2	Willingness to pay function for security of supply	Bollen (2008)
3	Oil Vulnerability Index	Gupta (2008)
4	Geopolitical energy security Measure	Blyth & Lefevre (2004)
5	Risky external supply Index	Le Coq and Paltseva (2009)
6	Energy Development Index	IEA (2010)
7	Energy Sustainability Index	Doukas et. al (2012)
8	Aggregated Energy Security Performance Indicator	Martchamadol and Kumar (2013)
9	4 A Framework	Yao and Chang (2014)
10	SES Index	Narula, Reddy & Dev (2017)

Compiled from Narula et. al, 2017

Using a similar approach Tongsopit et. al. (2016) applied the 4-As framework to measure the status of energy security of ASEAN countries. SES Index (Narula, Reddy & Dev, 2017) examines four quantitative indicators for each A's related to availability, applicability, affordability and acceptability and examines the trends from 2005 to 2010.

Energy communicates with sustainability issues multidimensionally. A representative framework for energy linked sustainability measurement thus primarily falls on contention and context of the analysis. In this study our attempt is to map the impacts associated with ongoing Indian solar transitions from a economic perspective. This necessarily involves trying to evaluate the process of change i.e. integration of renewable energy technology is already existing energy mix and its implications on economy.

A shift from fossil fuel based economy to renewable energy base is one of the most endorsed sustainable development agenda. Energy sector as a whole is responsible for approximately 70% of total global greenhouse gas emissions, constituting a major cause of climate change. Over the past two decades there has been increasing recognition and consensus that a transformation of the energy systems is required if the disastrous impact of climate change were to be reversed (UNCTAD, 2009).

According to Moroney (1992), although energy's cost share in GNP is observed to be small as compared to employment or capital but its role is primary coequal with capital formation. Kraft and Kraft (1978) in their pioneering study confirmed that there exists a unidirectional causality running from energy consumption to GNP for the United States during the period of 1947-1974. The relationship between energy and economic growth for India has also been extensively researched and a few common trends have been reaffirmed by existing studies.

2.3.2 Economic Growth & Energy Use in India

Substantial prior literature exists dealing on various aspects of linkages between energy and economic growth in India. According to Ghosh (2002), there is bi-directional causality between energy consumption and economic growth. The long-run causal relation runs from GDP to energy consumption and the short-run causal relation runs from energy consumption to GDP. Chen et. al. (2007) tested causality for 10 Asian countries including India and found a unidirectional short-run causality running from economic growth to electricity consumption, and a feedback in the long-run. Salim et. al. (2008) examined the short-run and long-run causal relationship between energy consumption and output in six non- OECD Asian developing countries and found that energy consumption to output in India, Pakistan and Bangladesh remains as an energy neutral economy, confirming the fact that it is one of the lowest energy consuming countries in Asia. In a similar study, Rafiq (2008) also finds mixed results for the major developing economies of Asia.

Further a study finds unidirectional short-run causality running from economic growth to electricity supply (Ghosh 2009) higher income propels higher demand of electricity, through the extensive use of electrical appliances in end-use sectors specifically in industrial commercial and domestic sectors, which necessitates supply augmentation to mitigate demand obligations. There is an absence of causality running from electricity supply to real GDP. Further Pradhan (2010) finds that there exists a unilateral causality from economic growth to electricity consumption for both long and short run.

The power mix in India is predominantly coal based but a positive causality between coal and economic growth is not well defined. Jinke et. al (2008) find no causual relationship between coal and economic growth in India (Jinke 2008). Subsequently relationship between coal and economic growth was revisited to and it was revealed that there exists a unidirectional causality running from coal consumption to economic growth in India (Wolde-Rufael 2010, Li 2 011). Further Jayayantha kumaran (2012) compared CO_2 emissions, energy consumption, trade and income of India and China and concluded that per capita income and energy consumption contributed to more emissions in India than China. **Table 2.4** tabulates the results discussed above. The empirical relation between coal and GDP shows a unidirectional causality from coal to GDP but ironically the relationship between energy consumption and GDP for India shows a unidirectional causality from GDP to electricity consumption, Greater economic growth thus would lead to more electricity demand in long run. There also exists reverse causality and a feedback loop from economic growth to electricity demand. A proactive initiative towards clean energy transitions transforming the energy mix as discussed in the previous section provides an opportunity to reduce the expected environmental impacts from energy use across the developmental trajectory for India. The next section takes up the case of renewable energy scale up in India and frames the context of sustainability impact evaluation for the thesis.

Table: 2.3 Economic growth – Energy relationships in India

Study	Relationship studied	Conclusion
Ghosh, 2002	GDP ⇄ Energy consumption	Energy to GDP short run causality GDP to energy long run causality
Chen et. al, 2007	GDP ⇒ Energy consumption	Unidirectional short run causality
Salim et. al 2008	GDP ⇒ Energy consumption	Energy neutral
Ghosh, 2009	GDP ⇒ Energy supply	Unidirectional short run causality
Pradhan, 2010	GDP ⇒ Energy consumption	Unidirectional causality in both short and long run
Jenke, 2008	Coal ⇒ GDP	No causal relationship
Rufael, 2010	Coal ⇒ GDP	Unidirectional causality from coal to growth
Li, 2011	Coal ⇒ GDP	Unidirectional causality from coal to growth
Jayanthakumaran 2012	GHG Emissions -Income-energy consumption-trade	Per capita income and energy consumption contribute to more emissions in India than in China

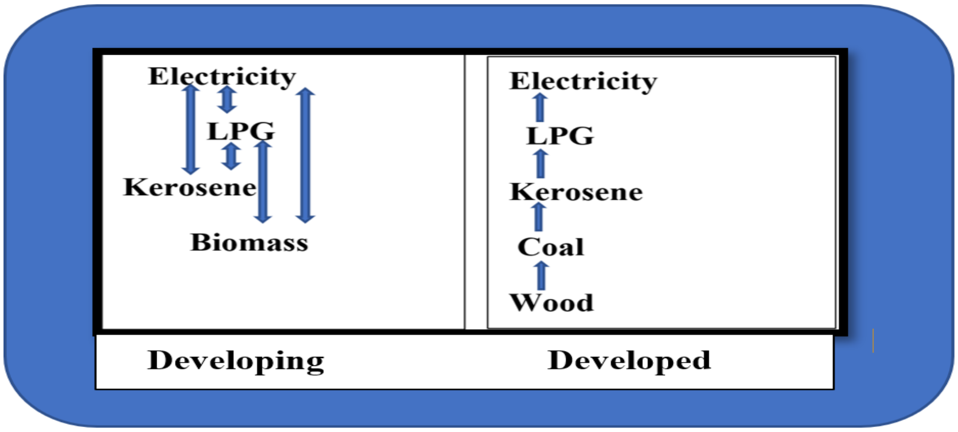
Source: Author's Compilation

2.3.3 Energy Transitions

This section discusses the phenomenon of energy transition and its characteristics for India as an emerging economy. The term energy transition refers to long term structural changes in energy system. Historically, energy transitions were understood to be following long wave pattern involving homogeneous single energy source regimes and gradual switches **(Figure 2.2).** According to Schulz et. al, 2006 the understanding of energy transitions as homogenous regime of a single energy source aligns well with the trajectory of energy use in developed countries. The nature of energy transitions for developing nations is strikingly different and various energy sources coexist in the energy bundle. The primary energy use is extremely heterogenous at household level with frequent parallel usages between various sources **(Figure 2.2.)** (Smith, 1993), thus energy use involves multiple fuel strategies, using a number of different energy sources (of varying efficiency) simultaneously (Masera, Saatkamp, & Kammen, 2000).According to Marcotullio & Schulz (2006) energy transitions experienced by developing countries are occurring sooner (at lower levels of income) increasing faster (over time) and emerging in a more simultaneous (overlapping) fashion. These transitions are more efficient in terms of its economic growth, energy supply and consumption.

This type of transition pattern can be attributed to the fact that the countries that industrialize later in time leap-frog over more advanced countries by purchasing technologies that are newer and cleaner than those found in countries that industrialized previously (Goldemberg, 1998; Mielnik & Goldemberg, 2002). Further the context under which national economies expand now is different from that of the past in several ways. The speed of economic growth is faster (Crafts, 2000). The efficiency and effectiveness of the transmission of goods, services, and knowledge across geographical space has improved, making these items available at lower costs, in greater quantities, and across a larger geographic span than ever before (Drucker,1986).. The renewable energy mediated energy transition cut across the naturally occurring established transition process by provided systematic policy mediate incentive. The section details this RET mediated new energy transitions and their emerging characteristics for India.

Fig 2.2 Energy Transitions in Developing and Developed Economies



2.3.3.1 Renewable Energy Technologies

Last decade witnessed that natural trajectory of energy transition in both developing and developed counties was intervened to resolve prevailing concerns of climate change mitigation, security of supply and energy adequacy for rapidly growing low- and middle-income countries. Developing and developed countries alike have resorted to policy mediated energy transitions focusing aggressively on renewable energy deployment and endorsement of energy efficiency regime.

Germany had been the pioneer setting a new trend for energy transition with a systematic policy to phase out its nuclear capacities and bring decentralized renewables and energy efficiency regime. However, these policies mediated transition are known to differ in terms of motivation, objectives, drivers and governance. According to Rio & Burguillo (2008) main motivation behind the major renewable energy incentives was rejuvenation of local rural economy in Germany putting it as a classic case of green growth initiative.

The endorsement of renewable based growth in India is an effort to diversify the coal centric energy base, ensuring and consolidating security of supply for the rapidly growing economy. Further, opportunity to leverage potential economic growth through exports diversification in new high technology sector and creation of domestic jobs have been the major drivers. India has been an early mover in the wind sector with systematic incentives to the sector dating 1983-1984. This along with the turnaround in global wind market has established India as major global player in wind energy market. The total installed capacity in the country stands at 32.17 GW till March 2017, fourth largest in the world (GWEC, 2016).

Being a tropical country potential of solar based energy generation was recognized quiet early in the country with multiple initiatives promoting solar thermal and photovoltaic installations more from the stand alone end user perspective. A systematic supply side intervention for solar scale up came up under flagship of national solar mission in 2010. A highly ambitious target of the time (20GW) was set up in the program with an umbrella of incentives for scaling up grid connected centralized solar power plants.

Sharp decline in global PV costs led to revamping the already existing solar target to 100 GW by 2022. As of April 2017, the country's solar grid had a cumulative capacity of 12.28 GW. India quadrupled its solar-generation capacity from 2,650 MW on May 2014 to 12,289 MW on 31 March 2017. The country added 3.01 GW of solar capacity in 2015-2016 and 5.525 GW in 2016-2017, the highest of any year (MNRE, 2017). The next subsection analyzing the emerging trends in Indian solar sector

2.3.3.2 Emerging trends in Indian solar Sector

Unlike Germany, solar sector in India is emerging as predominantly supply-side interventions towards energy transitions. The market structure demonstrates oligopolistic traits with a handful of major players articulating greater capacity addition in the initial phase (Bridge to India, 2015).

The price of solar generation has been drastically falling with the lowest quoted generation price of 2.44 Rs/ Kwh for Bhadla project in Punjab in May, 2017 (Bridge to India, 2017). This has brought the cost well within the grid parity providing a positive incentive for further installations. However, this supply side consolidation do not tackle the issue of energy access and demand side energy security critically important for India and therefore cannot be directly evaluated as energy linked sustainability issue.

However, commitment to 100 GW of solar deployment (accounting for more then 30% of already existing generation capacity in India) would bring in concomitant concerns in terms of substantial lock in of capital and resources across the deployment process in a short-span of time. This can potently influence the future development trajectory and therefore evaluating sustainability impacts of solar deployment process become critically important. The next section details some topical developmental concerns for India and stated potential possibilities associated with regional solar deployment. The section ends by setting up a framework for sustainability analysis of solar transition in India.

2.4 Developmental Concerns & Solar transitions

India proactively launched a comprehensive program under the umbrella of National Action Plan on climate change (2008) delineating eight major initiatives for climate change mitigation in the country. The current ambitious solar program i.e. National Solar Mission is one of the key initiatives. The agenda not only internalizes country's commitment towards climate change mitigation but also provides a base for alleviating intrinsic climate change vulnerabilities, facilitating climate change adaptation efforts.

According to Stern's report (2006) developing regions are at a geographic disadvantage with respect to climate change phenomenon as they are already warmer, on average, than developed regions, and they also suffer from high rainfall variability. As a result, further warming will bring poor countries excessive costs and few benefits. Anthropogenic climate change would impact all sectors of the Indian economy. Increase in atmospheric temperature above normal would lead to higher fluctuation in rainfall patterns. Abnormality in rainfall would result in severity and frequency of floods and drought. Further rising atmospheric temperature would lead to melting of polar icecaps increasing mean sea levels impacting large populations in peninsular and coastal areas. Agriculture is most vulnerable sector that directly gets affected by climate change compared to other sector of economy both physically and economically (Gbetibouo & Hassan, 2005). Thus, it would impact livelihoods of people occupying around 40% of the global land, 70% of global water resources and affect biodiversity at all scales (Masters *et. al.*, 2010).

The Stern report 2006 has forecasted that in India, poorest of the strata which are heavily dependent on agriculture, would be, the most climate-sensitive of all economic sectors. More over their low incomes and vulnerabilities make adaptation to climate change particularly difficult. Because of these vulnerabilities, climate change is likely to reduce further already low incomes and increase illness and death rates in developing countries. Falling farm incomes will increase poverty and reduce the ability of households to invest in a better future.

Many of the socio-economic indicators used for climate change vulnerability measurement in various studies like Ruijven et. al, 2013, Brikmann et. al, 2011(World Risk Index), Global Adaptation institute, 2011 (GAIN index) show inextricable link with availability of energy supply. For instance, climate change impacts on indicators for health, agricultural productivity and water accessibility can be favorably modified by access to modern energy supplies.

Further, various research studies show that the process of increased solar deployment can have favorable impacts on economies both during deployment and ex post. Increased deployment contributes to regional development (Lopez et. al, 2007; Mıguez et. al, 2006; Faulin et. al, 2006), enhanced employment opportunity especially in rural area (Caldes et. al 2009, Heallebrand et. al, 2006, Bergmann et. al, 2006; El Bassam and Maegaard, 2004) along with improved health conditions due to minimized environmental impacts during energy generation. Moreover, energy accessibility also has close links with alternative livelihood generation capabilities leading better prospects for adaptation to any climate change genic vulnerabilities.

Thus, the process of solar deployment should be scrutinized in a way that existing developmental concerns for India are addressed. Thus, in the following section we integrate the green growth expectation with the above stated topical developmental concerns to synthesis a framework for evaluating sustainability impacts of solar deployment.

2.5 Framework for evaluating sustainability of India solar transitions

Ensuring sustainable supply of energy is a critical challenge for an emerging economy like India posed with conditions of energy poverty, greater climate change vulnerabilities and high population growth rates. National Solar Mission is one of the key initiatives undertaken under the umbrella of National Action Plan on Climate change (NAPCC) by government of India in the year 2008. According to Mercure et. al (2016) the alleviation of climate genic environmental degradation strongly depends on the diffusion of energy-related innovations, technologies and practices throughout industries and between households. In many cases, low-carbon alternatives already exist. However, whether their adoption can be incentivized in time to avoid dangerous environmental change, and whether this is economically or technically possible, are debatable. There are four major areas where uncertainty contributes to decisions for clean technology transitions for climate policies (1) the dynamics of technology adoption and diffusion; (2) macroeconomic impacts of low-carbon policies; (3) interaction between human and environmental systems; and (4) policy implementation and effectiveness.

The extent to which technology diffusion can support economic development is not well understood. Moreover, it is also unclear whether climate policies may influence access to food, water and energy, and – if so– how. Hence, guidance on how to understand the complex interactions between technology, macroeconomy, and the environment is much needed. The rationale behind the current analytical framework stems from the needs to internalize complexity and uncertainty in interactions between technology, society, macroeconomy and environment.

It is argued that policies formulated for renewable energy scale up and deployment have to be scrutinized for their efficiency to meet multiple developmental goals. Evaluation of solar transitions in Indian economy should transcend the existing framework of conventional industrial policy strategy and free trade obligations to bring in perspectives of developmental strategy fine-tuned for alleviating intrinsic climate change vulnerabilities and aspired developmental concerns.

A shift from fossil fuel based economy to renewable energy base is one of the most endorsed sustainable development agenda. Renewable energy promotion has been identified and promoted as the major driver for green growth in India. Taking cues from emerging dynamics of global RET based green growth, India has scaled up its renewable energy deployment targets to 175 GW by 2022 in the year 2015 (MNRE, 2015).

This has come in union with India’s ratification to UNFCCC Paris Agreement (2015). The country has put up an ambitious target of Intended Nationally Determined Contributions (INDCs), for climate mitigation. This includes an effort to reduce carbon emissions relative to its GDP by 33% to 35% from 2005 levels by 2030. Further a target of sourcing 40% of the country's electricity from non-fossil fuel-based sources such as wind and solar power by 2030 has been set. An upgraded target of 100 GW grid connected solar installation by 2022 from the existing 20 GW laid down by national solar mission in 2010 is expected to be the key game changer for these targets.

The interpretation and strategy towards green growth by economies have been disparate. The year 2008-9 economic stimulus packages for green growth by some governments was approached from a short-term growth perspective where the potential to boost jobs and incomes through increased investment in some green (notably low-carbon) technologies remained the focus. Others approached green growth agenda from an environmental perspective. Here, the potential to internalize environmental externalities by mainstreaming sustainable development requirements into economic decision-making, notably through resource pricing and land use/infrastructure choices was focused. A third imperative, of equity and inclusion, has more recently been asserted especially by developing countries following the notion that green growth should serve those excluded by the current economic system. **Table 2.4.** delineates a generic set of green growth outcomes that developing countries are increasingly intending to pursue

Table: 2.4 Green Growth: Expectations of developing economy

Economic
1. Increased and more equitably distributed GDP
2. Increased production of unpriced ecosystem services (or their reduction prevented)
3. Economic diversification, i.e. improved management of economic risks
4. Innovation, access and uptake of green technologies, i.e. improved market confidence
Environmental
5. Increased productivity and efficiency of natural resource use
6. Natural capital used within ecological limits
7. Other types of capital increased through use of non-renewable natural capital
8. Reduced adverse environmental impact and improved natural hazard/risk management
Social
9. Increased livelihood opportunities, income and/or quality of life, notably of the poor
10. Decent jobs that benefit poor people created and sustained
11. Enhanced social, human and knowledge capital
12. Reduced inequality

Source: OECD Consultation draft, 2012

The thesis develops framework for quantitative assessment of impacts associated with scaling up grid connected solar deployment in India from a sustainability perspective. The boundary for analysis has been designed to asses economic, social and environmental green growth outcomes which are increasingly pursued by developing economies (OECD, 2012) while investing in clean energy technologies. Following aspects of triple bottom line have been analyzed for two different deployment mechanisms predominantly adopted in India i.e. deployment involving domestic content requirement (DCR) or deployments with imported solar panels.

The work limits itself to analyze and assess the impacts of the process of solar deployment on Indian economy. The impacts of energy transitions due to solar based generation post deployment have not been included in the analysis. The rationale of the boundary has been set as solar generation do not illicit strong and continuous inputs demand across the economy post deployment for its lifespan. The analysis of deployment process is crucial because it encompasses opportunity of inclusive economic growth needed by developing countries to reduce poverty and improve wellbeing; and improved environmental management needed to tackle resource scarcity. Further India has ratified Paris convention with a target of 100GW of solar generation by 2022. Thus, substantial resources would be diverted to the capacity creation in a small timeframe.

Table 2.5: Evaluating Developmental Impacts of solar deployment process

Parameters	Sustainability Assessment Variables
Economic	1. Increased and more equitably distributed GDP and employment 2. Economic diversification
Social	1. Increased, income and/or quality of life, notably of the poor 2. Decent jobs that benefit poor people created and sustained 3. Reduced inequality
Environmental	1. Environmental impact in terms of CO_2 emissions of solar deployment process

The above framework is assessed by developing a quantitative methodology for mapping expansive impacts of investments in solar sector from sustainability perspective. Systems research framework based Input-Output (I-O) analysis, Social Accounting Matrix (SAM) and Environmentally Extended Multiregional Input-Output (MRIO) analysis is performed to evaluate economic, social and environmental impacts (estimated in terms of embodied GHG emissions) of ground mounted grid connected solar photo voltaic (PV)[3] deployment process in India.

2.6 Conclusions

This chapter explored various critical aspects of green-growth – Sustainability paradox to set up a framework for analyzing developmental impacts of Indian solar

[3] Grid connected ground mounted solar PV presently constitutes 98% of total solar deployment capacity in India

transitions. The various section in this chapter were compiled to understand the linkages between the key elements under transition i.e. technology & energy, their conceptualized role in the sustainability discourse. This was then compared with the actual emerging structure and form of the policy mediated implementation of the stated developmental goals. The findings of the chapter can be highlighted as i) Sustainability agenda favors a technology centric pathway with concept of green growth emerging as the most endorsed interpretation of efforts towards sustainable development iii) The developing countries highlight differentiation in green growth goals focusing on equitable and inclusive green growth. iv) Energy forms a critical yard stick for evaluating developmental goals but cannot be integrated for evaluation in the case of Indian solar transitions as the emerging solar sector in India integrates from the supply side and do not directly link with issues of energy access and end use and livelihood generation. v) The renewable energy transitions are policy mediated and do not follow the conventional trajectory of energy transitions, they have a more socio political orientation and tend to explicitly hem in expectations of regional economic growth, vi) The process of solar deployment should be assessed under triple bottom line of economic, social and environmental impacts on Indian economy in order factor in topical developmental concerns of inclusive & equitable growth under climate constrained environment.

This chapter sets a rationale, boundary and framework for sustainability analysis of solar transitions in India. The next chapter **(Ch-3)** goes deeper into the policy structure and emerging landscape of solar sector in India dealing with technical and policy boundaries established for further quantitative analysis in the later chapters.

Chapter 3

Green energy internalization: Policies for solar promotion in India

3.1 Introduction:

This chapter highlights role of green growth policy mediated internalization of renewable energy technologies with in an economy. The key focus is to set in a framework for 'Technology-Policy' boundary of this research. This chapter thus compiles key characteristics of transitions in Indian solar sector. The procedure involves mapping existing solar policy structure in India followed by delineation and analysis of the emerging trends in the solar sector with respect to the policy in place.

In this context, the initial section details process of socio technical transition and challenges associated with developing clean technology innovation system. This is followed by discussion on the existing framework for the solar innovation system in India, its performance and visible future trends. A brief history of solar promotion in India is compiled, followed by details of solar policy structure and elements. The delineation of policy structure leads to discussion on structure and emerging trends in solar panel and BOS manufacturing ecosystem for India followed by analysis of emerging solar deployment ecosystem in India.

The following section delineates pedagogy of conceptual frameworks for solar transitions analysis which has been informed by various emerging concepts of sustainability transitions, technology transitions and socio technical regime. An input in the form of policy-based incentives towards technology transition is expected to provide an outcome in the form of sustainability transition.

3.2 Sustainability Transitions

The conceptualization of sustainability transitions as explained by Smith et. al (2005), talks of developmental dynamics targeting at long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption. One of the key characteristics of these transitions is that guidance and governance would play a particular role in the transformation process.

As discussed in Chapter 2 technology transition has been universally endorsed as preferred means to actualize sustainable mode of consumption & production. According to Berkhout et. al (2010) alternative pathways for technology transition will manifest differently for industrialized and rapidly industrializing economies as much of the innovation and learning that contributes to technology centric alternative development pathway will be occurring in late industrializing countries. Further, according to Schulz et. al (2006) the technology transition process for developing countries will involve time-space telescoping where transitions would be happening much sooner, faster and more simultaneously as compared to developed countries.

Solar transition in India effectively demonstrates phenomenon of time-space telescoping. The grid connected solar generation capacity in India grew from less than a 100 MW in 2010 to more than 12 Giga watts in 2017. The rapid growth in the sector can be attributed to growth in global solar markets following Germany's nuclear phase out and major incentives to solar deployment in 2009 (Renewable Energy Sources Act, 2009). Taking the clues from then emerging global trends, India proactively set a target of 20 GW grid connected solar by 2022 under the flagship of National Solar Mission (MNRE, 2010). The solar panel price have plummeted about 80% due to unprecedented increase in manufacturing capacity in China's where integrated assembly lines were introduced for solar panel manufacturing in 2010. Since then, India has revamped its existing solar targets to 100 GW of grid connected solar by 2022 with the new national electricity plan, Govt of India (NEP, 2016) targeting renewables to constitute 56.5% of total installed electricity capacity in India by 2027.

The development pathways of economies are known to be constituted by a set of interlocking and interacting socio-technical regimes. India on its developmental path has proactively endorsed solar transitions for overcoming overarching challenges of security of supply and also to fortify its commitment towards climate change mitigation. The specific set of regimes represented in a given place and time shapes and lock-in its resource and environmental footprint. A technology intervention such as solar integration provides India a possibility to design an alternative balance of technological regimes involving cleaner technologies for providing energy, mobility, nutrition and recreation to the society (Berkhout et. al, 2009). The next section details the concept of socio technical regime and technology innovation system.

3.2.1 Socio technical regime & sustainability transitions

Transition's research has its basis in system's approach and bring in the concept of socio technical regime (Kemp et. al, 1998. The concept of regime is based on the premise that scientific knowledge, engineering practices, and process technologies are socially embedded thus seamlessly intertwined with the expectations and skills of technology users, institutional structures and broader infrastructures. The existing or incumbent regime consist of actors networks (individuals, firms, and other organizations, collective actors) institutions (societal and technical norms, regulations, standards of good practice) as well as material artifacts and knowledge (Geels, 2004; Markard, 2011). The different elements of the system interact, to provide specific services to the society. This incumbent regime imposes a logic and direction therefore allowing only incremental socio-technical change along established pathways of development sociology of technology . Therefore, energy transitions guided towards sustainability would involve a set of directed processes that could break this regime and lead to a fundamental shift in existing socio-technical energy systems (e.g., Geels and Schot, 2010; Kemp, 1998).

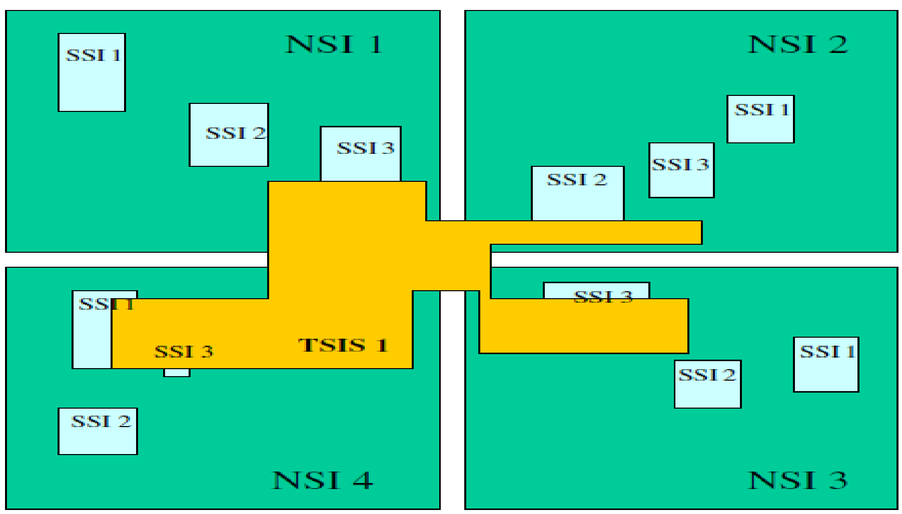
Much of the early work in the field of sustainability transitions dealt with the question of how to deliberately reorient regimes and manage transitions toward sustainability (Kemp, 1994; Kemp et. al., 1998; Schot, 1992; Schot et. al., 1994.). The existing socio-technical regimes are characterized by path dependence and lock-in, resulting from stabilizing mechanisms on the three dimensions (Unruh, 2000). First, incumbent actors have vested interests and social networks representing ‘organizational capital’. Second, regulations and standards may stabilize regimes, and cognitive routines may blind actors to developments outside their focus. Third, existing machines and infrastructures stabilize through sunk investments and technical complementarities between components. These stabilizing mechanisms although provide growth of regimes, but also serve as obstacles to their transformation once they have achieved maturity. During transitions, each of these stabilizing forces must be weakened, allowing new regimes to grow, achieve stability and to become dominant. Usually an alternative to the existing innovation system will have to be articulated with the help of policy incentives to sustain new regime. The next section details feature of solar technology innovation system.

3.2.2. Solar technology innovation system (TIS)

According to Hekkert et. al (2007), the TIS can be effectively explained in the case of development and diffusion of solar cells. Solar cell innovation and adaptation depends on technological progress made in research institutes and universities all over the world. Thus, the solar cell innovation system overlaps with those parts of national innovation systems that concentrate on solar cell research. In turn, global diffusion strongly depends on different national policy regimes that stimulate the adoption of solar cells by means of investment subsidies or feed-in laws.

The solar cell innovation system overlaps with various national innovation systems in terms of stimulating institutions for solar cell diffusion. Furthermore, the production conditions for solar cells strongly depend on the microelectronics sector due to competition over silicon wafers. Silicon wafers are produced for the microelectronics sector, but the surplus of wafers is sold to solar cell manufacturers. High growth rates in the microelectronics sector lead to silicon shortages and higher prices of solar cells. Furthermore, the application of solar cells strongly depends on the housing sector, including architecture. Solar cell friendly architecture can greatly influence the potential for solar cells in the building environment and the energy output of these cells. Thus, the technological progress, price, and diffusion of one technology is influenced by the various national innovation systems and sectoral innovation.

Figure 3.1 A Technological Innovation System



Source: Hekkert et. al, 2007

The TIS of a technology is also defined by spatial mobility (Carvalho, 2015) of a technology. For instance, wind technologies (and their sub-components) are physically large, thereby having high shipping costs (Pew, 2013). The risk of damage to components during shipping is large, potentially leading to malfunctions. To avoid these conditions, manufacturing plants for wind components tend to be close to the deployment markets (Gosens & Lu, 2013; Lewis & Wiser, 2007). Biomass electricity generation is another example of a green industry that has high transport and logistics costs, with the sourcing biomass products accounting for a significant proportion of these overall costs (GWEC & BNEF, 2013). Thus, the large-scale markets for wind and biomass technologies tend to source technologies from local manufacturing plants. In contrast, solar PV technologies have low transport and logistics costs. The modularisation of solar PV enables its sub-components to be produced and assembled in discrete economies and exported to final markets. Therefore, solar PV production networks are integrated globally (Wang, 2013) and vulnerable to trade tariffs (Zindler, 2012).

Along with technology development and diffusion which crosses geographic boundaries incentives for transitioning into new technological regime is not purely technocratic process. The use of public investment and policy to support green technologies means that it is subject to domestic, political and social contestation. Domestic Institutional factors along with characteristics of technology itself play a crucial role in determining overall structure of technology innovation system. A strategy to fully leverage benefits of investments in green growth solar sector warrants a trade regime that favours locally produced technologies over those produced outside the country by putting up local content rules. The latter requires that imported technologies are produced using a defined level of inputs sourced in the target economy. Industrial policies for Brazilian and Chinese wind markets, as well as Chinese and Japanese solar PV markets, all have local content rule restrictions (Lewis & Wiser, 2007; Matthiessen et. al, 2013; UNEP, 2011). Therefore techno-nationalist industrial policies can structure domestic market mechanisms to retain manufacturing within the domestic economy despite global competition.

DCR /LCR were introduced as policy instruments for aiding the developing solar innovation system under national solar mission in India which has been recently objected by WTO with India to reconsider the trajectory of solar growth in India. This has been additional to already existing difficulties in developing clean technology innovation system as discussed in following section.

3.3. Developing Clean Technology Innovation System

One of the overarching global challenge is inducing innovation in the existing energy system for stabilizing the climate. This would involve selecting, timing and implementing institutional changes to break the incumbent regime and pave way for transitioning to cleaner energy systems. According to Nemet (2008) innovation in low carbon energy technologies is difficult due to multiple market failure conditions. According to Jaffe et. al, 2005, Fisher and Newell 2008 and Acemoglu et. al. 2010, there exists double externality problem associated with environmental innovation. Firstly as major knowledge generation occurred in public domain there exists a strong possibility of knowledge spill over as firms have under invest relative to socially optimal level of R&D (Nelson, 1959: Arrow 1962 b, Teece 1986, Jones & Williams 1998) Therefore other firms can reverse engineer new products using the knowledge in public domain. The second market failure is that pollution externality of GHG emissions is an unpriced negative externality (Dales, 1968).

As GHG emissions create future damages thus offsetting GHG emissions is a public good thus its value appropriation of future damage is difficult by the firms. The failures can also be attributed to some extent on the fact that interaction effect of the above two market failure create further disincentive for investment (Fischer 2004). Further increasing returns that accrue by technology already in the market discourage development of technologies which are not already commercialized (Kaldor, 1972 , Arthur, 1989, Drissen, 2003, Sanden and Azar, 2005).

According to Nemet(2010) low carbon innovation amongst multiple market failures poses a dilemma for technology policy as how should public funds be allocated across a diverse set of policy instruments for an unknown number of technological options over multiple decade time scale. Further there also exists a national or regional agenda that need to be addressed while diverting public funds towards clean energy technologies. The local issues can be summarized as diversification of energy supply, enhanced regional and rural development opportunities, creation of a domestic industry and employment opportunities (Rio & Burguillo, 2007).

According to Vona et. al (2012) two global oil shocks of 1970's have been the major turning point bringing a fundamental shift in the perception of the developed world from energy being an inexpensive and plentiful resource to one which is limited and whose future was unpredictable. These crises not only increased the oil prices but also provided the first push for investments in energy efficiency and green R&D. Thus concerns regarding of security of supply instigated policy makers to increase public sector spending on R&D activities that can lead to energy self sufficiency. According to Nemet (2010) many demand pull and technology push strategies in case of global energy transitions can be traced to this shift.

To increase the share of renewable sources in total energy supply, many governments have sought to encourage further development and adoption of RETs. For instance a European Union (EU) directive of 2001 (Directive 2001/77/EC) provides development of renewable energy in Europe. In March 2007 EU heads of state have agreed to set a binding target for renewable energy use at 20 percent of EU's total energy need by 2020. In United States, federal tax credits for renewable energy were extended in 2006, granting production tax credits from bio energy, geothermal, wind and other renewable energy sources (US DOE 2007).

Renewable energy scale up in India has also been initiated to fulfill multiple goals. Major drivers can be summarized as ensuring security of supply for an emerging economy, overcoming climate change vulnerabilities along with enhanced development opportunities through creating domestic industry and employment opportunity. Next section summarizes the policy structure and solar Innovation system in India.

3.4 Solar Innovation System in India

India's engagement with renewable energy promotion has been very long. It was recognized pretty early that renewable energy provide key possibilities for securing security of energy supply in India. The country is distinguished to have established a separate Ministry for Non-Conventional Energy Sources (MNRE) very early (1987) which has been responsible for targeting and financing renewable energy initiatives in the country. Conventionally MNRE through its subsidiaries like Indian Renewable Energy Development Agency (IREDA), have been instrumental in providing soft-loan and subsidies for solar promotion, often administered at the state level to both technology suppliers and consumers (Bakthavatsalam, 1999). Currently most states have a state nodal agency that administers the loan. In 2001, the central government passed new energy legislation that called for the increased provision of renewable energy to meet rural energy needs and provide decentralized off-grid energy supply for the agricultural, industrial, commercial, and household sectors in rural and urban areas .

India being a tropical country has immense potential for solar power generation. Country enjoys over 300 sunny days annually There have been a number of long running programs promoting demand side use of solar energy for cooking, lighting, water heating, small solar home systems and water pumping for agricultural use. India undertook a long term solar cooker promotion program (1980-1994) where in 30% subsidy was available on the solar cooker purchase which was subsequently reduced to 15 % thereafter subsidy is being available to manufacturer on 50% cost sharing basis (Since 1994).MNRE initiated a solar lantern program in early 2000 providing 30% capital subsidy on solar lantern purchase till 2009. Punjab electricity development authority under took a program for financing large scale PV pumps between (2000-2004) providing more that (70 %) subsidy on agricultural water pumping

There have been series of sectoral reforms augmenting renewable promotion in India. The liberalization regime lead to two major reforms in early 1990's for the energy sector. The initial reform in the year 1990 opened utility companies to private competition in India followed by a second reform in 1993 imposing demand side subsidy reduction. This has been followed by few major institutional changes for integration of renewable energy in the power mix as summarized below

• **Electricity Act 2003:**.The aim of this act was the modernization and liberalization of the energy sector through the implementation of a market model with different buyers and sellers. The main points included making it easier to construct decentralized power plants, especially in rural areas and for captive use by communities, and giving power producers free access to the distribution grid to enable wheeling.

• **National Electricity Policy 2005:** Allows State electricity regulatory commission (SERC) to establish preferential tariffs for electricity generated from renewable sources. National Tariff Policy 2006: Mandates that each SERC specify a renewable purchase obligation (RPO) with distribution companies in a time-bound manner with purchases to be made through a competitive bidding process.

• **Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) 2005**: Supports extension of electricity to all rural and below poverty line households through a 90% subsidy of capital equipment costs for renewable and non-renewable energy systems.

• **Eleventh Plan 2007–2012**: Establishes a target that 10% of power generating capacity shall be from renewable sources by 2012 (a goal that has already been reached); supports phasing out of investment-related subsidies in favor of performance-measured incentive. The latest national electricity plan (NEP-2016) puts the target of 40 % renewables in the energy mix by 2027. The major composition change is expected to come from the existing target of 100 GW grid connected solar by 2022 with over

As the major capacity addition in renewable energy sector is post reforms, The Indian renewable energy sector is predominantly driven by the private sector. The next section delineates the details of the current solar policy and program initiated under flagship of national solar mission (NSM) in 2010.

3.4.1 National Solar Mission (NSM)

For realizing immense solar potential in India an ambitious program, Jawaharlal National Solar Mission (JNNSM) was launched on January 11, 2010. The objective of the program has been to establish India as a global leader in solar energy by creating the policy conditions for rapid technology diffusion and investment across the country. The key initial mission targets are enumerated below

- To create an enabling policy framework for the deployment of 20,000 MW of solar power by 2022. As the global dynamics of solar based generation transformed this target has been revamped to installation of 100 GW of grid connected solar by 2022
- To ramp up capacity of grid-connected solar power generation to 1000 MW within three years by 2013; an additional 3000 MW by 2017 through the mandatory use of the renewable purchase obligation. As the capital cost of solar utility installation drastically dropped the earlier targets have been already surpassed and Indian solar capacity stands at over 6 GW
- To create favorable conditions for solar manufacturing capability, particularly solar thermal for indigenous production and market leadership.
- To promote program for off grid applications, reaching 1000 MW by 2017 and 2000 MW by 2022
- To achieve 15 million sq. meters solar thermal collector area by 2017 and 20 million by 2022.
- To deploy 20 million solar lighting systems for rural areas by 2022.

The Mission adopted a 3-phase approach, Phase I – up to 2012-13, Phase II from 2013 to17 and phase III from 2017 to 2022.

The policy uses a wide umbrella of dynamic policy instruments aimed at efficient rent management under the conditions of emerging cost and technology trends both under domestic and global spaces. The aim was to protect government from subsidy exposure in case expected cost reduction does not materialize or is more rapid than expected (MNRE, 2011). The next sections detail various policy instruments, structure and elements put in place for solar scale up and their performance.

3.4.2 Policy instruments for Solar Promotion

The Indian government subsidizes solar power through a variety of policy mechanisms like financial incentives, public financing and regulatory policies and their associated instruments as illustrated in **Table (3.1)** Renewable energy source (RES) subsidies constitute market intervention on the part of the regulator are designed to increase RES production by either lowering production cost or consumer costs to under market rates or requiring demand to purchase certain volume of RES such subsidies can be direct or indirect (Kammen & Pacca, 2004). Table **3.2 & 3.3** delineates various direct and indirect subsidies for solar promotion

Table 3.1: Policy Mechanisms & Instruments for Solar Promotion

Policy Mechanisms	Policy Instruments
Financial Incentives	Capital Subsidy , grants , rebates Tax Incentives Energy Production payment
Public Financing	Public investments, loans or Financing Public competitive bidding
Regulatory Policies	Feed-in-Tariff Utility Quota Obligation Net Metering Obligation and Mandate Tradable renewable energy certificate

Indirect subsidies are not explicit payments or discounts but rather institutional support tools. They include research and development funding, below cost provision of infrastructure or services or positive discriminatory rules such as regulations facilitating grid access for RES power. Direct subsidies are explicit and quantifiable payments, grants, rebates or favorable tax or premium (Batlle 2011). High inherent substitutability of energy as commodity makes it difficult for a clean technology to replace the established energy technologies in the existing centralized energy regime. Promotion of clean technologies therefore invariably depends on subsidies and incentives made available by policy makers.

Table 3.2 Direct Subsidies for Solar Deployment : NSM Phase I

Subsidy Type	Details
Power Purchase Agreements	State government undergo long term power Independent power producers
High Feed- in Tarrifs	CERC fixes a premium solar tarrifs (11 Rs to 14 Rs per unit of power produced)
Distinct REC solar credits	Rs 9.30 to Rs 13.4 per Kwh

Source : MNRE reports 2011-12

The policy targets have been revamped as the solar generation costs have been falling primarily due to the more that 80% reduction in production costs of C-Si solar PV panels. The cost of solar generation which was 15-16 INR/ kwh in the year 2010-2011 have already reached grid parity with some new mega projects like Bhadla in Punjab quoting as low as 2.44 INR/ kwh in May, 2017. The next section details the solar policy structure under national solar mission.

Table 3.3 Indirect Subsidies for Solar Deployment: NSM Phase I

Subsidy Type	Act
Providing renewable power producers (IPP) free access to the distribution grid to enable wheeling*	**Electricity Act 2003**
Setting up preferential tariffs for RE generation from and differentiated renewable purchase obligations for Discoms (state wise targets for solar generation)	**National Electricity Policy 2005**
Policy targets for renewable energy generation (10 % by 2012)*	**Eleventh plan 2007-2012**
Power unbundling and development of Renewable Energy Credit trading markets	**CERC, 2010**
Single window clearance for renewable projects	**NSM 2010**
Allows 100% FDI in the sector through JV	**MNRE 2003**
Research & development Funding	**NSM 2010**
Relaxation on Environmental Clearance i.e. no EIA for PV based solar power projects	**NSM 2010**
States facilitate utility scale solar power projects transmission substation (land, water and clearances	**NSM 2010**
Proposed solar parks in states for facilitating targeted solar capacity addition	**NSM**

* Some states like Karnataka have indicated to charge evacuation and wheeling charges in case power is wheeled out of the state

3.4.3 Solar Policy Structure

The solar policy structure is two tiered where in state governments have the autonomy to formulate and operate through a separate state level solar policy. Each state already has a state energy development authority (SEDA) which had been traditionally routing the renewable energy projects facilitated through IREDA. The policy framework and implementation get highly heterogeneous at state level.

The NSM mandates a differentiated solar capacity targets for various states with Renewable Purchase Obligation (RPOs) and Renewable Energy Credits (REC) under state jurisdiction. For specific technologies, central government policies and guidelines have been implemented to different degrees by individual states, which has resulted in inconsistencies between states. For example, states have different policies regarding which entity (developer, power purchaser, or transmission and distribution company) is required to finance the extension of transmission and distribution lines when generation facilities are developed beyond the reach of the current grid. States also have different regulations regarding technical standards such as mandating the location of the meter, which affects the measurement of the amount of energy that is sold to the grid**.** (NREL, 2011).

Most of the initial solar scale up in the country has been through the state routes. Many states did not conform to the initial domestic content requirement (DCR) put in place for the JNNSM projects and thus have been major drivers of the solar capacity scale up, by providing much needed arbitrage opportunity for international solar manufacturers to route their solar panel into Indian market. Further states were provided autonomy for instrumenting many direct and indirect subsidies to solar power plants like State of Gujarat added more than 800 MW solar capacity by providing a secured Power Purchase Agreement to the solar plant installers with no DCR requirement. The entry of international solar panels drastically reduced the cost of solar power generation from Rs 16/ KWh in 2011 to Rs 3.40 / KWh as quoted by Rewa project of Madhya Pradesh in Dec 2016 (in a short span of 6 years) falling still further . The next section details the important policy elements and sketches the details of growing solar innovation system in India.

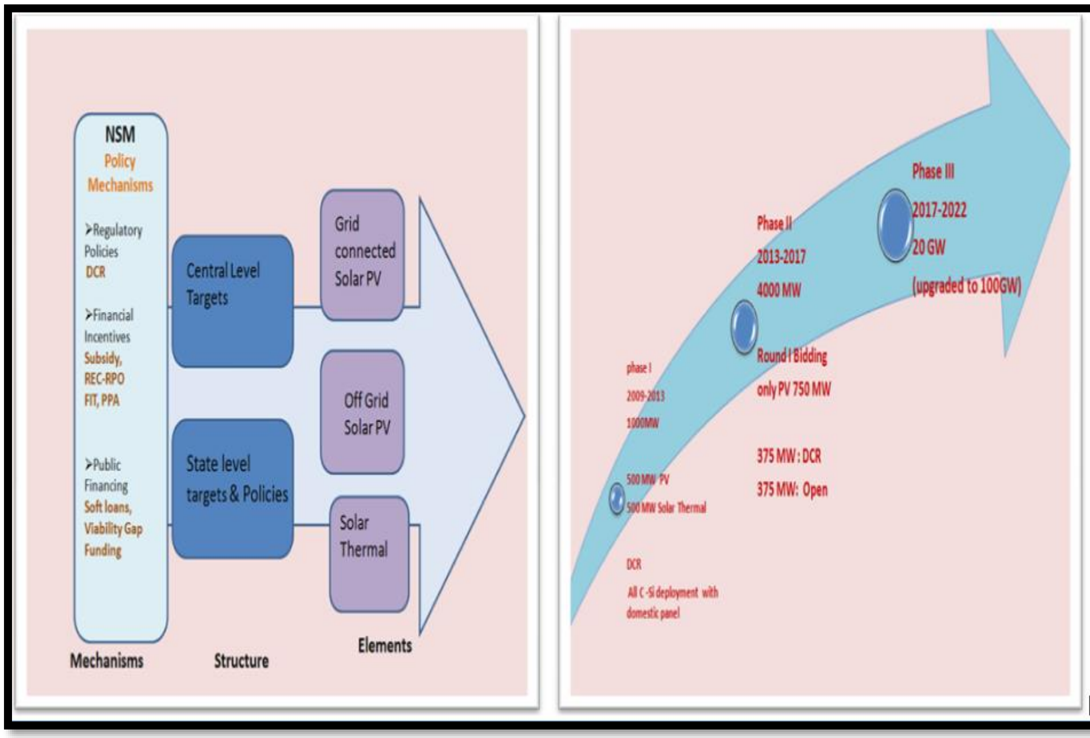
3.4.4. Solar policy Elements

The initial NSM draft provides separate incentives and performance standards for the three routes of solar promotion on the basis of technology characteristics, existing market conditions, energy security coverage and the scale of deployment. The three elements of solar scale up include

1) Utility scale grid connected PV based solar power
2) Off grid PV installations with battery storage, along with various end use devices for lighting and ventilation catering demand side market
3) Solar thermal based power generation along with solar water heaters for domestic and industrial use.

The performance of the three policy elements have been heterogeneous with grid connected solar PV generation outperforming not only the other two but also the laid policy targets due to unprecedented advances in global solar PV manufacturing. The drastic fall in solar panel prices (almost 80% between 2009-2013) led to steep fall in levelised cost of energy production (INR 11/ kwh to INR 3.40 in 2017) for grid connected solar thus reaching grid parity for industrial and household users in India. The last few years have seen the solar promotion in India largely skewed towards scaling up of grid connected solar PV installations with off grid solar and solar thermal targets not coping with the solar PV growth. The **figure 3.2** below illustrates elements of solar innovation systems, transitions and transformation of policy targets along with key players in the domain.

Figure 3.2: Elements of solar Innovation system in India & Transition process



3.4.5. Protecting the niche solar manufacturing market in India

The national level policies for promotion of RETs focus more on socio-economic benefits taking the endogenous development route. For example, renewable energy policies of many developed countries complying to Kyoto protocol targets like Spain, Germany and Italy focus on employment generation potential from the sector (Rio and Burguillo, 2009). Further, emerging economies like India and China focus on export possibilities through promotion of their in-house solar manufacturing.

According to Kuntse and Moerenhout (2012) renewable energy policy of many countries, at different levels of economic development attach local/ domestic content requirements to their support schemes and procurement tenders. Local content requirements are policy measures that mandate foreign or domestic investors to source a certain percentage of intermediate goods that are being used in their production processes from local manufacturers or producers. These local producers can be either domestic firms or localized foreign-owned enterprises. Often, the legislation foresees a gradual increase in the percentage of inputs that needs to be sourced locally. The overall objectives of local content requirements is seldom spelled out explicitly, but usually developing local competitive industries or increasing employment are addressed. (Tomsik and Kubicek 2006)

Instruments like local content requirements/domestic Content Requirement (LCR/DCR) have been imposed in countries like Brazil, Spain, China and Canada for wind based generation while other countries like Denmark and Germany have resorted to soft loans for projects having high local content based elements. Recently, even the developed technology market resorted to trade restrictions with European markets imposing antidumping regulation on Chinese solar panels. In India, policy makers initially focused on distinct local content requirements for its grid connected solar PV and solar thermal projects . Further , as the DCR content in Indian solar policy was questioned in WTO , Directorate General of Anti-Dumping (DGAD) in India had proposed to impose anti-dumping duties of up to \$0.48 per watt on solar cells coming from the US and \$0.81 per watt from China. For countries like Malaysia and Taiwan, it is \$0.62 per watt and \$0.59 per watt, respectively (Economic Times, 2014). The strategy took a U turn post India's ratification to Paris convention of UNFCCC, where a target of 175 GW grid connected renewables was proposed with 100 GW capacity addition only with solar.

Although WTO in the year 2016 has ruled against the DCR content in Indian solar policy, mandating that it violates the free trade agreements and has to be removed , studying the impacts of DCR on Indian solar sector is critically important to understand the economy wide impacts of promoting local manufacturing of solar panels in the perspective of solar scale up as one of the major elements in green growth strategy for India.

As the trade tug war continues with USA imposing import duties on goods from many exporting economies Indian government revisited its provision for import restrictions through antidumping duties and setting up new targets for DCR based deployment. India imposed 25 percent duty on imports of solar cells and modules from China and Malaysia for one year in August 2018 to try to counter what it sees as a threat to domestic solar equipment manufacturing. Falling prices of solar cells and modules, over 90 percent of which India imports from China, have triggered a decline in the cost of solar power generation and led Indians increasingly to adopt the technology. India plans to make renewable power account for 40 percent of its total installed capacity by 2030, from 20 percent currently. The proposed safeguard duty, which would apply for two years in total to imports from China and Malaysia, would be reduced in the second year to 20 percent for six months and then 15 percent for six months. Further MNRE have come up with a proposition to reinforce DCR content for NSM projects to incentivize solar panel manufacturing in India. (**Appendix C3).**

As it has already been mentioned in section **3.1.2**, the solar technologies are characterized by comparatively high spatial mobility , the supply chain tend to integrate more globally than locally. According to Farrel (2011) capability of LCR to create green jobs serves as the first economic objective that helps in gaining political support. According to (Rio & Pablo, 2008) ability to create a high quality permanent job in case of PV sector occurs only during panel manufacturing. The process of power plant installation is short for about initial 3-4 months usually creating temporary local labour jobs followed by a handful of jobs for plant operation and maintenance over the entire life cycle of about 25 years . Thus the possibility of permanent green job creation through solar promotion lies predominantly in the manufacturing sector.

Secondly, as LCR/DCR is aimed at fostering infant industries by protecting them from foreign competition but may subsequently aimed at growth of an export oriented new sector. India traditionally has been an exporter of solar panels and advent of JNNSM opened a path for indigenous demand creation. The timing of the policy also coincides with unprecedented growth of Chinese solar panel and BOS manufacturing sector adversely impacts the Industry niche creation in India. The

LCR criteria provided a security net for domestic manufacturing against Chinese dominance in the sector. According to Lewis & wiser 2001 the LCRs also provides an increased tax base for the government due to increased growth in manufacturing. Although GDP and tax base consolidation due to in house manufacturing is economically favourable there have been concerns regarding inflation in panel price in interstate transaction reducing their viability w.r.t imported panels not needing to pay state taxes. The government in the new GST regime has decided on 5 % tax on the use of solar panels thereby attempting to make up for the revenue loss due to use of imported solar panels (Bridge to India, 2017).

The LCR as a policy instrument can be effective when the proportion of required domestic content is not too high and are gradually phased in (Lewis and Wiser (2005)). The first phase of JNNSM (2010-2011) has set the requirements that the projects to be selected in the first round (2010-11) that are based on crystalline silicon technology had to use modules manufactured in India. This requirement was strengthened in the second round (2011-12) in which all eligible PV projects must use cells and modules manufactured in India. (Government of India, 2010). The JNNSM further required that 30% of a project's value in solar thermal projects must be sourced locally. The scheme was administered by the NTPC Vidyut Vyapar Nigam Ltd (NVVN), which is a subsidiary of the public power producer National Thermal Power Corporation.

Lewis and Wiser (2005) and Volso (2001) find that LCR are only effective if applied to a large stable market for a longer period. The JNSSM sets a long term policy target for scaling up solar installed capacity to 20 GW by 2020 revamped in 2015 to 100 GW of grid connected solar by 2022. Thus the policy holds potential for a large solar market but the markets have been volatile with an unprecedented fall in the cost of solar panel manufacturing globally. The second round of JNNSM encompassing a capacity of 700 MW was later modified to effectively factor in discrepancies in the cost of power generation for PV projects by equally dividing the II phase quota to be auctioned under two heads through viability gap funding mechanism with 350 MW of installed capacity routed through DCR route and 350

MW through non DCR based route. According to Bridge to India (2014) the differential in bidding between DCR and Non DCR projects translates to an additional expense of 65% incurred by the government.

The DCR content in Indian solar policy have to be phased out in accordance with the WTO rulings but this also makes it crucially important that impacts of not including a DCR content is evaluated from a developmental perspective. A cognizance of the fact that the Indian solar policy articulated under national solar mission is a major initiative within national action plan for climate change (NAPCC, 2008), catering also to the climate change vulnerability and climate change induced adaptations for India.

The existing incentives and policy structure have led to development of a unique ecosystem with respect to solar panel manufacturing firms and entities involved in the overall solar deployment process for India. The next two section discusses structural characteristics of solar PV panel manufacturing ecosystem in India.

3.5 Solar manufacturing Ecosystem in India: Elements & Structures

This section deals with understanding impacts of solar policy on solar panel manufacturing sector in India by using a firm level analysis. Policies aiming at enhanced manufacturing capabilities for renewable energy technologies under the national boundaries focus towards endogenous development by promoting use of local resources i.e. physical, human and capital. For facilitating this type of development, the sector should be integrated well within the local economy leading to backward and forward productive linkages (Pablo, 2009). **Figure 3.2** illustrates detailed supply chain of solar PV based power generation. The figure provides a cross sectional view of the existing sectoral structure and various boundaries in terms of imports and exports, policy integration points for solar panel manufacturing in India. The analysis takes solar panel manufacturing as the key step and explores a cross sectional view for the sector. The figure also attempts to integrate synergies from the firm level data (73 solar panel manufacturers) collected from Enfsolar global photovoltaic directory (2015) and individual websites of solar panel manufacturing firms in the directory records.

According to concept note by MNRE (2017) the installed capacity for solar PV manufacturing is limited to that of cells and modules, and other stages of the manufacturing chain have not yet started in the country. Even this capacity is not being fully exploited because of obsolete technology as the existing capacity is mainly under the conventional technology of multi-crystalline Al-BSF (Aluminium-Back Surface Field) solar cells, which have efficiency limitations. Very few players have ventured into the superior PERC (Passivated Emitter Rear Cell) technology. The present solar manufacturing capacities in India are tabulated in **Table 3.4.**

The data reveal that installed capacity is limited to that of cells and modules, and other stages of the manufacturing chain have not yet started in the country. Even this capacity is not being fully exploited because of obsolete technology as the existing capacity is mainly under the conventional technology of multi-crystalline Al-BSF (Aluminium-Back Surface Field) solar cells, which have efficiency limitations. Very few players have ventured into the superior PERC (Passivated Emitter Rear Cell) technology. The domestic manufactures have to borrow at higher interest rates, compared to foreign manufacturers, pushing up their cost of production.

Table 3.4 Solar PV manufacturing capacity in India (Source: MNRE 2017)

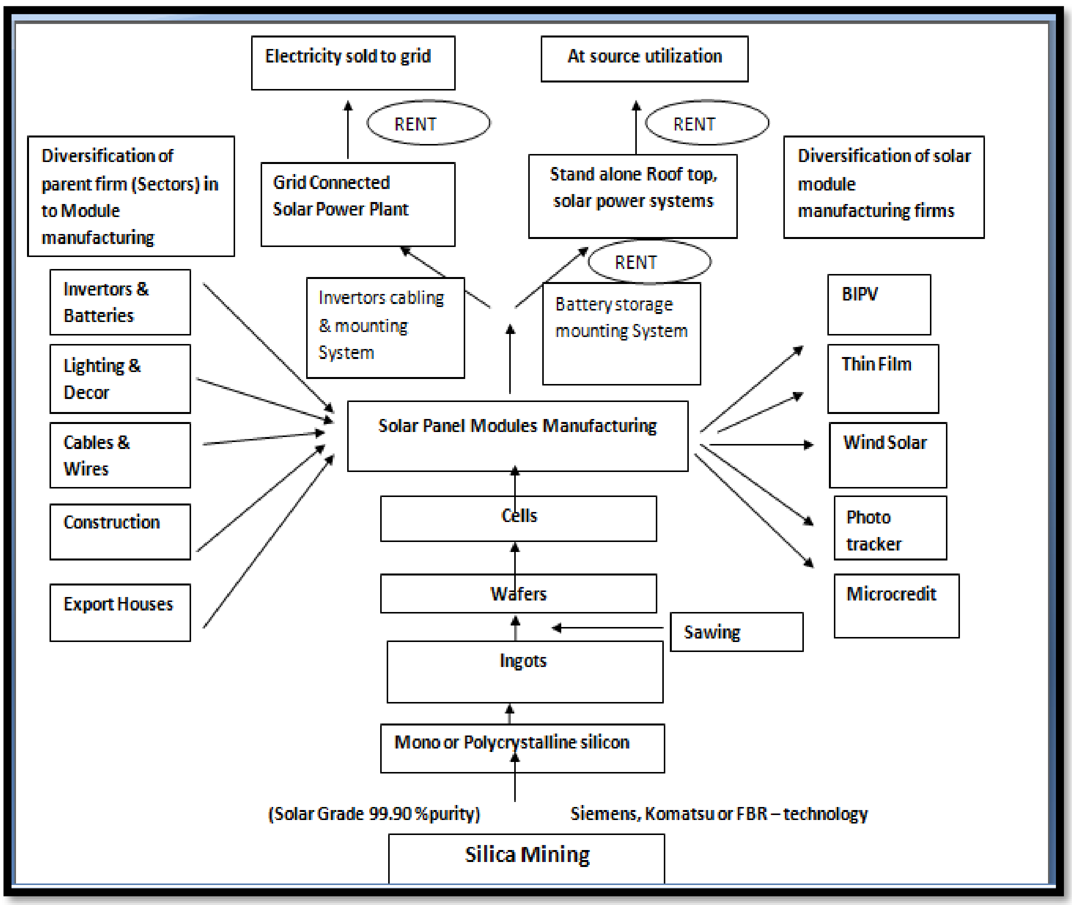
S No.	Particulars	Cell Capacity (GW)	
		Installed	Capacity utilisation
1	Polysilicon	-	-
2	Ingot/Wafer	-	-
3	Solar Cells	3.1	1.5
4	Solar Modules	8.8	2.0-3.0

The price of solar equipment produced in the country is not competitive as compared to that of foreign manufacturers, especially Chinese manufacturers. In light of the ambitious targets set under the National Solar Mission, and the limited manufacturing capacity available, the country is heavily dependent on imports. The present maximum solar cell manufacturing capacity per year is only around 3 GW against an average requirement of 20 GW i.e. 15 %. Balance capacities have to be procured from international market. Energy Security demands that at least 60-70% of the manufacturing capacity should be located within the country.

The crystalline silica-based PV module account for approx. 77% of global module production (Powell,2013). These are also the predominantly used and manufactured solar panels in India. The value chain of solar Mono/ poly (m-p) crystalline panels starts with silica mining involving either Siemens, Komatsu or Fluidised Bed Reactor (FBR) technology to produce 99.9% pure crystalline (m-p) silicon . The silicon are molded into ingots and sawed to produce silicon wafers. Indian industries do not engage into silica mining therefore imports ingots or wafers for solar and semiconductor industry. China is the major global supplier of silicon ingots supplying to about 80 % of the global semiconductor market (Powell, 2013). The Indian manufacturing firms primarily process the silicon wafers into solar cells and subsequently into solar panels. The other components of solar panel manufacturing include copper wire ribbons (used in modules), back sheets and EVA sheets are also imported by the Indian solar manufacturers.

The firm level data collected for Indian solar manufacturers was used to develop a cross sectional view of solar panel and BOS manufacturing sector in terms of forward and backward integration of the sector. This was done to study vertical integration in solar panel manufacturing sectors along with study of horizontal linkages exploring diversification trends of associated sectors into solar panel manufacturing and the module manufacturers diversifying into associated niche technologies. The cross-sectional profile of the solar panel and BOS manufacturing sector in India shows that suitable incentives for the solar sector is leading to diversification of firms primarily operating in an associated sector like invertors and batteries, Light decors, cable and wires, construction and export houses into the solar sector. Further, the existing manufacturing firms are diversifying into more complex set of solar technology products like wind solar, thin film, photo-tracker and build in photovoltaics.

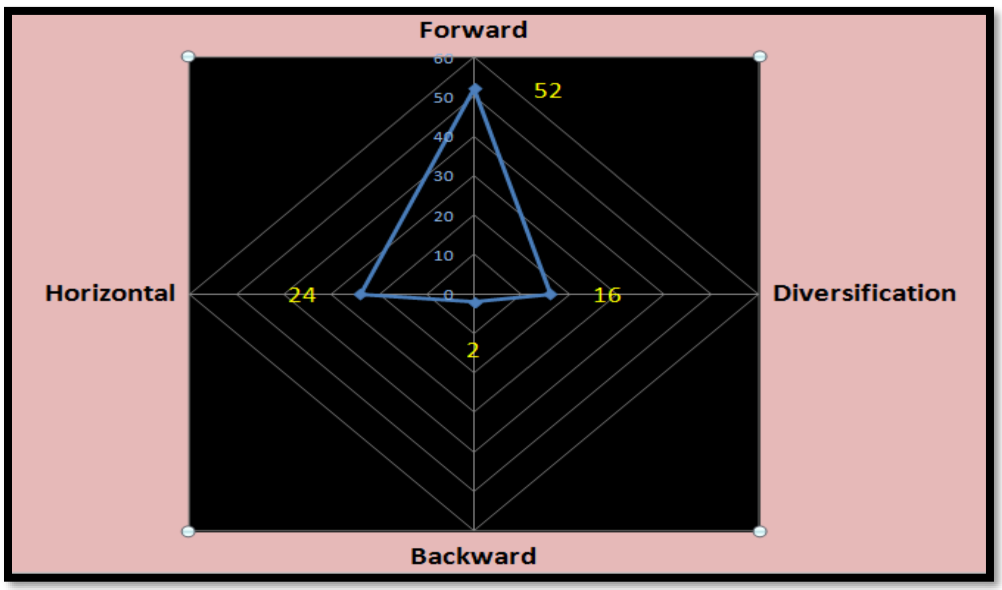
Figure 3.3: The Developing Solar panel and BOS manufacturing Ecosystem



Source: Authors Compilation, 2015

Further, the analysis as illustrated in **figure 3.5** reveal that Indian solar sector exists as strong forwardly integrated sector with very weak backward integration (only two firms in the data quote manufacturing of solar ingots and cells). This structure can be attributed to the fact that the existing Indian solar policy predominantly provides generation based incentives, Thus, policy rents are being created upstream of the manufacturing process i.e. either for solar power supplied to the grid or for the energy end use services like lighting, ventilation and pumping. The study demonstrates rent seeking tendency of the manufacturing firms indicated by a strong tendency to forwardly integrate towards power production. The study also provides an indication of policy mediated spillover effects with various sectors associated with power generation diversifying into solar manufacturing. The solar panel and BOS manufacturing sector also shows diversification into other peer technologies leveraging incentives available in other sectors along with stability benefits of diversification.

Figure 3.4: Solar panel manufacturing firms: Sectoral Integration Profile



The solar panel and BOS manufacturing ecosystem thus provides an evidence that the demand created for endogenously manufactured solar panels with the help of domestic content requirement in Indian solar policy has lead to an growing and expanding niche for solar panel and BOS manufacturing in India. The economy in last six years has been able to develop an operational solar panel and BOS manufacturing capacities of over 5.3 GW. Although as the main focus and the structure the solar policy has been to provide generation based incentives there is a well-developed and efficiently performing solar deployment ecosystem which is studies in next section **(3.5).**

3.6. Solar Deployment Ecosystem in India

The Solar deployment ecosystem has been fast expanding for Indian solar sector initiated by ambitious targets of National Solar Mission launched in 2010. There are a series of individual enablers at policy and project levels along with a broader supporting environment which work in coordination catering to the ecosystem. The policy level enablers can be in any of the three categories central level National solar mission executed by various agencies like Ministry of New Renewable Energy MNRE), NTPC Vidyut Vyapar Nigam Limited (NVVN), IREDA (Indian renewable energy Development Agency), MOP (ministry of Power), NTPC (National Thermal Power Corporation). The state level policies and other market based instruments like REC- RPO mechanisms.

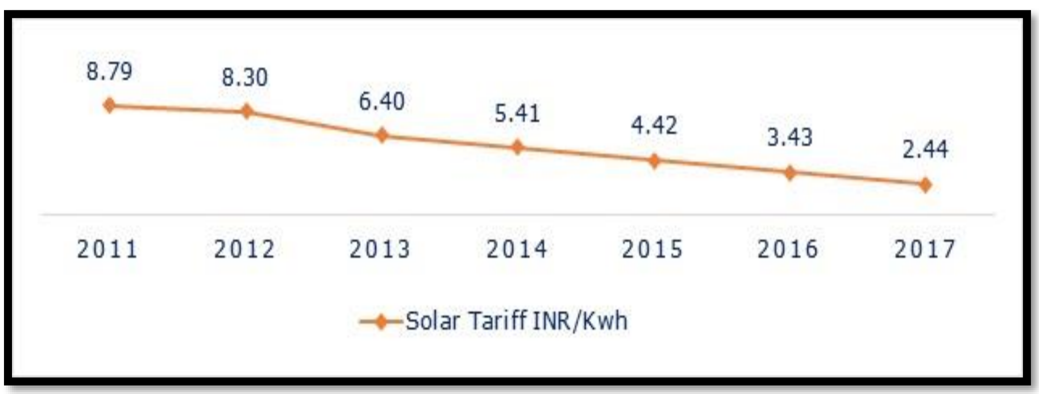
A favorable policy level incentive lead to established chain for solar power project deployment including firms dealing with project development like Azure, Welspun, Mahindra etc. working in cohesion with EPC (Engineering, Procurement Commissioning) firms like Lanco, Tata BP solar finances through series of financial institutions like ICICI, OPIC, Axis bank.

The solar deployment also involves a conducive supporting environment in terms of solar panel manufacturing firms as discussed in last section. Also, broader enabling environment with respect to industry network and requisite infrastructure like special economic zones or solar parks across the country. The role of indigenous research and development for assimilation and effective dissemination of technology dissemination. Further, community support also plays an important role in technology acceptance and development of successful solar deployment ecosystem. The figure 3.6 details the solar deployment system developing for Indian economy. The growing solar deployment ecosystem would further expand as India embarks on solar based energy transition with a target to install 100 GW of grid connected solar by the year 2022. The initial networks have been established to integrate solar technology within India economy with an effort to consolidate both backward and forward linkages in the sector.

According to Solar Quarter (2017) Indian Solar Power Industry is anticipated to have double digit growth during next few years, due to the government's policy to increase the share of solar power in the country's energy mix and falling equipment (PV Module) costs globally. Moreover, solar power tariff in India has witnessed a drastic fall over the last few years. The solar power tariffs in India have fallen in nominal terms from INR 15 /Kwh in 2009 to INR 2.44/ Kwh in 2017, due to decline in module prices and improvements in capacity utilization factor. This recent fall came in during the online bidding for a 750 MW solar power park being set up at Bhadla near Jodhpur with viability gap funding (VGF) from Solar energy corporation of India Limited. This comes after much brouhaha over tariffs falling to INR 3.25/ kWh (levelized) and INR 3.15/ kWh in Rewa, Madhya Pradesh and Kadapa, Andhra Pradesh respectively in the last three months.

However, the ever-declining solar power tariffs has encouraged good investments into the sector but have raised concerns over the long -term sustainability of the projects.

Figure 3.5 Trends of Indian Solar Power Tariff, 2011-2017

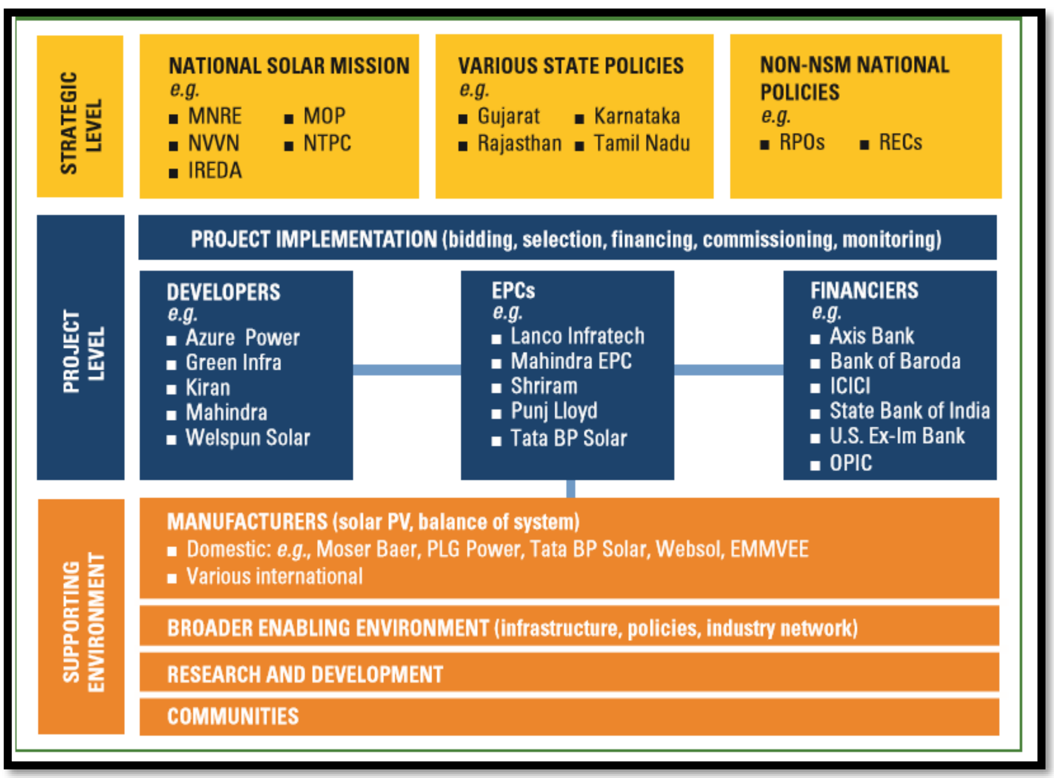


Source : Solar Quarter (2017)

Improving manufacturing technology has led to the reduction in cost of solar panels which has resulted in reduction in cost of solar power generation. The reduction in the cost of solar power coupled with strategic policy of the government has resulted in increase in solar power into the energy mix of the country.

The growing solar deployment ecosystem would further expand as India embarks on solar based energy transition with a target to install 100 GW of grid connected solar by 2022. The initial networks have been established to integrate solar technology within India economy with an effort to consolidate both backward and forward linkages in the sector. However, the preference of the configurations in terms DCR or open category deployment would be critical in deciding the most strengthened networks stabilizing the new regime for the solar sectors. The proposed massive solar scale up entail huge lock in of critical resources and capital across the deployment trajectory and therefore would require greater scrutiny in terms of evaluation of the choices for economic, social and environmental impacts of solar deployment in India as discussed in later chapters **(4-6)** of the thesis.

Figure 3.6: Solar Deployment ecosystem in India



Source: Council on Energy, Environment & Water (CEEW, 2015)

3.5 Conclusions

One of the overarching challenges for policy makers is selecting, timing and implementing institutional changes for facilitating transitions to cleaner energy systems. The policies should be effective in breaking through the incumbent regime and establishing new technology in the existing socio technical regime. The efforts require implementing a dynamic innovation system which balances technological, institutional, economic and social elements for successful technology scale up.

The analysis of key emerging trends in Indian solar innovation systems reveal that the existing solar innovation system in India demonstrates the time-space telescoping phenomenon (Schulz et. al, 2008), a key characteristic associated with energy transitions in developing economies. The Indian solar policy uses a wide umbrella of dynamic and evolutionary policy mechanisms which have resulted in efficient rent management under the conditions of emerging cost and technology trends with cost of solar generation effectively reaching grid parity.

The incentive under national solar mission has resulted in growing solar panel and BOS manufacturing sector, with panel manufacturing firms demonstrating a strong trend towards forward integration. This indicates tendency of firms to orient towards the incentives provided for solar sector, which are predominantly generation based. The firm level trend for Indian solar panel and BOS manufacturing sector also reveal the process of diversification of firms operating in associated sectors like invertors, lighting, cable and wires into solar manufacturing.

The study also reveal that solar deployment ecosystem for India is developing rapidly through coordinated involvement of actors at strategic level (involving both central and state level agencies), project level (involving developers, EPCs and financial institutions) along with other enabling mechanisms for manufacturing, research & development and community support.

The solar deployment targets are being predominantly achieved through the deployment of grid connected ground mounted solar deployment under two differentiated deployment categories of DCR (using domestically manufactured solar panels) and open using imported solar panel. The actors and the stake holder involved in the two deployment categories differ and therefore the deployment process needs a critical comparative investigation.

The existing target for solar capacity addition stands at 100 GW of grid connected deployment by 2022. The study argues that the policy decision aiming at energy transition of such magnitude implies concomitant lock-in of substantial capital and material resources across the deployment process. Thereby potently influencing the trajectory of existing developmental pathways for India necessitating further evaluation.

Following this the next three chapters quantitively evaluate triple bottom line impacts (Economic, social and environmental) of solar deployment process in India. The next chapter deals with estimating economic impacts of solar deployment process under DCR and open category deployments

Chapter 4

Economic Impacts of Solar Deployment
Input-Output Analysis

As already discussed in Chapter 2, green growth discourse for developed and developing economies differ. An environmental imperative is evidently bolded for scaling up renewables in developed economies while developing and emerging economies frame it as an opportunity to leap frog and move towards low emission developmental pathways along with an expectation of inclusive and equitable economic growth. However, in both the cases national policy documentation find it essential to provide political justification by highlighting implicit social and economic benefits emerging from green industrial growth opportunity (Carvaloh, 2015, Hallegate et. al 2011).

Public policies for renewable promotion thus are endorsed with multiple performance expectations. Policy makers usually delineate a list of benefits which range from climate change mitigation to security of energy supply, creation of domestic industry & local employment, expansion of domestic export and also as climate change adaptation strategy. (Joshi & Sharma, 2014; Allan et. al, 2011; Hallegatte et. al, 2011; Rio and Burguillo, 2009; Reddy et. al 2007).

India has voluntarily committed to divert substantial resources towards RET scale up under its national action plan on climate change. National solar mission (NSM) is the most ambitious of the proposed renewable energy promotion program. This makes it essential to critically assess implicit socio-economic benefits associated with Indian solar scale keeping a developmental perspective in mind. This chapter estimates macro-economic impacts of grid connected solar PV deployment on Indian economy in terms of GDP and employment generation potential along with distributive efficiency of wage income generated amongst various skill categories and sectors across economy. The work also compares impacts associated with the two distinct categories of solar deployment under NSM i.e. projects with Domestic Content Requirement (DCR) and open category projects to understand the localization impacts.

This chapter maps economic impacts of Indian solar deployment using Input Output (IO) analysis. Direct and indirect impacts of solar deployment are estimated by tracing Inter industry transactions involved in installing a unit of grid connected ground mounted photovoltaic (GGPV) solar capacity. An Independent solar I-O block is constructed for both DCR & Open category deployment in order to compare the economic impacts of technology localization. The analysis involves Input-Output analysis with solar deployment integrated as a new sector in Indian economy. Estimation solar deployment impacts reveal that technology localization through DCR deployment leads to greater net positive impacts on Indian economy estimated in terms of direct & indirect GDP (>24.74%) and employment generation (>36.64%). Further, use of endogenously manufactured solar panel leads to higher GDP and employment generation up the value chain, a discernable positive trend for India's developmental trajectory.

The next section provides overview of literature on impacts of renewable energy deployment categorized as ex-*ante* & ex-*post* studies, followed by discussion on use domestic content requirement as policy instrument for renewable promotion. This sets a background to development an IO based a framework for analyzing economic impacts of solar deployment process. This includes construction of solar block and multiplier analysis. The methodology section is followed by section that presents and discussed results followed by concluding section.

4.1 Renewable Energy Technologies: Deployment Impact

This section provides an overview of growing body of literature dealing with socio-economic impacts of renewable promotion. Literature on estimating of socio-economic impacts associated with renewable promotion can be broadly classified into two categories i.e. ex ante and ex post based on pre and post deployment discourses. The *ex-antes* involve pre-technology deployment policy impact forecasts and are indicative of net positive impacts of the RET deployments. Ex post studies primarily involve post implementation impact analysis, pointing towards ambiguities associated with estimation of overall socio-economic impacts of renewable energy scale up.

4.1.1 Ex Ante Studies: The focus of these studies has been estimation of employment generating capacities of renewable energy deployment. The analysis frameworks for this literature can be broadly classified into three groups i.e. 1) Policy Impact studies 2) Sectoral studies 3) Technology specific studies

Policy impact studies are the earliest and deal with forecasting impacts of economy wide engagement in renewable energy technologies. These include studies like US DOE (1992) & Cook (1998) for USA, followed by Ecotech (1999) study on agenda 2020 promoted by European Union. A study by Ministry of Human Resource Development on impacts of scaling up RETs in India (MHRD, 2008) which provides initial estimates of direct employment generation potential of renewable scale up in India.

A second set of study involves whole energy system planning under an integrated framework using IO based analysis (Pfaffenberger et. al., 2003; Umweltbundesamt, 2004; Hillerbrand et. al., 2006; Lehr et. al., 2008) and conclude positive effects of economy wide RETs deployment. Assessment of technology specific macroeconomic impacts associated with renewable deployment have been done in studies like Kulistic et. al. (2007) which determines net impacts of biodiesel production on Croatian economy, Caldes et. al. (2008) assessing economy wide impacts of policy goals to install 500 MW of solar thermal capacity in Spain. Recently studies like Malik et. al. (2014) deal with analyzing impacts of biofuel refining in Australia and by Baer et. al. (2015) which analyzes job generation impacts of cogeneration for USA. All these studies are based on economy wide Input-Output frame work. This present study also adopts a similar framework of technology specific economy wide impacts analysis in case of grid connected ground mounted solar PV deployment for India.

The ex-*ante* studies prime facie concludes an overall positive impact of future RET deployments on an economy. This can also be a necessary step for politically justifying the public expenditures diverted towards ambitious renewable deployment targets. As the experience with renewable deployment grew globally an active discourse has emerged ex post in nature studies pointing to ambiguous impacts of renewable deployment in economies as discussed in next sub section.

4.1.2 Ex post Studies

Ambiguities in forecasted values of green job creation associated with renewable energy deployment in both meta and country specific studies have been reported. For instance, Cameron et. al (2015) find significant uncertainties in quoted figures of job creation potential for RETs, both across and within the existing studies. Jain & Patwardhan, (2013) analyze impacts of renewable energy policies in India and conclude mixed impacts of scaling RETs for Indian economy, depending mostly on character and configuration of specific RETs.

Further, Cai et. al. (2011) estimate that a percentage increase in Solar PV generation in China will lead to 0.68% percent increase in total employment. A later study by the authors (Cai et. al, 2014) also points towards aggravated gender inequality in the new, fast growing renewable energy sector for China.

Cox et. al (2015) find a negative unconditional cross price elasticity of labor demand and rising electricity prices due to renewable installation. The study shows that increase in electricity prices would lead to output reduction with low and high skilled labor being impacted more than medium skilled thus resulting in adverse distributional effects and potential overall job losses by renewable energy deployment.

Thus, although ex-*ante* studies report positive socio-economic impacts of RET scale up, as greater deployment actualize various repercussions of the RET scale up regime also became evident. This chapter focuses on estimating economy wide impacts of solar PV deployment under two well defined categories of DCR and open category projects in India, a distinction already discussed in chapter three**.** The next section provides an overview of existing literature associated with use and role of domestic content requirement, as policy instrument in existing renewable energy policies of various economies.

4.2 Domestic Content Requirement in Renewable Energy Policies

The socioeconomic expectations implicit in renewable scale up often warrant use of unique, normatively tailored policy design that fits well with economy specific developmental agenda. A highly criticized but popular strategy amongst policy makers have been to instrument channelization of intermediate goods for renewable energy deployment through local producer or manufacturer by including Domestic or local content requirements (DCR/LCRs).

DCRs are often promoted on the premise of stated need for effective niche protection of nascent RET sector in both developing and developed economies. For instance, Brazil, Spain, China and Canada are effectively using DCRs for rendering protection to their growing wind sector while others like Denmark and Germany have opted for soft loan incentives to projects having greater local content element (Kuntse & Moerhout, 2013, Bradsher, 2010).

Paradoxically even after being readily endorsed globally, status of DCR as a policy instrument has been controversial & often criticized for its performance ambiguities. For instance, Shrimali & Sahoo (2014) point at performance inconsistencies even within the limited context of renewable energy industry while Pack and Saggi (2006) find use of DCRs in industrial policies limiting for the purpose of building competitive domestic market.

Contrastingly, Veloso (2001) evaluates DCR impacts positively pointing to the fact that negative welfare assessments ignore gap between social and private evaluations. According to him DCRs encourage growth of networks between domestic firms and protected industry, trigger learning effects and attract greater foreign direct investments. Lewis & wiser (2001) find that DCRs increasing growth in manufacturing and also bringing concomitant environmental benefits mainly in the form of spillover effects with more competition lowering the cost of green energy technology.

According to Farrel (2011) capability of LCR/DCR to create green jobs serves as an economic objective strongly backed by political support. Augmented by the fact that possibility of creating high quality permanent job in solar PV sector occurs predominantly during panel manufacturing phase (Rio & Burguillo, 2009), Kuntze and Moerenhout (2013) recommend case by case basis analysis of DCR impacts that internalize complex country and technology specific conditions.

Taking the clue this study takes the case of DCRs associated with targeted solar PV deployments under Indian National Solar Mission (NSM). Existing literature on the issue (Shrimali and Sahoo ,2014 and Sahoo & Shrimali 2013) point at deficiencies in Indian solar innovation system prescribing removal of DCR requirements in order to make Indian solar sector globally competitive and also to leverage trade benefits associated with open markets in sector. However regional socio-economic benefits rendered by Indian solar DCRs have not been assessed.

National Solar Mission (NSM) introduced a dynamic Domestic Content Requirement (DCR) for solar capacities deployed under National Solar Mission covering all the three phases of policy road map. Phase I (2010-2013) stipulated a stringent domestic content requirement (DCR) criteria prohibiting installers from using imported Crystalline-Silicon (C-Si) solar panels for NSM projects. However, policy allowed use of imported thin film panels leading to an evident arbitrage towards thin film installations.

For enhancing overall economic efficiencies of the program NSM phase II January, 2014) applies a strategy of partial DCR based capacity addition. Thus NSM phase II, batch I bidding involves bids for 750 MW of capacity deployment comprising equally divided capacity of for 375 MW DCR and 375 MW open categories (SERC, 2013).The mandatory DCR criteria although applies only to NSM projects funded by central (federal) government (MNRE, 2009) making the policy sufficiently open to leverage trade induced benefits from imported panels in state level deployment, WTO has recently passed a ruling against the DCR criteria classifying it as violation of free trade agreement in 2016.

The inquiry implicit in this work thus relates to developing an understanding from techno-economic perspective of the qualitative differences in the economy wide impacts of the two modes of solar deployment in India. As the green growth potential of a technology relates to its localization effects which is markedly different for different renewable energy technologies, critical analysis of the deployment preferences for Indian solar transitions become crucially important.

According to IRENA (2015) Solar PV employs 125,000 people in grid-connected and off-grid applications in India. The latter supports 72,000 jobs, according to an estimate by MNRE and CII (2010). For grid connected applications, IRENA and CEEW estimate that direct employment increased by 28% to reach 53,000 in 2014, with 29,000 jobs in installation and operation and maintenance and the remainder in manufacturing. India's solar PV manufacturers have struggled to compete with suppliers from China, the United States, Japan and Germany. In 2014, only 28% of India's module production capacity and 20% of its cell manufacturing capacity were being utilized (Chadha,2014; Climate Connect, 2014). Further, the Indian government has announced ambitious plans to expand installed solar and wind power capacity to over 200 GW by 2030. These along with the government's "Make in India" initiative should encourage local and foreign manufacturers to establish a strong domestic industry. For instance, Sun Edison announced in early 2015 that it would build a 7.5 GW production plant, creating about 20,000 construction jobs over three years (Doom, 2015). If the government reaches its goal of installing 100 GW of solar PV by 2022, CEEW and NRDC (2015) project that India could create 1.08 million jobs. Under the mix of projects proposed by MNRE, three-quarters would be short-term jobs (construction, etc.). Prioritizing rooftop projects over mega-scale solar parks would raise the country's total solar PV employment potential to 1.31 million.

The next section **(4.3)** compiles an input-output based simulation to assess economic impacts associated with deployment of a unit MW of grid connected ground mounted solar PV capacity in India. The impact estimation compares projects using DCRs and those constructed under open category where primarily imported solar panels have been used.

4.3 Model Compilation & Data

The section details methodology and data sources used for estimating direct and indirect impacts of grid connected solar PV deployment under DCR & Open categories**.** Impacts of adding grid connected utility scale solar PV plants under DCR and open category is traced by determining inter sectoral productive relations of Indian economy using input output analysis. The methodology includes three subparts. The first subsection details methodology and data sources for constructing solar blocks for DCR and open category projects followed by subsection two which provides IO analysis details The third subsection deals with methodology and analysis for distributive efficiencies of employment generation in the deployment process.

4.3.1 Constructing the solar block

Miller & Blair (1986) propose two approaches to capture new economic activity with in an economy: i.e. through construction of a new final demand vector or through addition of new elements in technical coefficient table of an economy. Both the approaches assume already existing technical coefficients

In this work we introduce solar generation as a new production activity for Indian economy through construction of a separate final demand vector. Solar deployment uses characteristically different inputs as compared to prevalent coal based power generation, Independent solar I-O blocks for both DCR and open category deployment are constructed and integrated as a new sector in 35x35 national input output table (2011) compiled from world input output databases (WIOD).

As there do not exist substantial contribution of grid connected PV solar based power generation in Indian energy mix till 2011 a solar production block is designed using expert data integrating engineering principles as elaborated later in the text. Direct coefficients for employment and household income obtained from WIOD socio-economic accounts were used to estimate output multipliers. **Figure 4.1 a & b illustrates** solar block formulation for both DCR and open category projects. The constructed solar blocks are presented in **Appendix A1 and A2**.

Both solar blocks compile data at purchaser's price obtained from 2013, MNRE benchmark pricing which include prices for C-Si PV panels, mounting structure, power conditioning unit, construction, preoperative costs, operation and maintenance along with various financial intermediation activities undertaken in India during deployment of ground mounted solar power plant. The component inputs for a unit MW installation were further detailed using various technical inputs (detailed in **Appendix A3**). This is followed by adjustments for existing fiscal elements like applicable subsidies, VAT, excise duty and incurred transportation costs. The input data is prepared at producer price for IO analysis

The DCR block is differentiated by dissociation of solar panel manufacturing Industry into inputs for manufacturing module, wafer and cells within the economy while in case of non DCR solar blocks, solar panels feature in the imports column. The silicon ingots and investors are modelled imported for both the categories. The constructed solar blocks are added as a new sector (36th) in already existing 35X35 IO table for India obtained from WIOD data base. The following subsection details the IO analysis undertaken

WIOD national IO tables combines National Account System data which is generated on the annual basis with national supply use table (SUTs) to derive time series of SUTs (Termurshoev & Timmer, 2011). National supply and use tables are available at current and previous year prices (35 industries by 59 products and National Input-Output tables in current prices (35 industries by 35 industries) data. The database also provides a socio-economic account sectorally for the 15 year time series. The data includes sector wise employment coefficients and labor distribution data essential for employment impact assessment.

Figure 4.1 (a) Solar Block for DCR power projects

Inputs Solar Sector	Solar Panels	Balance of Operation	Charge Controller and Switches	Inverter	Construction and Civil Work	Land Transport	Water Transport	Insurance Pre-operative Cost	Financing Cost	Project Management Cost	Land acquirement
Sector Concordance for WIOD IOT	**Solar Sector (36)**	Basic & Fab Metal **(12)**	Electrical & Optical equipment **(14)**		Construction **(18)**	Surface travel **(23)**	Water Travel **(24)**	Financial Intermediation **(28)**			Capital formation

Input Solar Sector	Module						Cell					Silicon Wafer
Sector concordance	Packaging	JB, Ribbon, Back sheet	Frame	Electricity	Maintenance	glass	Screen	Energy	Chemicals	Maintenance	Metal Paste	IMPORT
Sector Concordance for WIOD IOT	Paper & pulp (7)	Basic & Fab Metal (12)	Basic & Fab Metal (12)	Electricity supply (17)	Machinery (13)	Other non-metal (11)	Basic & Fab Metal (12)	Electricity supply (17)	Chemical (9)	Machinery (13)	Basic & Fab (12)	Solar Sector (36)

Figure 4.1 (b) Solar Block for Open Category Solar Deployment

Inputs Solar Sector	Solar Panels	Balance of Operation	Charge Controller and Switches	Inverter	Construction and Civil Work	Land Transport	Water Transport	Insurance Pre-operative Cost	Financing Cost	Project Management Cost	Land acquirement
Sector Concordance for WIOD IOT	IMPORT Solar Sector **(36)**	Basic & Fab Metal **(13)**	Electrical & Optical equipment **(15)**		Construction **(23)**	Surface travel **(23)**	Water Travel **(25)**	Financial Intermediation **(28)**			Capital formation

4.3.2 Input Output Analysis

I-O methodology facilitates integrated analysis by assessing direct and indirect economy wide impacts of growing solar sector on all other sectors of Indian economy. The study uses the basic Leontief I-O model of linear equations tracing out sources of each sectors inputs, whether they are purchased from other firms in the economy, imported or contributed by labor (wages and salaries). It also provides sales of each sectors output with sales to other industry and of final demand along with consumption, gross fixed capital formation.

The information from IO table has been utilized in the general form of Leontief model

$X=AX+Y$ (1)

Where A is the matrix of technical coefficient, X the vector of sectoral output and Y is the vector of sectoral final demand component. Eq 1

$X= (I-A)^{-1}$ (2)

Where I is an identity matrix, Matrix $(I-A)^{-1}$of interdependence. Each element of that matrix indicates total (direct & indirect requirement of sector i for final demand output of sector j).

World Input output database (WIOD) also provides associated annual Socio-economic Accounts (SEA) with industry wide wages and employment by skill type which has been used to estimate employment and income impacts.

As grid connected solar PV installations is considered as a new economic activity all fixed assets are newly purchased and calculated through perpetual inventory method (Quang Viet, 2000). This is to make block maximally adjusted to existing national peculiarities.

A commodity flow table was created to ensure balanced supply and use of inputs and or outputs of solar block and adjusted to conventional form of I-O table. The output of solar sector is in the form of electricity directly connected to the grid, the new sector is assumed to supply its entire output to the electricity sector. The study initially simulates the inter industry exchanges involved in an year when the solar power plant is installed.

The industry specific literature indicates (Bridge to India, 2013, MNRE, 2013) that on an average it takes 10 months for solar power plant to start its operation fully after successful land acquisition. Therefore in the year of commissioning (t) output equivalent to 2 months of solar generation is considered with average normative capacity utilization factor of 19 % (CERC, 2009) prevalent in India. The year t includes all the inputs required for installing the solar power plants along with factor inputs in terms of labor and capital formation and output in terms of 2 months of power generation. MW of solar power generated was converted to million dollars of value using latest input output table for India (2007) adjusting for inflation and currency depreciation.

Input output linkage in terms of Leontief coefficients were obtained for the two scenarios. These were used to obtain value of output, income and employment impacts on the economy due to solar power plant deployment under DCR and open categories.

4.3.3 Estimating distributive efficiencies of solar deployment

Further, distributive efficiencies of DCR and open category deployment in terms of type of labor compensation generated with DCR and non DCR based solar deployment was estimated on the basis of the total sectoral direct and indirect output generated and sectoral employment coefficient for India (WIOD Socio-economic Accounts (SEA). The accounts provides data for sectoral labor distribution in terms of low skilled labor, medium skilled labor and high skilled labor. The data was used to estimate job compensation distribution under DCR and open categories for India **.**

The study involved estimating economic activity associated with manufacturing components and deployment of grid connected ground mounted solar power plant in India in the commissioning year calibrated to 2011 IO table in WIOD. The model assumes an existing idled capacity fulfilling the input demands for 750 MW of solar deployment along with 375 MW of solar panel manufacturing. Thus, the capital creation associated with increasing manufacturing capacities has not been included in this study

The study also estimates the differences between the socio-economic impacts of solar deployments under DCR and open category in India trying to bring in a nuanced perspective to the existing criticism for DCR element existing in Indian solar policy. The estimations of socio-economic impacts of DCR and open category deployments are presented in the following section.

4.4 Results & Discussion

Development of an energy project generates impacts on local economy by creating direct and indirect sectoral demand along with employment generation. The estimations of the study reveal favorable impacts on output multipliers under both DCR and open category deployments in India when compared to no solar scenario. However, positive economic impacts of DCR based solar deployments are estimated to be both quantitatively higher and qualitatively better as compared to open category.

Solar deployments would increase direct demand in economic sectors that provide inputs directly consumed by solar sector. This demand would also trigger an indirect demand in the sectors that providing goods and services to the directly associated sector under both DCR and open deployment categories. The IO based estimates show that DCR deployments produce 24.74 % more output (GDP generation) along with 36.64% times more employment (direct & indirect) as compared to projects under open category (illustrated in **figure 4.2 & 4.3**). Thus

the higher costs of DCR deployments are effectively compensated with benefits more widely distributed in the economy .

The solar deployment under DCR and Open categories also generate qualitatively different economy wide wage profile. Labor compensation profile estimated using WIOD, Socio-economic Account (SEA) database show that DCR deployments are associated with 35.4 % greater economy wide wage generation. **Table 4.1** provides sector wise labor compensation profiles for Open and DCR categories. The estimates of labor compensation distribution profile indicate generation of more medium skill (38.8 % & 40.1 %) compensation followed by high skill (31.1 & 35.5 %). DCR deployments however generates 35.4 % higher labor compensation. These results provide a qualitative insight into the known positive employment effects (Hillebrantdt, 2007) of solar deployment. The results indicate that localization of technology by using endogenously manufactured solar panels leads to higher GDP and employment generation up the value chain, a discernable positive trend for India's developmental trajectory

Labor compensation profile for I-O analysis highlights a strong evidence towards disparate socio- economic impacts of DCR and open category deployments. The results indicate that DCR deployments will generate highest compensation in public admin and social security sector followed by financial intermediation. The highest share of labor compensation will be generated in medium skill jobs for both DCR and open category but DCR based deployment will lead to high retail trade compensation while for open category highest labor compensation will be in the whole sale trade sector . In case of low skill sector greatest impacts would be seen in agricultural and forestry sector followed by retail trade while whole sale trade will generate highest compensation for open category deployment showing maximum value. The differentiated sectoral multipliers for the two set of deployments provide a clear evidence that impacts on rural and urban population for India would be very different in two categories of solar deployment leading to very different socioeconomic impacts. These impacts will be critical for future

development trajectory of India and are further analyzed by creating a social accounting matrix in the next chapter (chapter 5)

Thus, DCR deployments would lead to greater economic engagement and benefit in terms of GDP and jobs generation. Recent literature dealing with employment impacts of renewable energy policies (Rivers, 2013) indicate that local socio-economic benefits from renewable energy policies are only possible when elasticity of substitution between labor and capital is low and when capital is not internationally mobile. Further, the benefits would accrue when labor intensity of renewable generation is high as compared to conventional generation.

In case of solar PV sector possibility of high skilled permanent employment generation predominantly occurs during manufacturing stage, followed by a small number associated with operation and maintenance of the plant (Rio & Buiguillio, 2010). Furthering this is the fact that at present there exists a strong trend towards vertical integration of solar PV manufacturing sector instrumented by use of fully automated assembly lines leading to greater probabilities of labor capital substitution in the sector. This trend reduces future probabilities of international fragmentation of factors or splicing of supply chain thus concentrating manufacturing of solar panels in a region or territory which already has monopoly in the market

High skilled, medium skilled and high skilled labor generation are also different. The estimates of labor compensation distribution indicate generation of more medium skill (38.8 % & 40.1 %) compensation followed by high skill (31.1 & 35.5 %).

According to Veloso (2000) welfare effects of DCR are well established primarily in the cases where there exists a generic gap between social and private opportunity costs of resource use by an industry or when there is a strong possibility of learning and knowledge spill over associated with foreign manufacturer investing in developing economies.

Figure 4.2: Gross GDP Generation for DCR & Open deployment

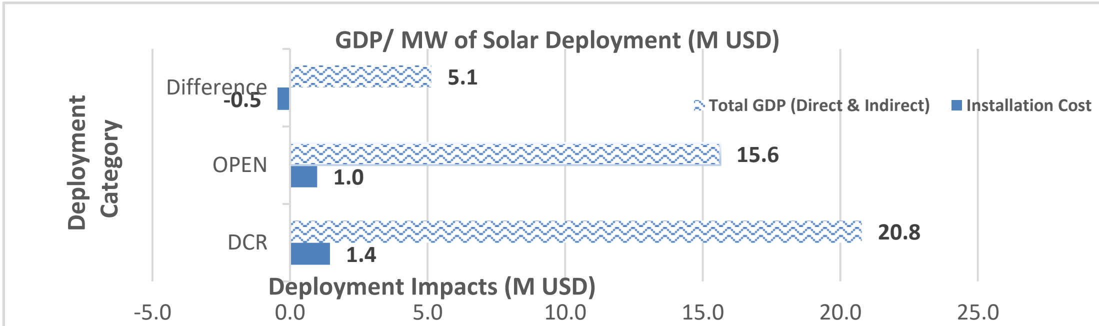


Figure 4.3: Employment generation for DCR and Open deployment

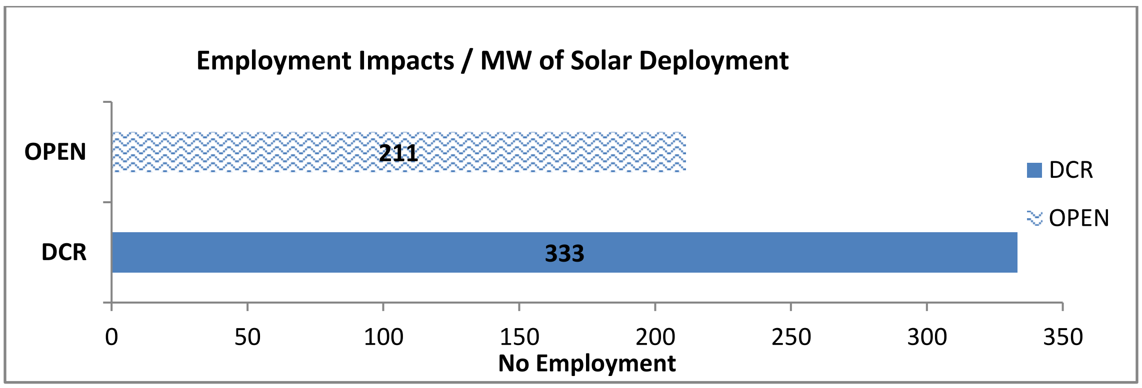


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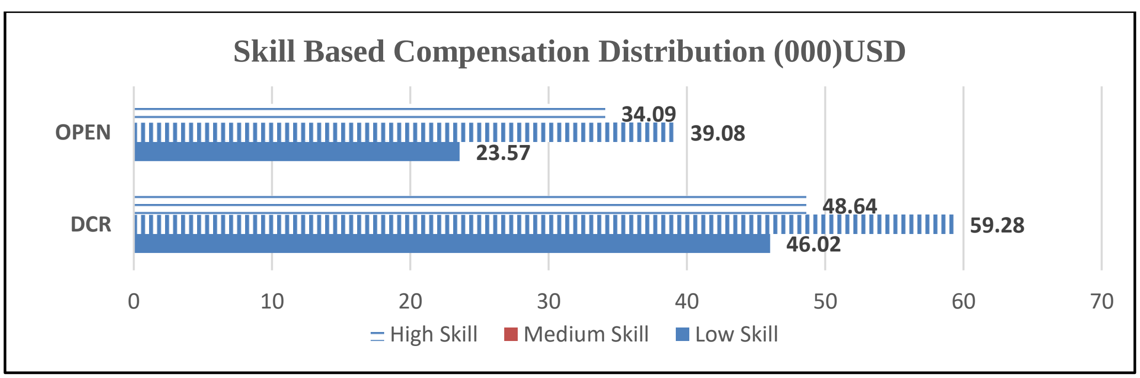
Figure 4.4: Labor Compensation profile for High, Medium and low skilled labor in DCR and open category deployments



The authors argue that for efficiently leveraging economic growth opportunities rendered by National Solar Mission, strategies to bring in the capital associated with solar panel and BOS manufacturing becomes critically important. Policy instruments like DCR have potential to play a pivotal role in homing the characteristically mobile capital of solar PV manufacturing by providing an opportunity of long term stable solar market demand and also ensuring domestic employment creation. The argument is also supported by the established fact that solar PV technologies have high spatial mobilities due low logistics costs as compared to wind and biomass which tend to naturally source their inputs from local manufacturers or supply chains (Gosen's & Lu, 2013)

NSM is one of the key initiatives undertaken under the umbrella of National Action Plan on Climate change (NAPCC) launched by Indian government in the year 2008. Therefore, impacts of various policy instruments like Domestic Content Requirement (DCR) under NSM have to be analyzed through a more holistic perspective bringing in the concerns of distributive efficiency under climate constrained conditions and economy wide welfare impacts of the policy into focus.

Our results shed light on the disparate economic impacts of DCR and open category solar deployment. The final demand for goods and services for both the deployment categories are not only quantitively but also qualitative different leading to strikingly different employment and wage profile. The estimated results only consider the expansive effects of solar deployment. The impacts of loss in demand due to rise in electricity prices or substitution of electricity from thermal to solar is not considered. The electricity price is centrally regulated in India by CERC, whole is using a unique bundling mechanism so that the price differential of solar are not be directly transferred to the economy. Further, currently the price of solar generation have plummeted and reached grid parity so the negative impacts of renewables as quoted in Hillerbrand et. al, 2006, Lehr et. al, 2012, Frondle 2010 may not be evident in Indian scenario

Table 4.1 Labor Compensation profile for High, medium, low skilled labor in DCR open category solar deployment

High skill labor compensation (000) USD		DCR	OPEN
1	Public admin and defence; compulsory social security	9.51	4.40
2	Financial intermediation	6.47	3.00
3	Education	5.49	2.13
4	Retail trade, except of motor vehicles and motorcycles; repair of household goods	4.76	1.39
5	Renting of m&eq and other business activities	4.26	4.01
6	Post and telecommunications	3.89	5.96
7	Solar sector	0.74	0.26
8	Rest of sector	13.52	13.78
9	Total	**48.64**	**34.93**
Medium skill labour Compensation (000) USD			
1	Retail trade, except of motor vehicles and motorcycles; repair of household goods	13.61	3.98
2	Public admin and defence; compulsory social security	8.68	4.02
3	Other community, social and personal services	6.21	1.49
4	Agriculture, hunting, forestry and fishing	4.56	1.37
5	Post and telecommunications	4.41	6.75
6	Wholesale trade and commission trade, except of motor vehicles and motorcycles	3.94	6.26
7	Solar sector	0.54	0.19
8	Rest of sectors	17.33	15.03
9	**Total**	**59.28**	**39.08**
Low skill labour Compensation (000) USD			
1	Agriculture, hunting, forestry and fishing	11.89	3.57
2	Retail trade, except of motor vehicles and motorcycles; repair of household goods	9.15	2.67
3	Other community, social and personal services	6.41	1.54
4	Construction	3.01	0.82
5	Wood and of wood and cork	2.50	1.54
6	Wholesale trade and commission trade, except of motor vehicles and motorcycles	2.32	3.69
7	Solar sector	0.15	0.05
8	Rest of sectors	10.60	9.67
9	**Total**	**46.02**	**23.54**

The DCR incentives appear as subsidy to the sector and are integrated into government deficit. The main contention of the analysis is to highlight the macro-economic differences associated with the two categories of deployment and there relevance with respect to green growth and prevalent developmental concerns of India.

4.5 Conclusions

This paper estimates direct and indirect impacts of attaching domestic content requirement (DCR) in Indian solar policy in terms of output, employment generation and distributive efficiencies of income generation using input output analysis. The results show that for NSM deployments i) Overall GDP generation under DCR category deployment would be much higher, ii) DCR deployments would be associated with significantly higher sectoral demand, employment generation potential iii) There would be more GDP and employment generation up the value chain

Ensuring sustainable energy supply is a pressing challenge for an emerging economy like India posed with conditions of energy poverty, greater climate change vulnerabilities and high population growth rates. Policies formulated for renewable energy scale up need to be scrutinized for their efficiency to meet multiple goals focusing towards sustainable economic growth and domestic employment. The results of this research indicate that DCR based deployment has the potential to emerge as an effective endogenous growth policy aligned to accrue better distributive efficiencies towards economic sustainability in India.

A detailed study of distributive impacts of associated with PV deployment would not be representative if the micro economic impacts of the deployment at the household level are not estimated. The macroeconomic impacts estimated in this chapter in terms of GDP generation potential and employment would lead to wage generation and distribution amongst various household categories in India expected to bring a change in per capita expenditure of the households. The sustainability impacts of solar PV deployments can thus be traced by mapping the changes in quality of life indictors like household income and consumption expenditures. The next chapter (Ch-5) compiles a Social Accounting Matrix (SAM) for India simulating household level impacts of grid connected solar PV deployment for the DCR and open category solar deployments in India.

Chapter 5

Mapping Meso-economic Impacts
Social Accounting Matrix Approach

5.1 Introduction

An effective developmental strategy not only internalizes concerns with accelerating economic growth, but also caters to a direct concern associated with improving standard of living for a sizable segment of population largely is largely bypassed in the unequitable growth process. Thus, analyzing green growth strategy through sustainability lens renders that expected economic growth implicit in solar scale up is also scrutinized for developmental goals like equitable growth and poverty alleviation.

Policy decision to logarithmically scale up solar generation capacities in India (100 GW by 2022) may not only transform existing, predominantly coal based energy mix for the economy but also usher opportunities for regional economic growth and development. This section studies meso- economic impacts of solar technology scale up on Indian economy by constructing a Social Accounting Matrix (SAM) including solar deployment as new production activity in Indian economy.

Commitment to a systematic, target driven scale up of grid connected solar PV capacities in India would elicit a constant demand in the terms of direct and indirect inputs from within or across economies channelized towards the solar installation process. Mapping the phenomenon would thus imply a challenging task of linking various targets or interventions to macroeconomic, structural and social policies within a consistent framework thereby tracing and quantifing each stage of propagation channel. According to Pyatt (2001) Social Accounting Matrices (SAM) form an ideal choice in such situation as the methodology holds a strong reference to structure of economy and effectively articulates salient characteristics of interface between different households and monetized economy.

This study compiles a representative model for existing grid connected solar PV deployment policy strategy in India using the SAM framework. Deployment of a new solar capacities would not only create direct and indirect sectoral demand but also concomitantly generate local employment and wage incomes. As Indian solar policy distinguishes between projects using imported and domestically manufactured solar panels, Independent solar I-O blocks has been constructed in Chapter 4 and integrated as a new sector in 35x35 national input output table (2011) for India from world input output databases (WIOD) . Wage incomes associated with installation of a unit of grid connected ground mounted photovoltaic solar power capacity in India is estimated in terms of skill based labour compensation generation using WIOD Socio-economic Account database.

SAM extends the existing IO framework and depicts solar deployment leading to income generation which in turn are allocated to institutional sectors. The impacts in the study are distributed between two economic agents' households getting labor incomes and private corporations getting capital gains. The households are categorized into nine categories on the basis of occupation. The relationship between production structure, income distribution and consumption profile of nine household groups is harmonized for the analysis.

The analysis reveals greater wage generation for urban household in medium and high skill category associated with current solar deployment strategy. The study also highlights the fact that projects using domestically manufactured solar panels lead to higher income generation and provides comparatively wider distribution of wages across the household categories and with better penetration in lower deciles of per capita incomes thus favorably catering to both concern of inclusive and equitable green growth.

The following section sets in a brief background for the research work in terms of green growth and development predicaments for India. The section is followed by details of data collection and compilation with respect to solar block compilation and SAM construction. Section four undertakes multiplier analysis for associated Output and GDP multipliers of the economy and income and consumption multipliers for household categories under study followed by results and conclusion in section five

5.2 Green Growth & Development Predicament

Public policies for renewable promotion are usually endorsed with multiple performance expectations ranging from climate change mitigation to security of energy supply, creation of domestic industry & local employment, expansion of domestic export and climate change adaptation strategy (Joshi & Sharma, 2014; Allan et. al, 2011; Rio and Burguillo, 2009; Reddy et. al 2007).

Further, rationale for renewable promotion vary for countries at different stages of development. For developing countries, the most likely reasons to adopt renewable technologies is providing access to energy, creating employment opportunities in the formal (legally regulated & Taxable) economy and reducing the cost of energy imports. An initial strong focus on grid connected ground mounted PV solar installations in India can be seen as a integrated efforts towards creating short term green jobs and meeting long term economy wide energy transitioning goals.

For economic growth to be sustainable and effective in reducing poverty it needs to be inclusive (Berg and Ostry, 2011 and Kray, 2004). An inclusive growth strategy refers to both pace and distribution of economic growth. The economic indicators like GDP growth, GDP per capita or GDP per capita growth thus would not be enough as GDP per capita is a measure of production. To asses living standards more accurately Stiglitz et. al (2009) propose use of consumption rather production-based measure. Thus per capita household consumption become critical indicator of standard of living. Consumption is closely related to income; Thus, the poverty or inequality and economic growth need to be analysed together. This study analyses both income growth and income distribution in a consistent frame work i.e. SAM to analyse the social impacts of solar deployments under sustainability framework.

5.3 Pattern & Process of Economic Growth in India

High economic growth rates of Indian economy since 1994 has led to substantial poverty reduction. The poverty head count rate measured using the national poverty line, declined by 1.5% points in the year 2004-2005. The most recent data (2004-2011) show a greater decline of 2.2% point per year which is about three times the pace of poverty reduction of preceding decades. Yet India continues to have largest number of poor (approx 300 million) in the world. The period of rapid growth and poverty reduction (2004-2009) also witnessed a rise in inequality with Gini Index risen from about 0.27 in rural to 0.35 in Urban in 2004 to 0.28 and 0.38 respectively in 2009-10. Further regional inequalities between states also escalated. (Anand et. al, 2014, Planning commission of India, 2013).

Taking cognizance of the widening disparities, the government declared achieving faster and more inclusive growth as stated objectives for both eleventh and twelfth fiveyear plan. The stated vision of the recently released draft is “of India moving forward in a way that would ensure a broad – based improvements in way that ensure a broad –based improvement in living standards of all sections of the people through growth process which is faster than in past, more inclusive and more environmentally sustainable” (Planning Commission Gov of India, 2013).

Annual growth rate of real GDP per capita accelerated to about 8.5% on average during 2004-2009 from an average of 6.25% during 1993-2004. The annual growth rate of real GDP per capita accelerated to an average of 6.5% during 2004-2009 from 4.5% in 1993-2004. A similar pattern was observed in national accounts-based growth of per capita consumption. Household survey data (National Sample Survey, NSS 2010-2011) , however suggest somewhat slower growth rate. The rate further shrunk to 44 % of the NAS during 2004-2009. This discrepancy in NAS & NSSO data is indicative of either systematic under estimation of consumption of all respondents (Bhalla,2003) or a disproportionately large increase in the income of very rich, who are much less likely to be picked up in expenditure surveys (Banerjee and Piketty, 2005). The gap between two has definitely increased over time (Central Statistical Organization, 2011)

Table 5.1 India: Economic Growth Profile

(Annual Average percent change per capita)

	GDP	**Private Consumption NAS**	**Private Consumption NSS**	**Private Consumption NSS (Rural)**	**Private Consumption NSS(Urban)**
1993-2004	4.5	3.1	1.7	1.8	1.8
2004-2009	6.8	5.9	2.6	1.8	3.0

Source: IMF report, Anand, Tulin & Kumar, 2014

Rural and urban area differ markedly in growth of private consumption. While average growth in private consumption remain nearly same in rural areas growth in urban private consumption accelerated during 2004-2009. The ratio of urban to rural average per capita consumption rose by over 6% between 2004-2009. Thus, a relatively higher rural inflation resulted in deterioration of rural household purchasing power.

Indian agriculture has grown at an annual rate of around 3 per cent over the past three decades. This has helped improve farm incomes and reduce rural poverty (Datt and Ravallion, 1996; Warr, 2003). However, of late, the farm sector has come under stress — the growth therein being decelerated to 2.7 per cent per annum during 1995-96 to 2009-10 from 3.2 per cent per annum during 1980-81 to 1994-95. But, the more worrisome is the continuance of excessive employment pressure on agriculture, despite a significant decline in its share in the national income. The sector engaged 52 per cent of the country’s workforce in 2009-10, compared to 69 per cent in 1983, while its share in the gross domestic product (GDP) declined from 40 percent to 15 per cent during this period. Further, the Indian agriculture is dominated by small landholdings, and the average size of landholding has shrunk to 1.16 ha in 2010-11 from 1.84 ha in 1980-81. Given these trends, there arises a basic question: how far farm households would survive on such tiny pieces of land? In a recent study, Chand et. al. (2011) have reported that if agriculture were to the sole source of income for small landholders, the majority of them would have remained poor.

This makes mapping developmental impacts of incentivized green growth for both rural and urban population in India in order to analyze long term impacts of grid connected solar deployments within the existing economic structure. An exercise like this would help understand the movement of development trajectory towards or away from sustainable development goals. The next section details compilation of solar blocks and solar added social accounting matrix for India.

5.4 Methodology

A social accounting matrix (SAM) based analysis is performed to analyse channels through which demand driven interventions associated with grid connected solar PV deployments (DCR & Open) may affect income of various occupational classes in India. This is done in two steps. First structure of Indian economy (inclusive of the newly introduced solar sector) is sketched with Social Accounting Matrix (SAM) frame work. This involved juxtaposition of macro (national accounts and input –output table) and micro (national surveys) data under a unified data matrix to portray meso level interactions of various economic agents. The agents include production sectors, factor of production, household groups and other institutions. Subsequently, SAM is used to develop a multiplier simulation model aimed at tracking and quantifying the nature and extent of linkages among demand created due to solar deployment, economic growth and income generation reflecting on concomitantly poverty reduction and distribution impacts of solar deployment under DCR and open category.

A SAM for India with Keynesian Type multiplier model was built and the following research questions are being answered:

- How do solar scale up under DCR and open category deployment affect household income generation via their effects on sector, production factors and consumption pattern
- How does solar sector[4] induced economic growth trickle downs to poor for the two scenarios?

5.4.1 SAM Construction

The SAM approach is a flexible tool which can be deployed with varying degree of sophistication. The structure of SAM varies across countries. The differences are with respect to kinds of classification applied, the kinds of sectors and groups transactions distinguished and the degree of detail with which SAM is designed. In general, the formats of SAMs are guided by socio-economic structure of the countries to which SAMs apply to, varying situations as regards to availability, scope and nature of basic data needed for SAM and are often tailored to the pertinent research questions (Round J, 1981).

A SAM was compiled for India with specific integration of new solar sector representative for DCR and open category deployments in India. The production sector involved 36 sector Indian economy modelled using 35 sector Indian IO table (World Input Output Database, 2011) and one solar sector previously compiled in chapter 4. Further, the National Sample Survey 68th round (2010-2011) for India provides distribution of per capita consumption expenditure for nine household occupational classes. NSSO data also provides distribution of the rural & urban population among five rural and four urban households. This data was used to estimate household class consumption expenditure for year 2010 -2011. NSSO sectorwise consumption data was concorded to WIOD 35 sectoral classification adopted for SAM construction. The consumption expenditure thus obtained was used to estimate household- class share of consumption expenditure.

Trade, Banking, Insurance, Business Services and real estate sector do not appear in NSSO's consumption list. The household consumption pattern given in recent

[4] grid connected ground mounted solar deployment

SAM for India (2007-2008) was used to obtain household consumption expenditure for trade, insurance & banking sector, business service and real estate sectors. Thus,the household final consumption expenditure was distributed among the nine household's classes in 2010-2011.

Table 5.2: **Distribution of Household income with respect to sources of Income and by wages & other components**

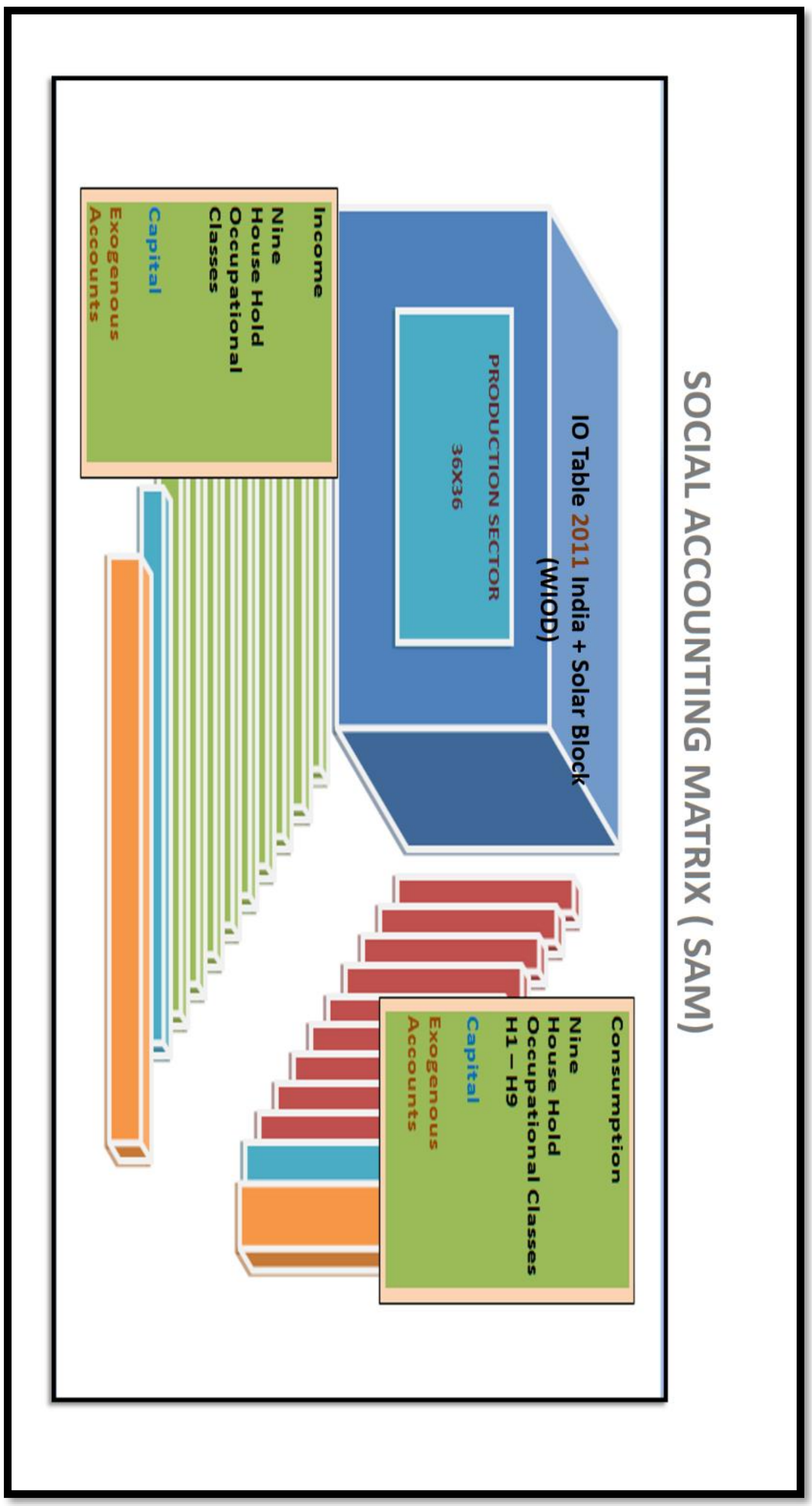
Rural Households	**Category**	**Urban Households**	**Category**
HH1	Self Employed in agriculture	**HH6**	Self Employed
HH2	Self Employed in non-agriculture	**HH7**	Regular wages/ salaries
HH3	Agricultural labor	**HH8**	Casual Labor
HH4	Casual labor	**HH9**	Other HH
HH5	Regular wages + others		

The total income of each of the nine households was estimated. The households receive income through various sources like labour income, income from capital owned by households, land income, and transfer income from government and rest of the world. The compiled data included only payments of wages for each of the domestic sectors thus wage income estimated and considered endogenously rest other components were exogenous to the model developed. The estimation of income distribution involved use of WIOD socio-economic accounts (SEA) data. The sector wise gross value added (GVA) was first segregated into labour and capital component.

The labor component which was available in three categories i.e. high skilled, medium skilled and low skilled labour was than estimated. The matching of skill-based income was performed with nine occupational categories. The procedure involved two set of data sources. The data on percentage distribution of population in various occupational classes according to educational qualification was used from NSSO 68 th round key indicators of employment and unemployment in Indian database. The data set. also provided distribution of working population sector wise (NIC 2008 classification) and also demographically (Rural & Urban). This data was concorded to 35 sector WIOD classification for the study.

To estimate household income from capital ownership data on payments of the domestic production sector for the capital for year 2010 -2011 was used. The payment of capital along with net capital income of from ROW is treated as gross capital income of the economy. The capital income was distributed into household classes by obtaining households capital income shares available in SAM of 2007-2008. This is followed by estimating land income received by agricultural households The incomes would apply only to the income from land is received only by rural agricultural self-employed household. The total payment for land factor as total land income of the class. The household personal income from different sources do not match the column total of each HH classes of our SAM. A pro-rata adjustment is done to obtain the control total i.e. the row total of theeach household's classes in the SAM. The figure 5.1 illustrates the SAM constructed for DCR and open category projects.

Figure 5.1: Schematic of Constructed SAM



The SAM was constructed by extending 36X36 solar integrated IO table already prepared in chapter 4 for both DCR and open category. The SAM matrix thus contained total 46 sectors, with 36 production sectors, 9 households and one for capital generation in the economy.

5.4.2 Multiplier Analysis

The impact of any demand addition on the exogenous accounts of SAM is transmitted through the interdependent SAM system among endogenous account. The interwoven nature of system implies that incomes of factor, households and production sectors are all derived from exogenous injection in the economy via multiplier

$$Y = A * Y + X = (I - A) - 1 * X = Ma * X$$

Y= Vector of endogenous variable, X= Vector of exogenous variables (accounts)
A is the matrix of average propensities of expenditure for endogenous accounts, I is the Identity matrix and M_a or $(I\text{-}A)^{-1}$ is the matrix of aggregate accounting multipliers.

Table 5.3: Impact Sub Matrices of Multiplier (M_a)

	Sectors	**Factor**	**Consumption**	**Household**
Sectors	**M11(36X36)**	**M12(36x2)**	**M13(36x9)**	**M14(36x9)**
Factors	**M21 (2x36)**	**M22 (2x2)**	**M23(2x9)**	**M24(2x9)**
Consumption	**M31(9x36)**	**M32(9x2)**	**M33(9x9)**	**M34(9x9)**
Household	**M41(9x36)**	**M42(9x2)**	**M43(9x9)**	**M44(9x9)**
Total	**Backward Linkages**	**Backward Linkages**	**Backward Linkages**	**Backward Linkages**

Total = aggregate multiplier = Gross output multiplier

When demand driven interventions occur through sectors, relevant block for impact analysis refer to M11(Gross output impact of 36 sectors) or output multiplier, M21(GDP impacts of two factor of production) Value added or GDP multiplie , M31(consumption impact in terms of 9 consumption items) Consumption multiplier M41, Household impacts of 9 household groups or Income multiplier.

One important feature of the SAM-based multiplier analysis is that it lends itself easily to decomposition, thereby adding an extra degree of transparency in understanding the nature of linkage in an economy and the effects of exogenous shocks on distribution and poverty." (Round, 2003, p. 271) The richness of the SAM multipliers comes from their tracing out chains of linkages from changes in demand to changes in production, factor incomes, household incomes, and final demands (Thorbecke, 2000, pp. 21-22). Therefore, the SAM framework permits tracing and quantifying all the propagation channels in the economy; and in doing so, provides a very useful policy instrument for meso level economy-wide impact analysis of demand driven interventions.

Multiplier Matrix can be decomposed either as multiplicative decomposition or additive decomposition. This analysis uses a multiplicative decomposition of matrix. A fully articulated SAM would include essentially all economic transactions and transfers between all economic agents. The matrix Z thus is a square matrix where row and column sums are equal. There are certain parts exogenously specified making opening for the model. For instance

$$G = \begin{bmatrix} Z & F \\ W & B \end{bmatrix}$$

Where F is the matrix of exogenous expenditure and B is matrix of exogenous income allocation to final expenditures and F includes categories of final demand which is specified exogenously.

For construction of SAM the endogenous accounts Z is also distinguished between interindustry transactions, final demand and value added categories and Let S be the matrix of SAM coefficients which can also be partitioned to corresponding coefficients for interindustry transactions (A), final demand (C) and value added category (V/H) . This work uses a reduced version of SAM where all value added are distributed into household incomes (wages & capital)

$$S=\begin{bmatrix} A & \cdots & C \\ \vdots & \ddots & \vdots \\ H & \cdots & 0 \end{bmatrix}$$

Where A is the matrix of interindustry coefficients

C is the matrix of endogenous final consumption

H is the matrix of coefficients allocating household income to value added

S can be defined as sum of two matrices

S= Q + R

Where

$$Q=\begin{pmatrix} A & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{pmatrix} \;\; \& \; R=\begin{pmatrix} 0 & \cdots & C \\ \vdots & \ddots & \vdots \\ H & \cdots & 0 \end{pmatrix}$$

$T= (I-Q)^{-1}R$

The matrix dissociation performed

M1 is intra group or transfer effect (within accounts effects) due external income injection where $M1 = (I-Q)^{-1}$

M2 is the extra group or cross effects where M2= (I+T)

M3 is circular or intergroup effects measuring full circular effects where $M3= (I-T^2)^{-1}$

Where Ma= M3*M2*M1

The next section addresses the question as to how changes in sectoral demand due to solar deployment under DCR and open category impact different sectors, factors and consumption patterns. The total multiplier impacts is **delineated in Appendix B1 & B2**

5.5. Results & Discussion

Development of an energy project generates impacts on local economy by creating direct and indirect sectoral demand along with employment generation. The estimations from chapter 4 already reveal favorable impacts on output multipliers under both DCR and open category deployments in India. The multipliers of the two deployment categories differ both within and is across sectors indicative of the fact that the two deployment categories will have different socio-economic impacts on Indian economy.

Any prior research involving SAM based analysis of socioeconomic impacts of solar deployment for India is not known to the author. The results are in line with finding of relevant literature on SAM based analysis of impacts associated with deployment of renewable energy project. Allan et. al (2011) used a social accounting matrix for the Shetland Islands to evaluate the potential local economic and employment impacts of a large proposed onshore wind energy project and concluded that local sourcing of material for 6oo MW Wind project will lead to increase higher GDP multiplier of 1.31 while employment multiplier value for the region will tripled Further the multipliers for associated sectors are different in case of local sourcing. The local economic impacts of renewable installations have been assessed in a number of studies to the local economic effects using ex-ante model analyses like Input-Output and computable general equilibrium (CGE) models. For instance, Slatterya et. al. (2011) conclude that the gains for the respective counties lie at 2,600 USD/MW in Texas. Focusing on a region in Oklahoma, Greene and Geisken (2013) find an increase in local gains by 9,730 USD/MW. Bristow et. al. (2012) conclude that in Wales, the economic incentives from the installations are rather marginal, so that Welsh counties have little interest in proceeding with wind power projects. Furthermore, potential investors often pay “community benefits” in order to gain local acceptance. Similarly, Munday et. al. (2011) find only small economic benefits for the involved counties in Wales.

The gross output multipliers **(Appendix B1&B2**) for the solar sector (sector 36) is highest in both DCR and open category projects although GDP, income and consumption multipliers do not indicate the same trend pointing to the fact that net economic and social impacts of solar deployments can significantly vary. The DCR category shows high GDP multipliers for sectors like agriculture, retail and whole sale trade. The open category GDP multiplier were highest for whole sale trade, followed by telecommunication and other supporting and auxiliary transport activities.

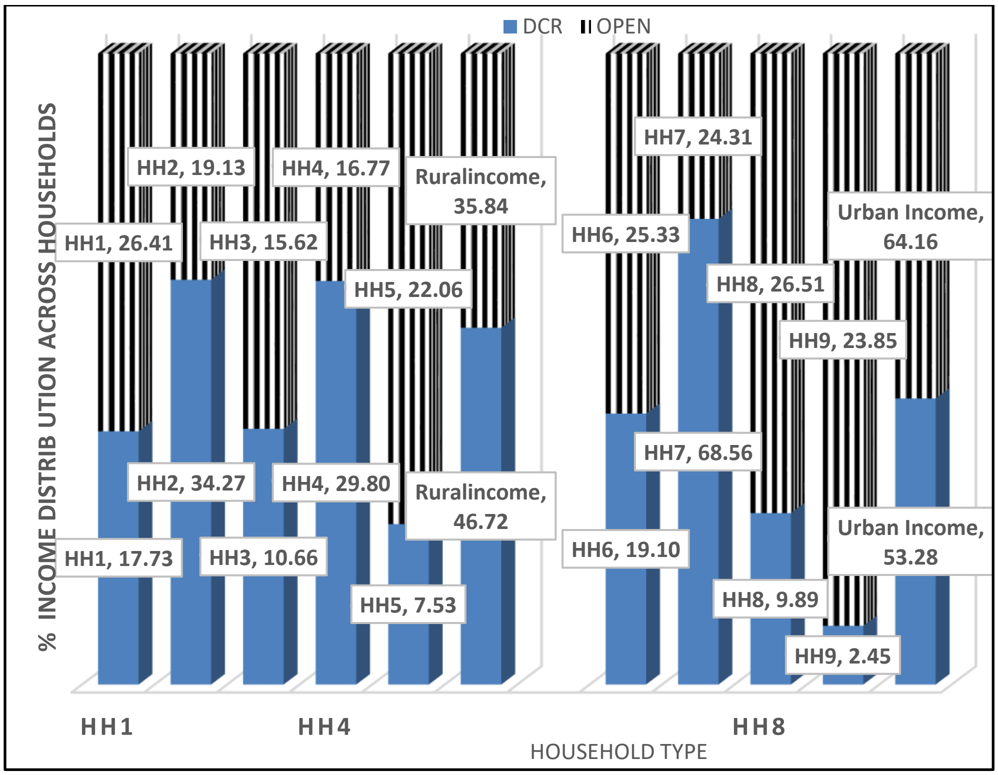
The income multipliers in case of DCR are highest for retail trade followed by agriculture and public administration. The income multipliers for open category are higher for whole sale trade followed by telecommunication and electricity supply. The consumption multipliers for DCR are highest for agriculture followed by construction and inland transport. In case of open category deployment agriculture has also has highest consumption, multiplier followed by inland transport & construction.

The multiplier model thus obtained was used to estimate income distribution across the nine occupational household classes segregated in SAM. The analysis indicated that total income generated /MW of Solar deployment in 23.35 % higher in case of DCR deployments. Further, the composition of rural employment compensation in total income is 46.7% in case of DCR and 35.84 % in case of open employment.

The DCR deployment triggers greater income generation in self-employed in non-agriculture (37.27%) and casual labor (29.80 %) categories for rural households while the income generated are higher for self-employed in agriculture (26.4%) & regular wages categories (22.01%). in case of open category. For urban households the highest income generation are in regular wages (68.56%) followed by self-employed (19.1%) for DCR. the household income is more uniformly distributed for urban households in open category with low of 23.85% for others to high of 26.51% for casual labour. The income composition profile is illustrated in **figure 5. 2.**

Further, multiplier decomposition was performed to segregate direct, indirect and circular impacts of solar deployment under DCR and open categories of deployment results are delineated in **Table 5.4.1.** The table delineates results in terms of net difference in multipliers (% change) under the DCR and open categories. Direct impacts of open category deployments (M1) is marginally higher than the DCR category but the indirect impacts or the cross sector impacts (M2) is predominantly under the DCR category with highest impacts mapped in textile, paper & pulp, leather and footwear, water transport and private household category, M3 circular effects are highest for other community &social services, agriculture and community services for DCR while sectors like electricity, whole sale trade and post & telecommunication are higher in case of open category deployment.

Figure 5.2: Income distribution across households for DCR & Open category solar Deployment



In case of Household Income multiplier M1 multipliers for Direct effects are equal in case of both DCR & open deployments, M2 Cross effect multipliers are higher for DCR category rural casual labor, rural wage & others, Urban self-employed, Urban others M3 Circular effects are higher for Urban other, Rural wage and others and urban casual labor for DCR and rural casual labor, urban regular wages and rural self-employed in agriculture in case of open category. The results thus indicate a good backward integration of DCR deployment in the Indian economy. The M3 or the circular impacts are mixed for DCR and Open categories.

Thus, DCR deployments would lead to greater economic engagement and benefit in terms of GDP and jobs generation. Recent literature dealing with employment impacts of renewable energy policies (Rivers, 2013) indicate that local socio-economic benefits from renewable energy policies are only possible when elasticity of substitution between labor and capital is low and when capital is not internationally mobile. Further, the benefits would accrue when labor intensity of renewable generation is high as compared to conventional generation.

According to the latest Indian census 2011 over 69 % of population stays in rural India, the distributive efficiency of income effects for solar deployment is better under DCR category having greater income generation for rural households. Further as highest income generation is in self-employed in non-agriculture and casual labor , studying the within group quintile data (NSHIE 2004-2005) indicates that over 68.8 % of the casual labor fall in the lower two income deciles.

Table 5.4: Summary of Direct (M1), Cross(M2) and circular impacts of solar deployment in India

Sector	DCR	Open	No of Sectors	High Impact Sectors
M1	present	present	36, 36	
M2	present	Not Detected	36,0	Textile, paper & pulp, leather, transport,
M3	present	present	18, 18	
Income			High Impact Households	
M1	present	present	9,9	
M2	present	Not detected	RH4, UH6, RH5, UH9	
M3	present	present	UH9, RH5, UH8	RH4, UH7

In case of solar PV sector possibility of high skilled permanent employment generation predominantly occurs during manufacturing stage, followed by a small number associated with operation and maintenance of the plant (Rio & Buiguillio, 2010). Furthering this is the fact that at present there exists a strong trend towards vertical integration of solar PV manufacturing sector instrumented by use of fully automated assembly lines leading to greater probabilities of labor capital substitution in the sector. This trend reduces future probabilities of international fragmentation of factors or splicing of supply chain thus concentrating manufacturing of solar panels in a region or territory which already has monopoly in the market.

According to Veloso (2000) welfare effects of DCR are well established primarily in the cases where there exists a generic gap between social and private opportunity costs of resource use by an industry or when there is a strong possibility of learning and knowledge spillover associated with foreign manufacturer investing in developing economies. The authors argue that for efficiently leveraging economic growth opportunities rendered by National Solar Mission, strategies to home the capital associated with solar panel and BOS manufacturing becomes critically important. Policy instruments like DCR have potential to play a pivotal role in homing the characteristically mobile capital of solar PV manufacturing by providing an opportunity of long term stable solar market demand and also ensuring domestic employment creation.

Further, authors argue that NSM is one of the key initiatives undertaken under the umbrella of National action Plan on Climate change (NAPCC) launched by Indian government in the year 2008. Therefore, impacts of various policy instruments like Domestic Content Requirement (DCR) under NSM have to be analyzed through a more holistic perspective bringing in the concerns of distributive efficiency under climate constrained conditions and economy wide welfare impacts of the policy into focus. The agenda for Indian National Solar Mission transcends the existing narrative of conventional industrial policy strategy for promoting RET deployment in India to a developmental strategy fine-tuned for alleviating impacts of intrinsic climate change vulnerabilities of Indian economy along with fulfilling the aspired developmental goals

5.6 Conclusions

The study attempts to understand the pathway for the economy wide impacts triggered due to deployment of solar power plants under DCR and open categories differentiated under Indian solar policy. The analysis reveals greater wage generation for urban household in medium and high skill category associated with current solar deployment strategy. Further, DCR deployments have higher backward integration in Indian economy with strong cross sectoral linkages. The study also highlights the fact that projects using domestically manufactured solar panels provide comparatively wider distribution of wages across the household categories and with better penetration in lower deciles of per capita expenditure. Thus, DCR deployments provide better opportunities for inclusive economic growth and development for India as compared to open category solar deployments.

Chapter 6

Environmental impacts: Environmentally Extended Multiregional I-O Analysis

6.1 Introduction

This chapter quantifies environmental impacts of solar deployment process in terms of embodied GHG emission and links it with distributive efficiencies of labor generation across multiregional boundaries. The environmental and economic impacts of DCR and open category deployments are mapped not only within the national boundaries but also into major exporter economies catering to the Indian solar sector.

A multiregional input output model was constructed for the two categories of solar deployment and economy wide impacts transacting across economies, contributing to inputs for solar deployment in India were simulated and compared. The results indicate that domestic manufacturing of solar panel brings substantial gains for Indian economy in terms of output GDP, employment and better quality of job generation, but it also produces greater GHG emissions highlighting the Development-Environment paradox faced by developing economies.

This chapter also explores and attempts to understand predicament in Indian solar policy to balance expectations between leveraging socio-economic benefits associated with domestic panel manufacturing in terms of regional growth prospects with adverse environmental impacts implicit in sticking to lower efficiency production processes. The study also reflects on the significant barriers associated with clean technology knowledge transfer to developing economies and its implications on long term development pathways. This sets in the context for estimating environmental impacts of DCR and open category solar deployments in India within the framework of sustainable development.

Following the above, next section deals with existing issues of clean technology transfer to developing countries and emissions embodied in trade with respect to solar PV deployment. This is followed by details of existing literature on life cycle assessment based environmental impacts associated with solar technology deployment followed by a profile of solar panel manufacturing firms in India w.r.t to their preference towards international environment management protocols in the solar panel manufacturing. This is followed by a description on construction of environmentally extended multiregional input output model and analyzing the environmental and economic impacts in the later sections

6.2 Indian Solar Scale up: Expectations and Predicaments

This section is composed of two subsections. The **section 6.2.1** reflects on the significant barriers associated with clean technology transfer to developing economies followed by a discussion on spatial mobility of solar PV technology and significance of estimating emissions embodied in trade components for solar deployment. In **section 6.2.2** existing literature on LCA based environment impacts assessment of solar deployment is detailed followed by performance assessment of Indian solar panel manufacturing firms with respect to proactive implementation of environmental management system to understand institutionalization of cleaner technologies in India. This sets in the context for estimating environmental impacts of DCR and open category solar deployments in India while also looking at the socio-economic parameters.

6.2.1 Barrier to Clean Technology Transfer

Developing countries on growth trajectory have greater need for adopting clean and efficient production processes procurement of associated technologies is still prohibitive due to barriers to entry posed by trade policies and various intellectual property regulations. Post Bali UNFCCC convention (2007) a demand for greater stress on creation of global exchange forums and fluid technology transfer mechanisms for technology transfer to developing economies became strong. The draft technology transfer agreement pinpoints certain goals for future progress which includes technology needs assessment, joint R&D programs and a healthy technology transfer environment and licenses (Hasper, 2009).

Ironically the predominant mode of technology transfer adhered to and justified by most developed countries have been to eliminate numerous tariffs and other barriers to trade for supplying climate change mitigation technologies to developing economies. However, no systematic mechanism facilitating flows of valuable skills and experience have been put in place. The debate has thus accentuated as developing countries viewed the strategy as "disguised protectionism" to boast exports from wealthy nations (UNFCCC,2008).

The process of technology transfer is complex, involving multiple considerations specifically for a developing economy. Developing countries are expected to play a vital role in global sustainability transitions by endorsing low carbon pathway. They have the scope and potential to "leap frog" or shift over from conventional dirty technologies to cleaner technologies thus avoid being trapped in high carbon paradigms. According to Perkins, (2003) the efforts to leap frog have conventionally centered around five prerequisite conditions i.e. i) A shift to clean production, ii) Immediate action, iii) Technology transfer from developed countries iv) Strengthening of incentive regime and international assistance.

The initial focus of technology transfer was to concentrate on efficiency enhancement to reduce environmental damage (World Bank, 2000) but has now been replaced by greater vigor towards rapid installation of technology capacities. Initially, the technologies were primarily made available through participation of transnational corporations (Shankle, 1997). These transfers were conventionally viewed as requiring economic policy supporting competitive markets and strong governmental frameworks towards cleaner production commitments, augmented also by international assistance for bridging the gap in cost, information and competition.

But the predicament lies in the fact that these channels (transnational corporations, international assistance and convenient trade flow channels) incompletely address the technology change over requirements (World Bank,2000). The technology diffusion process has to critically involve indigenous firms which are better aware of local needs and conditions and can better implement technologies concomitant with the demand and economic potential of the surroundings (Worrel et. al,2001). Further, leap-frogging would require not only strong incentives but capability of local firms to respond to incentives in terms of skills and expertise to manage technological change (Dooley et. al,2000). Even the channels of FDIs and transnational companies do not guarantee a positive spill over to local learning (Felipe,2000). Further developing smaller markets catering to low value items prevalent in developing countries cannot be tapped by transnationals firms (Perkins,2003).

Post UNFCCC, Bali convention there have been various international bodies and organizations working towards extending an array of technology transfer mechanisms and other solution to developing countries for instrumenting rapid clean technology dissemination. International agencies like International Energy Agency (IEA) and International Renewable Energy Agency (IRENA) are playing a major role in renewable dissemination. Further, Post Paris convention (2015) India has initiated formation of International Solar Alliance. The alliance aims at integrating resources for solar deployment in about 121 countries which are lying fully or partially between Tropic of Cancer and Tropic of Capricorn are endowed with excellent solar insolation, but the potential remains largely untapped (MNRE 2016).

According to UNCTAD (2013) countries use local content to “leap-frog” existing barriers to technological transfer. The use of performance requirements (particularly those on local content) are just one of many means to discipline and speed up the process whereby developing countries (or advanced economies seeking to quickly develop a new strategic sector) can learn, adopt and adapt technologies and production processes innovated elsewhere. The use of performance requirements is particularly prevalent not only (as noted above) in sectors with high rents and strong network effects, but also in highly sophisticated industries where these entry barriers are extremely high and potentially prohibitive for most developing countries. The LCR's are also expected to promote Foreign direct investments (FDI) and reverse FDI's enabling technology transfer. The positive spillover effects of FDI on renewable energy sector has been demonstrated by many studies. Magnani and Vaona (2013) demonstrated that renewable energy spillover has a positive impact on regional economic growth in Italy. Kathuria et. al. (2015) applied panel data techniques to investigate the impact of the policy differences on FDI inflow in wind energy. The results showed that the differences have significant resource potential over a seven-year period based on empirical research in eight Indian states. Liu et. al (2016) confirmed that FDI have a positive impact on renewable energy technology spillover in China.

An effort towards regional cooperation may help in effective dissemination of solar technologies in the region but strong evidence for systematic channelization of knowledge transfer do not exist do not exist in existing alliances. This study builds on the technology transfer discourse and attempts to provide a differentiation to the impacts associated with DCR and open category solar deployments in India. The aim is to map the socio-economic impacts alongside the environmental impacts to bring in a more holistic perspective for solar scale up regime in India.

6.2.2. Environmental Impacts of Solar Technology Scale up

Another aspect of critical interest is to study the environmental impacts of green growth in the context of technology specific characteristics. This can be further differentiated in terms of assessment of environmental impacts quantitively, institutional and geographical impacts. The solar PV technology is known to be highly modular leading to greater spatial mobility. This makes it essential that emissions embodied in trade are critically assessed and suitably accounted in while assessing the solar deployment impacts.

National and regional energy policies prefer environmentally friendly electricity generating technologies. Solar Photovoltaics being a renewable resource are considered clean source of electricity but any production activity has an associated environmental footprint for material and embodied energy use. The quantitative assessment of environmental impacts of PV based electricity generation using Life Cycle Assessment (LCA) framework is a comprehensive and well accepted procedure to estimate the environmental impacts of PV installations from cradle to grave.

During the PV life cycle, emissions to the environment occur mainly from using fossil-fuel-based energy in generating the materials for solar cells, modules, and systems. These emissions differ in different countries, depending on that country's mixture in the electricity grid, and the varying methods of material/fuel processing. The lower the energy payback times (EPBT), that is the time it takes for a PV system to generate energy equal to the amount used in its production, the lower these emissions.

Mono crystalline silicon panels are one of the most widely used solar panels globally. As indicated in **Table 5.2**, LCA studies reveal, that material and energy efficiencies of PV manufacturing have substantially improved over time but different installation methods and irradiation potential pertaining to geographies plays a very crucial role in determining overall environmental impacts of these installations.

Early studies by Wilson & Young (1996) estimated that the EPBT of the solar installations in U.K. will be in the range of 7.4-12.1 years considering panel efficiencies of 12% but in a later study Muneer et. al (2006) estimated an EPBT of 8 years and GHG emissions of 44 CO2-eq./kWh. Kato (1997;1998) investigated the total EPBT range from 8.9 to 15.520 MJ/m2 and GHG emissions in the range of 91-61 CO2-eq./kWh for Japan. Mathur et. al (2002) estimated GHG emission of solar installations in India at 64.8 CO2-eq./kWh with panel efficiency of 13 % while a later study by Nawaz and Tiwari (2004) revealed an EPBT of 8 years and GHG emissions of 47.8CO2-eq./kWh with a panel efficiency of 11%.

Studies post 2009 report an average panel efficiency of 14 % and low EPBT of 1.75 to 3.3 for various geographies like South Europe, Switzerland and China. The average panel efficiencies for solar panels currently range between 13-19 % providing an impressive EPBT in the range of 1-4.1 years (Bhandari et. al, 2015).

According to latest study by Fthenkis et. al (2011) the greatest potential environmental risk of the PV material cycle is linked with the use of several hazardous substances and toxic gases during the production however from a scale of consequence, PV technology is remarkably safer than other technologies. The end of the life dismantling of solar power plant accounts for 1.7 % of total life cycle energy consumption and 1.9% of total GHG emissions associated with solar PV technology use.

Table 6.1: **LCA studies: Mono-crystalline PV systems**

Author	**Year**	**Location**	**Efficiency (%)**	**Life time (yr)**	**EPBT (yr)**	**GHG emissions (g- CO2-eq./kWhe)**
Wilson and Young	1996	UK	12.0	20	7.4-12.1	N/A
Kato et. al.	1997	Japan	N/A	20	15.5	91
Kato et. al.	1998	Japan	12.2	20	8.9	61
Mathur et. al	2002	India	13.0	20	N/A	64.8
Nawaz & Tiwari	2006	India	11	35	8	47.8
Muneer et. al	2006	UK	11.5	30	8	44.0
Kannan et. al	2006	Singapore	7.3-8.9	25	5.87	217
Kannan et. al	2006	Singapore	10.6	25	4.47	165
Alsema and Wild-Scholten	2006	South-European	14.0	30	2.1	35
Wild-Scholten	2009	South-European	14.0	30	1.75	30
Ito and Komato	2010	China	N/A	N/A	2.5	50

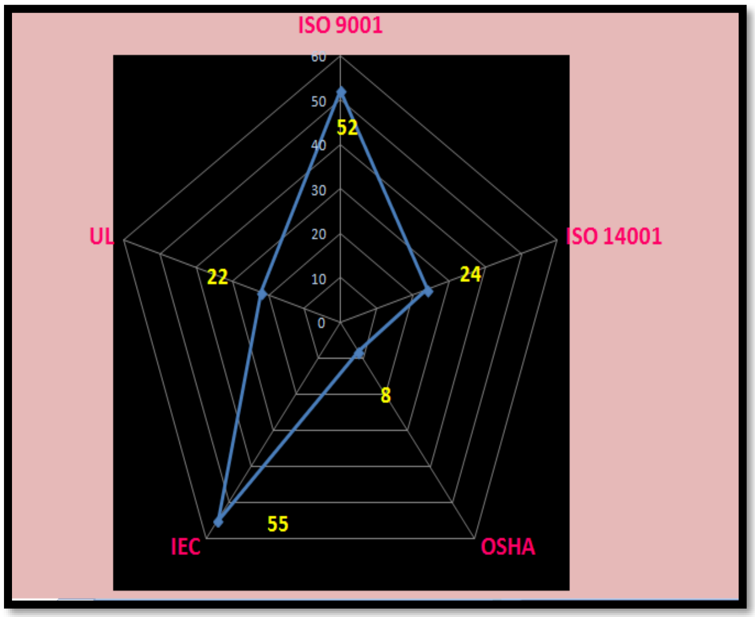
Source: De Groot, 2016; Baharwani, 2014

The following section deals with consideration of geographic and institutional impacts of solar deployments Solar PV technologies have low transport and logistics costs. The modular nature of solar PV technology enables its sub-components to be produced and assembled in discrete economies and exported to final markets. Therefore, solar PV production networks are integrated globally (Wang, 2013). The emissions embodied in trade and inclusion of emissions across the supply chain becomes very important when evaluating overall environmental impacts of solar deployment process.

Moreover, environmental impacts of growth trajectory in the Indian solar sector would also depends on institutional structure like stringency of environmental regulations in an economy. The developing countries usually have less stringent environmental norms thereby acting as pollution heaven's trading off environmental efficiency for opportunities of economic growth (Mani & Wheeler, 1999). A cross sectional analysis of solar PV panel manufacturing firms in India was performed to evaluate their preferential affiliation to various product quality management norms, differentiating also for the adherence to a standard environmental management norms.

The analysis involves data integration from entries enf-solar register for 78 solar panel and BOS manufacturing firms in India along with detail compilation from individual websites. **Figure 6.1** shows a profile of environmental performance sensitivity trends of the solar panel manufacturing firms in India. The figure indicates preference of the firms to seek certifications for quality management standards like ISO 9001 (71 % firms) and product standard specification IEC-61215 (67% firms), very small proportion of firms have opted for environmental standards like ISO 14000 (28 % firms) or UL/ CE standards (31% firms) still less are going in for employee safety standard certifications of OSHA (10% firms). Therefore, although most of the firms get certification for the product performance quality but very small portion seek the standards for environmental safety in case of solar panels manufacturing. **Appendix C1 & C2** details the various relevant standards associated with solar panel and BOS manufacturing sectors in terms of product quality, environment and labor conditions.

Figure 6.1: Indian Solar panel manufacturing firms: Environmental Performance Sensitivity



Taking the cognizance from the emerging trends in Indian solar sector this chapter in the next section attempts to understand environmental impacts associated with two categories of solar deployments with respect to GHG emissions across the solar deployment process by compiling an environmentally extended multiregional input-output analysis framework. The estimations involve estimating multiregional impacts of solar deployment in India considering inputs coming from Germany and China which are major suppliers of invertors and solar panels respectively to India (Bridge to India, 2012).

6.3 Methodology & Data Collection

As part of the globalization process, the production of goods and services is increasingly separated from their consumption, with supply chains often spanning multiple countries. Global multiregional input–output (MRIO) models are widely used to create macro-level accounts of factor use from the consumption perspective, as these models map monetary flows of goods and services between nations as well as the production factors. The embodied GHG emission in these flows can be easily tracked. The environmental impacts using MRIO framework have also been sketched out in many studies like Hertwich & Peters, 2009, Galli et. al 2012, Steen-Olsen at al., 2012, Weinzettel et. al, 2013. The study extends the country level study to technology specific case scenario for India in this chapter.

The solar deployment process not only derives input from India, main components of solar deployment i.e. solar panels and invertors are predominantly supplied from China and Germany respectively. A solar block for specific component manufacturing attributed to Germany and China was constructed.

The methodology includes three steps i.e. i) Constructing solar blocks for the two project categories detailed in section **6.3.1** followed by methodology for MRIO analysis detailed in section **6.3.2**. The last step involves estimation of GDP and employment generation, distributive efficiencies of wage generated and estimating embodied GHG emissions in the solar deployment process for the two categories.

6.3.1 Constructing the solar block

The exogenous components of solar panel and BOS manufacturing process which factored in as imports for the Indian solar block formulated in **chapter 4 (Figure 4.1& 4.2)** was disaggregated in the economies of China and Germany. This study introduces solar generation as a new production activity for Indian economy through construction of a separate final demand vector but it considers as exogenous demand increase in case of Chinese and German economy **Figure 6.2 & 6.3** delineate solar block formulated for two categories of projects distinguished by domestically manufactured and imported solar panels across multiregional boundary. (P.T.O.)

Figure 6.2 Multiregional Solar Block: DCR

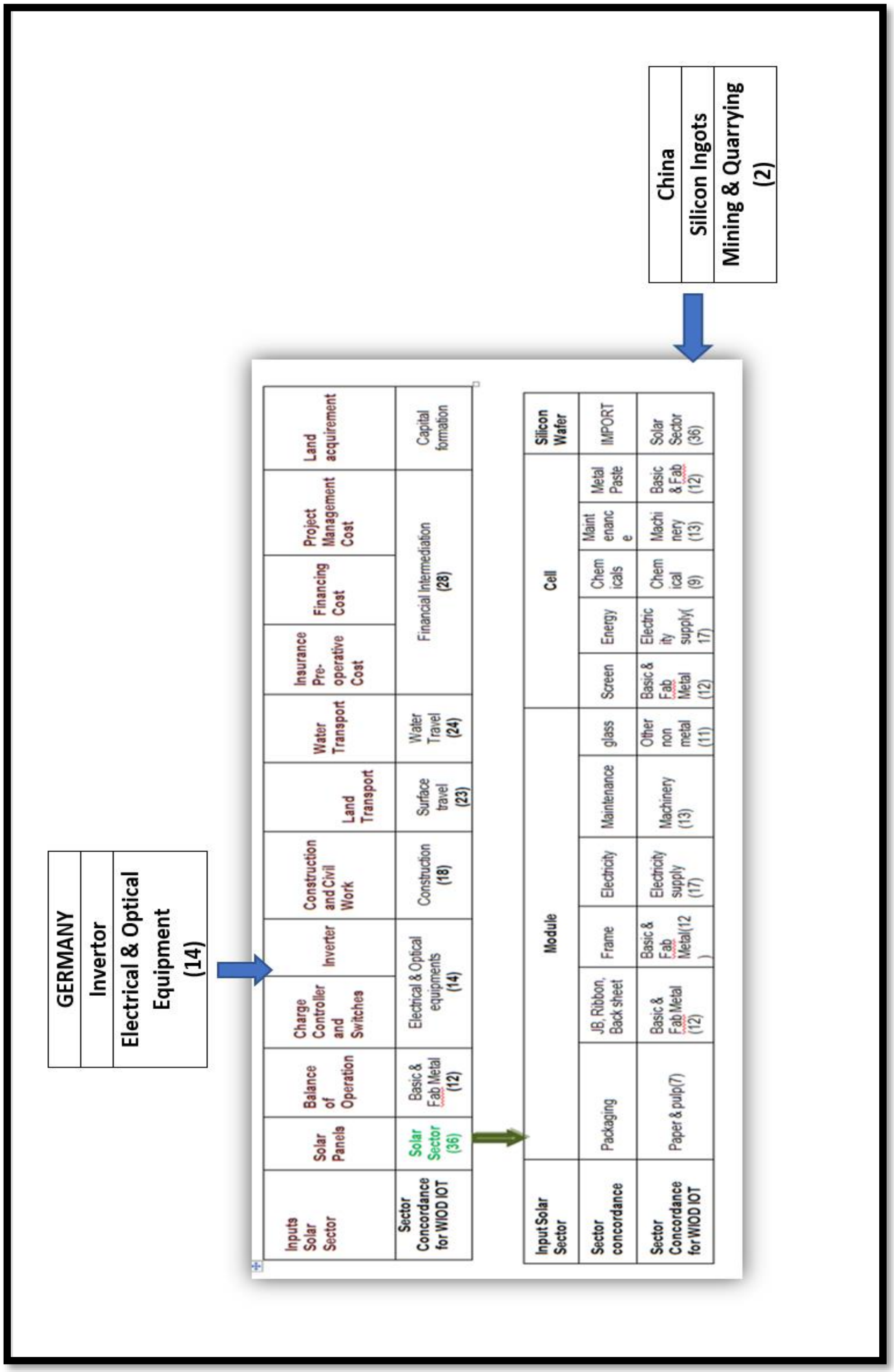
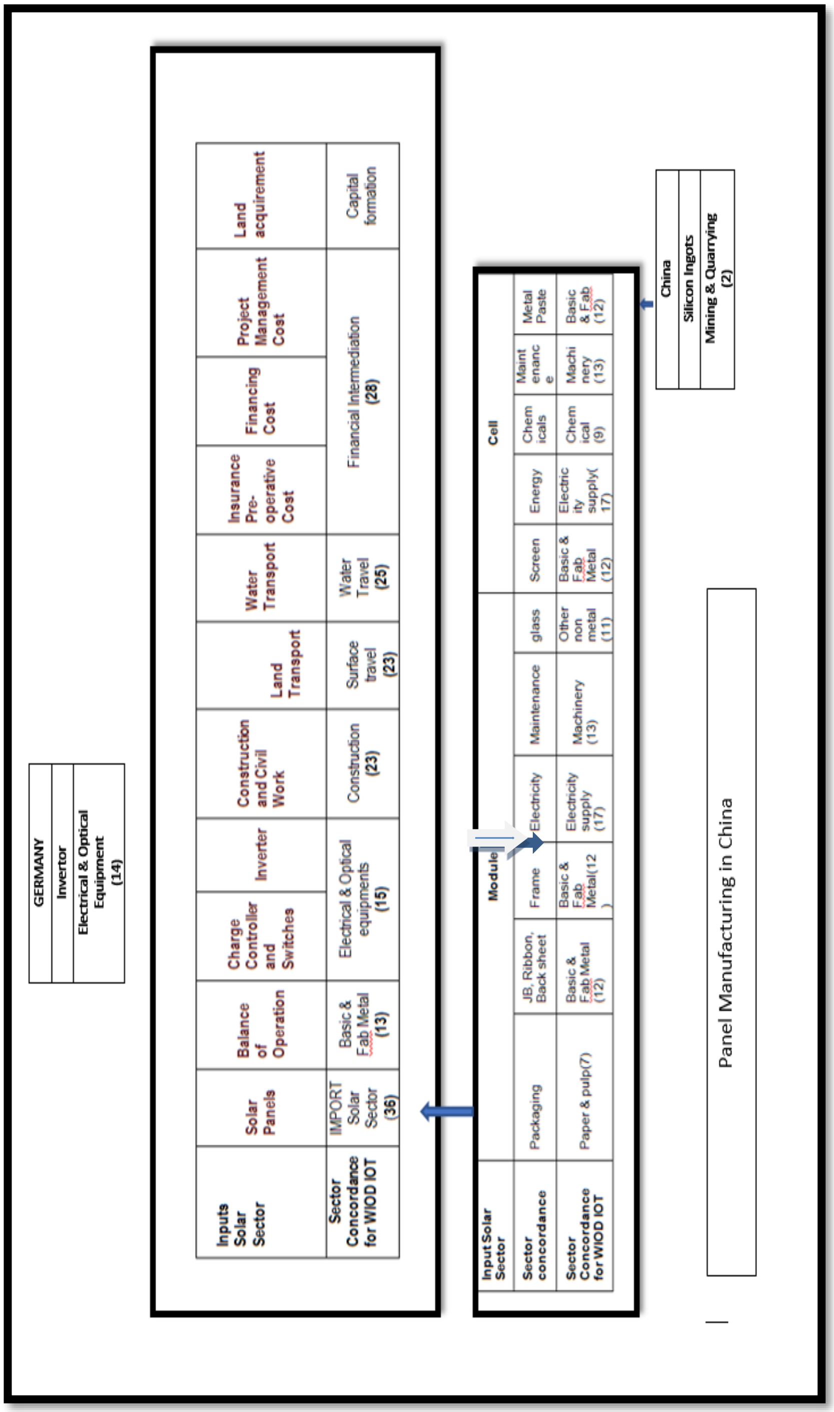


Figure 6.3: Multiregional Solar Block for Open Category



6.3.2 Multiregional Input Output Analysis

I-O methodology facilitates integrated analysis by assessing direct and indirect economy wide impacts of growing solar sector on all other sectors of Indian economy. The study uses the basic Leontief I-O model of linear equations tracing out sources of each sectors inputs, whether they are purchased from other firms in the economy, imported or contributed by labour (wages and salaries). It also provides sales of each sectors output with sales to other industry and of final demand along with consumption, gross fixed capital formation. The MRIO also includes the impacts of solar deployment on exporting partners (China & Germany)

The information from IO table has been utilized in the general form of Leontief model

$X=AX+Y$ (1)

Where A is the matrix of technical coefficient, X the vector of sectoral output and Y is the vector of sectoral final demand component. Eq 1

$X= (I-A)^{-1}$ (2)

Where I is an identity matrix, Matrix $(I-A)^{-1}$of interdependence. Each element of that matrix indicates total (direct & indirect requirement of sector i for final demand output of sector j).

The impacts of the imports obtained for the deployment project in the form of inverters from Germany and panels or silicon Ingots from China are estimated by using 35 sector, national IO table (2011) for China and Germany available in WIOD. The process involves estimating multipliers by creating Leontief matrix and subsequent estimation of multipliers for the relevant sectors engaged in production of Indian imports

The WIOD database also provides associated annual Socio-economic Accounts (SEA) providing industry wide wages and employment by skill type and satellite environmental accounts for the three economies which are used in further analysis.

The simulation assumes grid connected solar PV installations is a new economic activity thus all fixed assets are newly purchased and calculated through perpetual inventory method (Quang Viet, 2000). This is to make block maximally adjusted to existing national peculiarities.

A commodity flow table was created to ensure balanced supply and use of inputs and or outputs of solar block and adjusted to conventional form of I-O table. The output of solar sector is in the form of electricity directly connected to the grid, the new sector is assumed to supply its entire output to the electricity sector. The study initially simulates the inter industry exchanges involved in an year when the solar power plant is installed.

The industry specific literature indicates (Bridge to India, 2013, MNRE, 2013) that on an average it takes 10 months for solar power plant to start its operation fully after successful land acquisition. Therefore, in the year of commissioning (t) output equivalent to 2 months of solar generation is considered with average normative capacity utilization factor of 19 % (CERC, 2009) prevalent in India. The year t includes all the inputs required for installing the solar power plants along with factor inputs in terms of labour and capital formation and output in terms of 2 months of power generation. MW of solar power generated was converted to million dollars of value using latest input output table for India (2007) adjusting for inflation and currency depreciation.

Input-Output linkage in terms of Leontief coefficients were obtained for the two scenarios. These were used to obtain value of output, income and employment impacts on the economy due to solar power plant deployment for the two categories under study.

6.3.3 Estimation of embodied emissions in solar deployment process

The overall output generated along with the sector specific GHG emission coefficients for the three economies was used to determine overall GHG emissions for the two categories of deployments in kilotons of CO_2 per million US dollars of output generated. The emission coefficient was estimated separately for all three economies using the WIOD satellite environmental accounts for the year 2010-2011. This involved first creating of the sectoral emission coefficient matrix by estimating CO2 emission per unit of output generated across sectors in the three economies. This was followed by evaluating impacts of solar sector specific sectoral demand generation for two categories of deployment. The results obtained for all the estimations are detailed in the following section.

6.3.4 Distributive efficiencies of compensation generation across economies

Further, distributive efficiencies of the two categories of deployment are estimated in terms of type of labor compensation generated. The total sectoral direct and indirect output generation by the two deployments categories was used to estimate sectoral employment coefficient for the three economies by integrating data from WIOD Socio-economic Accounts (SEA). The accounts also provide data for sectoral labor distribution in terms of low skilled labor, medium skilled labor and high skilled labor. The data was used to estimate job compensation distribution for the two categories of solar deployment in all the three economies.

6.4 Analysis and Results

Deployment of ground mounted solar PV capacity generates economy wide impacts in terms of direct and indirect sectoral demand, employment generation along with concomitant GHG emissions embodied both in manufacturing as well as service inputs for the installations. Further, structure of inputs and outputs would differ for the projects using domestically manufactured solar panels to those opting use of imported crystalline silicon panels.

A Multiregional Input Output (MRIO) model was constructed to simulate input flows for solar deployments in India. Solar deployment was treated as a new sector in the economy. The DCR projects use domestically manufactured panels and imports invertors from Germany[5] and silicon ingots from China[6]. The projects using imported panels include estimations of demand & output flow for panel manufacturing in China and inverter manufacturing in Germany.

The output flows (GDP generation) associated with solar deployment along with sector specific GHG emission coefficients (Kilo ton CO_2/MUSD) for the three economies was used to estimate embodied GHG emissions for the two categories of solar installations. The figure 6. 4.1 (a & b) illustrates GDP and employment generation profile for the two categories of solar deployment

Figure 6.4. GDP and employment generation profile for the two categories of deployment

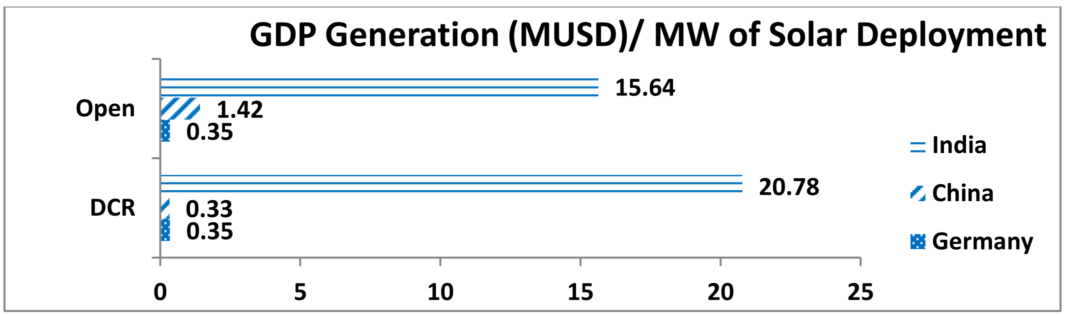
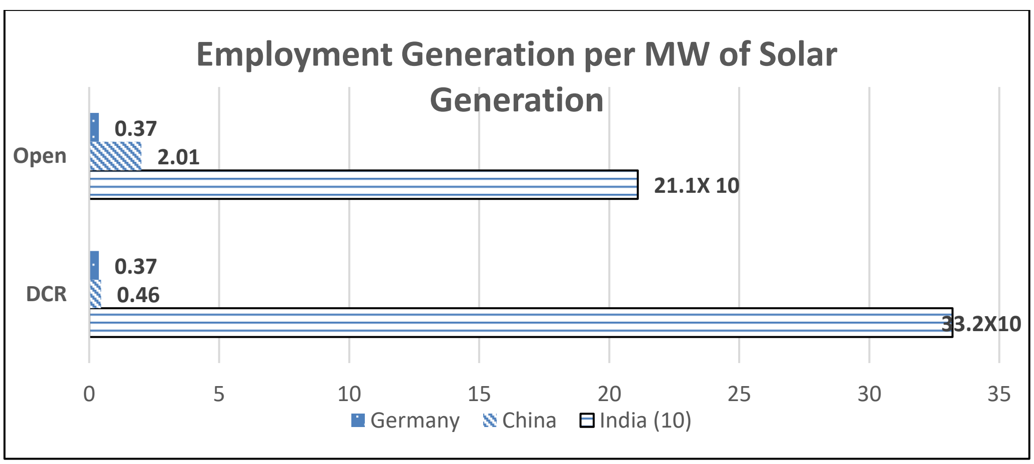


Figure 6.5: Employment generation profile



[5] Although the invertors are also sourced from few domestic suppliers and other international players a major marker share is catered by German heavy electric manufacturers like Schneider.

[6] China supplier more that 80% of crystalline silica in the global market

The analysis reveal that country wide GDP generated per MW of solar deployment for open category deployments generate greater GDP flows across Chinese economy when compared with those obtained for DCR category in China but overall GDP generation across economies is 51% lower .

The economic exchanges induced by Indian solar deployment projects under both domestic and imported categories have embodied GHG emissions located in all the three economies. GHG emission coefficients for the three economies were first estimated using WIOD Environmental satellite accounts and individual national input output table. An estimation of GHG emissions in terms of kilotons of CO_2 emissions per million USD of GDP generated shows that domestic panel manufacturing would lead to substantially higher emission when compared with imported panel scenario. The results can be attributed to higher sectoral emission coefficients for existing Indian manufacturing Industry compared to China and Germany. **Figure 6.6** Illustrates the overall GHG emission profile for domestic and imported solar panel-based deployments in India inclusive of emissions embodied in trade

The GHG emission per MW of solar deployment was estimated for the DCR and open category deployments . The GHG emission associated with DCR deployments is 58 % higher indicating an overall inefficiency of production processes

The emission coiefficient estimated in terms of GDP Generated/ KTon of CO2 emission is 49% lower in case of DCR deployments. This profile provides a strong evidence towards the need of not only a transition to clean energy but more effective technology transfer mechanisms for the overall economy wide tehnological efficiencies for developing countries like India.

The distributive efficiency of labor compensation generated in India, China and Germany in the process of deploying a MW of solar capacity in terms of high, medium and low skilled labor compensation generated is estimated for the both categories of deployment project under study. The results show that DCR and Open deployments both generate greater medium and high skill labor but total compensation genration is higher for DCR category. The wage generation for Germany lies predominantly in medium and high skill sector while China generates predominantly medium and low skill labor in the deployment process

Figure 6.6 GHG Emissions per MW of Solar deployment

Figure 6.7 GDP generation due solar deployment per KT of CO2 generated

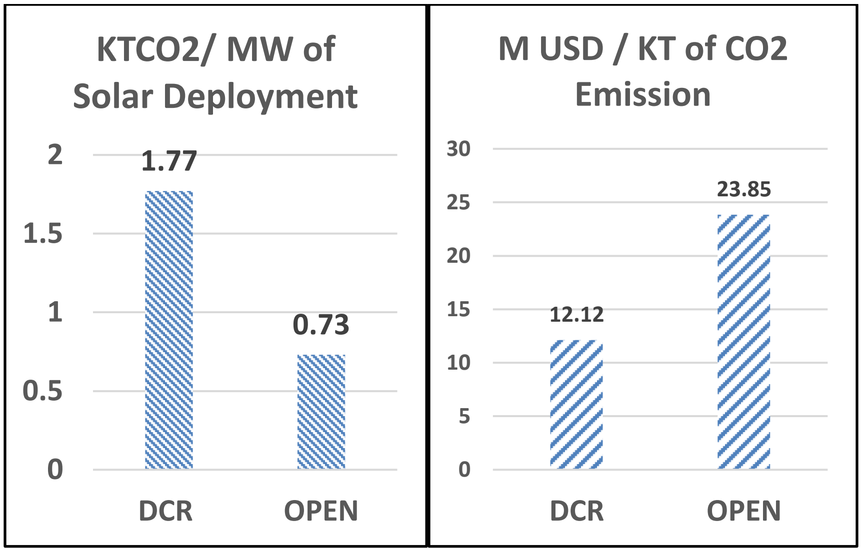


Table 6.2. & 6.3. present the results obtained in case of Germany and China respectively. The positive trend of moving towards greater high quality jobs in India as demonstrated by the domestic manufacturing option indicates a possibility to move up the value chain but is eclipsed by concomitant high emission trajectory of the growth path.

Table 6.2: Skill based labor compensation generated in Germany

	Sectors	**Domestic & Imported**
HIGH SKILL LABOUR (00 USD)1	Electrical and Optical Equipment	134.39
MEDIUMSKILL LABOUR 00 USD)	Electrical and Optical Equipment	188.64
LOW SKILL LABOUR (00 USD)	Electrical and Optical Equipment	31.56

A win- win developmental strategy for the economy needs also to alleviate adverse environmental impacts. This warrants an urgent need for facilitating appropriate and affordable technology transfer to avoid suboptimal lock-in of global resources.

Table 6.3. Skill based labor compensation generated in China

Category	**Sector**	**High Skill**	**Medium Skill**	**Low skill**
Open	Paper & Pulp	0.20	2.16	2.56
	Chemicals & Chemical	2.07	9.60	7.66
	Other Non-Metallic Mineral	3.37	42.30	80.80
	Basic Metals & Fabricated Metals	19.05	127.41	137.68
	Machinery	5.74	30.99	29.57
	Transport Equipment	6.97	19.38	5.76
	Financial Intermediation	4.00	8.23	0.15
Total (00USD)		**41.39**	**240.07**	**264.19**
DCR/ Open(00USD)	**Silicon Ingot**	**6.17**	**25.03**	**20.10**

The use of policy instruments like LCR's for promoting renewable energy policies have proven to bring favourable spill over effects for few early movers like canada and China. In Ontario, Canada the local content requirement (along with $110 million in economic development financing) has attracted a $7 billion wind turbine manufacturing investment from South Korea-based Samsung. Further Following a decade-long implementation period of LCRs China has now overtaken the United States in installed wind energy capacity and has gone from a small-scale turbine manufacturing base to having three of the global top 10 manufacturers in only six years' time (2003-2009). Similar successes have been noted in the domestic market: before 2000, Chinese companies held only a 10% share of the domestic market; in 2009 however, the top ten Chinese companies accounted for 85.3% of newly installed capacity (UNCAD, 2013)

6.8 Conclusion

The study reveals that process of technology localization through domestic content requirement would lead to a path with greater overall embodied emissions in the solar deployment process, however it will also generate greater employment generation opportunities for India.

Solar panel and BOS manufacturing firms in India show a lower trend towards effective environmental management as discussed in section **6.2**. The use of imported panels for solar deployment further incentivizes establishing supply chains which bypass the learning by doing process for learning by using mechanism. The scenario thus tend to not favor an environment where technology knowledge transfer and the spill overs for cleaner production process can be established in India. This would be a situation of lock- ins into less efficient developmental pathway not aligning with agenda key agenda of green growth which mandates technological innovation for cleaner production processes.

The policy decision to logarithmically scale up renewable energy technologies like solar PV need a greater scrutiny for efficiency to meet multiple goals of cleaner development agenda, economic growth and domestic employment for Indian economy. The exiting option of domestic manufacturing provides an option to move up the supply chain for India but for simultaneously actualizing the global green agenda a deeper engagement of international governance towards technology transfer and adaptation of clean technology transfer mechanism need to be created for developing country like India.

Chapter 7

Conclusion

The thesis focuses on understanding and evaluating expansive impacts of ground mounted grid connected solar PV deployment process in India from a sustainability perspective. The underlying key research inquiry deals with understanding implications of emerging Green Growth-Sustainability paradox associated with India's commitment towards renewable energy transitions. The thesis comprises of five core chapters besides the with introduction and conclusion. The introductory chapter provides a background for the thesis and delineates a rationale for taking up the research. This is followed by two descriptive chapters; chapter two studies important discourses relating to interpretation and implementation of the sustainability concept in policy making. The key effort is to understand sustainability-technology-energy interlinkages. Chapter three locates itself in the energy transitions research and evaluation of key aspects associated with Indian solar policy along with characteristics of the developing solar sector. These chapters also synthesize the research boundary for the work in terms of sustainability analysis and technology interpretation.

This is followed by the quantitative estimations of triple bottom line impacts (economic-social-environmental) associated with solar deployment process in India in the next three chapters. The chapter four deals with estimation of economic impacts of solar deployment process in India with the help of input output analysis. Chapter five maps the social impacts associated deployment process by constructing a social accounting matrix. This leads to chapter six which evaluates environmental in terms of embodied GHG emissions in solar deployment process across economies by using environmental extended multiregional input output analysis. The work leads to this concluding chapter which summarizes key findings and limitations of the study along with synthesizing contributions and policy implications of the research work.

This concluding chapter summarizes dissertation by revisiting the research analysis and highlighting the key findings. The main aim is to understand and map the developmental impacts of green growth mediated solar transitions for Indian economy. The involves presenting a summary of thesis in the initial section followed by a section discussing the synthesis and policy implications of the study. The section leads to understanding of research limitations and scope for future research in section three followed by concluding remarks.

7.1 Summary of the Thesis

The thesis evaluates impacts of ground mounted grid connected solar PV deployments on Indian economy from a sustainability lens. The structure of the work is exploratory in nature and focuses on the emerging ‘green growth: sustainably paradox’ in the context of developing economies. The thesis initially elucidates critical links between Energy, Technology and Sustainable development, followed by technology specific discussion with respect to Indian solar policy and the key emerging characteristics of Indian solar sector. This leads to applied quantitative analysis of triple bottom line impacts (Economic, Social and Environmental) associated with solar deployment process in India.

7.1.1. Sustainability – Technology – Energy Interlinkages

Sustainability analysis involves multidimensional evaluation across key developmental parameters. This thesis however, primarily focuses on understanding sustainability impacts of green growth associated with solar transitions in the Indian economy. Appropriate technologies are known to play a pivotal role towards sustainability transition, the expectations and outcomes of technological transitions strikingly vary for developing and developed economies. Therefore, conceptualization of green growth for developing economies would involve an extension to the three key aspects associated with the concept of green growth (Hallegatte et. al., 2011; Jacobs, 2012, Carvalho, 2015); namely i) to sustainable preservation of natural capital in the process of economic growth, ii) Technological and organizational innovation for reduction of environmental impacts & iii) Innovations for long term economic growth *via* growth of cleaner production processes. For the developing economies better representation of key developmental concerns like need for inclusive economic growth to reduce poverty and improve wellbeing and improved environmental management needed to tackle resource scarcities and climate change become critical (OECD, 2012).

Although energy linked indicators form a critical yardstick for monitoring many of these developmental concerns for India, the current process of solar deployment cannot be associated directly with energy indicators like energy access, end use and livelihood development as the emerging solar sector in India integrates predominantly from the supply side in the form of grid connected ground mounted solar utilities not intervening the demand side directly. Thus, the expansive impacts of the process of solar deployment as a growth strategy forms a more representative inquiry for research. The key criteria for analysis are presented in **Table 7.1**.

Table 7.1: Evaluating Developmental Impacts of Solar Deployment Process

Parameters	**Sustainability Assessment Variables**
Economic	Increased and more equitably distributed GDP and employment Economic diversification
Social	Increased, income and/or quality of life, notably of the poor Decent jobs that benefit poor people created and sustained Reduced inequality
Environmental	Environmental impact in terms of CO_2 emissions of solar deployment process

The renewable energy transitions are policy mediated and do not follow the conventional trajectory of energy transitions, however they explicitly hem in expectations of regional economic growth (Joshi & Sharma, 2014; Allan et. al , 2011; Rio and Burguillo, 2009; Reddy et. al 2007). The emerging solar transitions were also articulated to factor in topical developmental concern of climate adaptation for India but effectiveness policy implementations is being determined more by various national and international institutional barriers to regional green growth. The various strategies of niche protection, socio technical transitions and policy articulation for solar promotion in India is detailed in **section 7.1.2.**

7.1.2: Green energy internalisation through renewable energy policies

One of the overarching global challenge is to initiate innovation in the existing energy system towards stabilizing the climate change. This would involve selecting, timing and implementing institutional changes to break the incumbent regime and pave way for transitioning to cleaner energy systems. According to Nemet (2008) innovation in low carbon energy technologies is difficult due to multiple market failure conditions. Green energy transitions guided towards sustainability would involve a set of directed processes that could break the incumbent regime leading to a fundamental shift in existing socio-technical energy systems (e.g., Geels and Schot, 2010; Kemp, 1994).

Further, there also exists a national or regional agenda that needs to be addressed while diverting public funds towards clean energy technologies. The local issues like diversification of energy supply, enhanced regional and rural development opportunities and creation of a domestic industry and employment opportunities (Rio and Burguillo, 2007, Carvahlo, 2015) form some of the key concerns while formulating renewable energy policies.

With the prevailing concerns regarding energy security, India embarked on solar transitions under the flagship of National Solar Mission (NSM) in the year 2010. The aim was to establish India as a global leader in solar energy sector by creating the policy conditions for rapid technology diffusion and investment across the country. The program used a wide umbrella of dynamic policy instruments aimed at efficient rent management under the conditions of emerging cost and technology trends both under domestic and global spaces. The aim was to minimize cost and also protect government from subsidy exposure in case expected cost reduction does not materialize or is more rapid than expected (MNRE, 2011). The main aim of the mission include:

i. Creating an enabling policy framework for deployment of grid connected solar power
ii. Creation of favorable conditions for solar panel and BOS manufacturing capabilities focusing on solar thermal
iii. Promote off-grid applications of 2000 MW by 2022
iv. To achieve 20 million square meters of thermal collector by 2022 and deploy 20 million solar lighting system in India by 2022.

The program initiated systematic incentivization for the above targets with an array of policy mechanism an incentive operating both at the central and the state level. The elements of solar deployment innovation is illustrated in **Figure 7.1.**

As global dynamics of solar PV manufacturing transformed with costs of C-Si solar panel dropping more that 80 %, the initial target of 20 GW of grid connected solar was revamped to 100 GW in the year 2015. Further the momentum of solar deployment also accelerated with over 12 GW of solar deployment by March, 2017 surpassing the previous target of 3 GW solar by 2017 (MNRE, 2017). The costs of solar thermal manufacturing did not see the expected anticipated fall so the focus of solar transitions was shifted predominantly to solar PV generation

The trajectory of Indian solar energy transitions demonstrated, phenomenon of time-space telescoping as proposed by Schulz et. al (2006) with the record scaling up of grid connected solar deployments from less than 1 MW to 6000 MW in a short span of six years (2010-2016). Further, the existing incentives and policy structure has also led to development of a unique ecosystem for the sector with respect to solar panel manufacturing firms and entities involved in the overall solar deployment process for India.

The profiling of firm level data for 73 solar panel manufacturers show that Indian solar sector exists as a strong forwardly integrated sector with very weak backward integration (only 3% firms in the data showing manufacturing in the solar ingots and cells). Further, the study reveals that a trend towards policy mediated diversification into solar panel and BOS manufacturing sector is visible with firms in various associated sectors like lighting, invertors, cable manufacturing

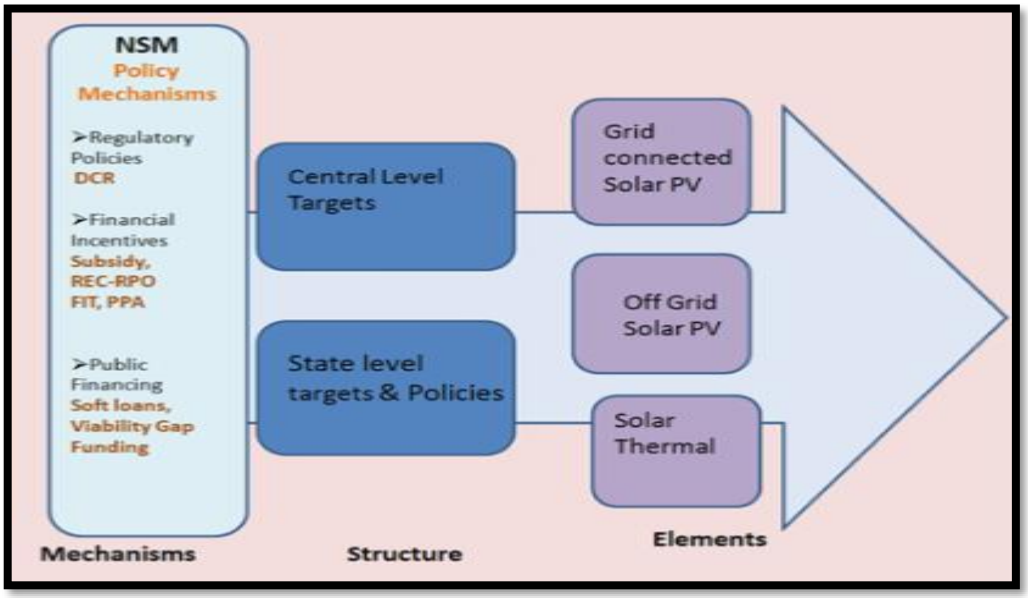


Figure 7.1: Elements of Solar Innovation System in India

diversifying into solar manufacturing. The core solar PV manufacturing firms also shows a level of diversification into other peer technologies like hybrid solar and wind and Build-in photovoltaics (BIPV) thereby leveraging incentives available in other sectors along with stability benefits of diversification.

The solar deployment sectors in India demonstrates well-structured topology with different categorical players contributing at different level of institutional resolutions. This involves interventions at strategical level, project level and effective supporting environment. The strategic level plays include central and state agencies like MNRE, MOP, IREDA, SREDA etc articulating the policy for effective solar promotion. The private players involved in solar project implementation include projects developers, agencies which undertake EPC (Contractors involved in Engineering, Procurement and construction and other enabling agencies involved in manufacturing, research and development and community support to the growing solar innovation system in India.

The growing solar deployment ecosystem would further expand as India embarks on solar based energy transition with a target to install 100 GW of grid connected solar by the year 2022. The initial networks have been established to integrate solar technology within Indian economy with an effort to consolidate both backward and forward linkages in the sector. The existing targets of solar deployment were initially articulated under two distinct categories for solar promotion. The projects which use domestically manufactured solar panels (DCR) with those using imported solar panels (open categories). The DCR as policy instrument was introduced to boost local manufacturing capacities while providing the protection to the niche market. The WTO (2017) has ruled against the DCR content in the Indian solar policy considering it as violation of free trade agreements.

The NSM is one of the key initiatives under national action plan for climate change and therefore the exploring the developmental impacts of solar deployment (economic, social and environmental) becomes very important. Understanding the impacts of solar deployment process under the two categories (DCR & Open) thus become critically essential to understand the trade-offs w.r.t. regional green growth agenda while phasing off DCR content. The next three sections develop a quantitative framework for mapping expansive impacts of investments in solar sector and evaluate it from a sustainability perspective. This includes internalizing dilemma of designing a balanced domestic industrial policy that allows leveraging solar mediated local green growth possibilities without obliterating WTO obligations for India. This is accomplished by integrating comparative study on direct and indirect impacts of attaching domestic content requirement (DCR) criteria in Indian solar policy within the framework of analysis

7.1.3 Economic Impacts of solar deployment process in India

This chapter estimates direct and indirect impacts of the solar deployment process in India. The key research questions evaluated were:

a) How does the process of solar deployment under DCR & Open category lead to demand generation across sectors.

b) How increased demand translates into direct and indirect GDP and employment generation.

c) What is the labor compensation distribution profile across different skill-based labor categories for solar deployment.

The estimation involved Input-Output modelling-based analysis. The methodology was based on the work of Caldes (2009) involving estimation of solar thermal installations impacts for Spain. India-specific solar block was compiled for integration of solar deployment as a new sector in the national IO table (WIOD, 2011) following Kulistic et. al's (2006) methodology involving compilation of biodiesel production block for Croatian economy. The solar block was constructed for both DCR based deployment where crystalline silicon (C-Si) solar panel manufacturing occurs within economy & Open category, where solar panels are imported, and manufacturing remains an exogenous activity. Employment impacts and compensation distribution across the skillbased labor categories were estimated using socio-economic satellite accounts in world input output database (WIOD, Dietzenbacke, 2012).

The analysis reveals that DCR based deployment has superior backward linkages in the economy leading to 24.74 % higher GDP generation when estimated in terms of direct and indirect value added. Further, DCR deployments generate 36.64 % more employment. The estimates of labor compensation distribution profile indicate generation of more medium skill (38.8 % & 40.1 %) compensation followed by high skill compensation (31.1 & 35.5 %). DCR deployments however generates 35.4 % higher labor compensation. These results provide a qualitative insight into the known positive employment effects (Hillebrantdt, 2007) of solar deployment. The results indicate that localization of technology by using endogenously manufactured solar panels leads to higher GDP and employment generation up the value chain, a discernable positive trend for India's developmental trajectory.

The methodology of chapter four involved an extensive process of solar block creation for Indian solar deployment process under DCR and Open category and integrating it with the IO table. The analysis though was restricted to exchanges across 36 production sectors on the economy. To evaluate the social impacts of solar promotion, the analytical framework needed an expansion into household level impacts. This limitation was overcome in the next chapter where evaluation of social impacts associated with solar deployment process in terms of distributive efficiency of income distribution and consumption impacts was performed by constructing a social accounting matrix (SAM).

7.1.4. Social Impacts of Solar deployment process in India

This chapter estimates meso - economic impacts of grid connected solar deployment process in India. The analysis involved evaluations of the following aspects:

a) How do solar scale up under DCR and open category deployment affect household income generation via their effects on sector production factors and consumption pattern.

b) How do solar scale up induced economic growth trickles down to the poor for the above-mentioned scenario.

c) What are the direct, cross-sectional and feedback impacts associated with a unit of solar capacity deployment.

Social impacts were modeled by the construction of a Social Accounting Matrix (SAM) in order to i) Link changes in value adding income to final demand through income-consumption effect ii) Study impacts of solar deployment across nine heterogeneous household categories for India[7], leading to poverty alleviation impacts of solar deployment iii) Decomposition of multiplier matrix to estimate sector wise direct, cross sectional and feedback effects of solar deployment with respect to income and GDP multipliers. The constructed Social Accounting Matrix (SAM) linked production sectors of the IO analysis to household income and consumption matrix. The analysis led to i) Identification of high impact sectors with respect to production, household income generation and associated consumption ii) Profile for household income distribution across nine occupational category iii) Direct, cross sectional and circular multiplier impacts of solar deployment with respect to income and GDP generation.

The income distribution across the nine-household categories for the DCR & open deployments was estimated with the help of income multipliers from SAM. The results revealed that technology localization by DCR leads to 35.84 % greater income generation across household. The income distribution is skewed towards urban households (53.2 %; 64.16%) in both the deployment categories though DCR generates 23.2% greater rural income.

The analysis with respect to income distribution across household categories reveals that technology localization by DCR based deployment triggers greater income generation for the self-employed in non-agriculture (RH2,37.27%) and casual labor (RH4, 29.80 %) categories in case of rural households. Higher income is generated for self-employed in agriculture (RH1,26.4%) and regular wages categories (RH5, 22.01%) for open category.

In the case of urban household, income generation is highest under regular wages (UH7, 68.56%) followed by self-employed (UH6, 19.1%) for DCR. The household

[7] RH1: Self employed in agriculture, RH2:Self employed in non agriculture, RH3:Agricultural labor, RH4: Casual labor, RH5 Regular wages + others, UH6: Self employed, UH7:Regular wages/ salaries, UH8:Casual labour, UH9:Other HH

income distribution trend is more uniform for urban households in case of open category (23.85% - 26.51% across all the four households).This was followed by multiplier decomposition to segregate direct, cross-sectional and circular impacts of the solar deployment for the two categories (**Table 7.2)**. Results reveal that direct impacts of open category deployments (M1) is marginally higher than the DCR category. However, cross sector effects (M2) are predominantly under DCR with sectors like textile, paper & pulp, leather and footwear, water transport and private household sectors as the main beneficiaries.

Table7. 2: Summary of Direct (M1), Cross(M2) and circular impacts (M3)

Sector	DCR	Open	No of Sectors	High Impact Sectors
M1	present	present	36, 36	
M2	present	Not Detected	36,0	Textile, paper & pulp, leather, transport,
M3	present	present	18, 18	
Income			High Impact Households	
M1	present	present	9,9	
M2	present	Not detected	RH4, UH6, RH5, UH9	
M3	present	present	UH9, RH5, UH8	RH4, UH7

Our analysis reveals that distributive efficiency of income effects for solar deployment is better under DCR projects with greater income generation for rural households. Further, highest income generation is indicated for households under self-employed in non-agriculture and casual labor category. The income quintile data reveal that 68.8 % of the casual labor falls in the lower two income classes, thus affirming that DCR based solar deployments provides greater integration in the local economy and better penetration efficiencies in lower income deciles indicative of better poverty alleviation impacts.

After evaluation of economic and social impacts of Indian solar deployment process the next section evaluates the environmental impacts of solar deployment process

7.1.5. Environmental impacts of Indian solar deployment process

This section summarises chapter 6 of the thesis which estimates embodied GHG emissions and distributive efficiency of labor generation across multiregional boundaries for the DCR & Open category projects of solar deployment in India. The following aspects were analysed to understand environmental impacts:

a) The mechanism of clean technology transfer to developing economies and the emerging trend amongst Indian solar panel and BOS manufacturing firms to endorse internationally accepted environment management practices.

b) Estimation of embodied GHG emissions within and across national boundaries.

c) Estimation of GHG emissions per unit of employment generation within and across region.

d) Compensation distribution profile across multiregional boundaries

Environmentally extended multiregional input output model (EE-MRIO) was applied for this analysis. The model simulates impacts of solar deployment process both within India and across the main exporter countries (China & Germany) providing inputs to Indian solar sector. The analysis involved estimation of embodied GHG emissions associated with such deployments (Andrew, 2009) inclusive of trade. The estimation has been augmented with topical debate on existing barriers for clean energy technology transfer to developing economies along with synergies emerging from rapidly growing solar sector there by connecting it with the developmental discourse.

The analysis involved estimation of total embodied carbon dioxide emissions inclusive of emissions from imported inputs in the Indian solar sector. Thus, the imports which were exogenously treated in previous chapters were modelled into the solar sector. This included modelling the process of solar panel manufacturing in China and inverter manufacturing in Germany along with the process of solar deployment in India. An environmentally extended multiregional input-output (EE-MRIO) analysis was performed. The analysis estimated GDP, employment and environmental impacts in terms of CO_2 emissions associated with of a unit of Indian solar deployment across economies of India, China and Germany.

The estimation reveals that GHG emission per MW of solar deployment is 58 % higher for DCR category indicating an overall inefficiency of production processes in India. The profile of country wise GDP generated per MW of solar deployment reveal that open category deployments generate greater GDP flows across Chinese economy when compared with those in DCR category as panel manufacturing is primarily located in china. The emission coefficient estimates in terms of GDP generated/ KTon of CO_2 emission is 49% lower in case of DCR deployments but overall employment generation is 21% higher. The results showcases the predicament of trade offs in green growth . It is indicative that without facilitation of appropriate clean technology transfer for developing countries like India either economic or environmental benefits would have to be compromised.

Following the estimation of environmental impacts the overall devlopmental impacts of solar deployment process can be summarised as presented in **Table 7.3**. The results reveal that harnessing green growth potential of the solar scale up in India would be more effective if domestic localisation of technology manufacturing can be maintained. The greater benefits in terms of GDP , quantity and quality of employment generation occurs when solar panel manufacturing occurs within India, as indicated by estimates of domestic content requirement based solar deployment. Further, the income generation would be higher and more equitably distributed for DCR deployments. Although the GHG emissions associated with DCR mediated solar deployment would be much higher that open category, DCR deployment generate more jobs per KT of GHG emissions warranting a need of effective mechanism for clean technology transfer to developing economies.

Table 7.3 : Triple Bottomline Impacts of Solar Deployment Process in India

Parameters	Indicators Assessed	DCR	OPEN
Economic	GDP Employment Income Economic diversification	**>24.7%** **>36.6 %** **> 35.5%** More Medium & High Skill Jobs	
Social	Increased, income and/or quality of life, notably of the poor Reduced inequality	Rural HH Income **> 23.2%** Greater income generation in lower income quintile	Urban HH Income **>44.1%**
Environmental	Environmental impact in terms of CO_2 emissions from solar deployment process	High	Low **< 58%**

7.2 Synthesis & Policy Implications of the study

The study developed an empirical framework to evaluate solar transitions underway in India intending to go beyond the prevalent industrial policy based discourse (Sahu & Shreemali, 2015) to relevant developmental perspective associated with process of renewable energy promotion .

The study reveals that harnessing green growth potential of the solar scale up in India would be more effective if domestic localisation of technology manufacturing can be maintained. The greater benefits in terms of GDP , quantity and quality of employment generation occurs when solar panel manufacturing occurs within India, as indicated by estimates of domestic content requirement based solar deployment. Some recent studies affirm these results for example Carvalho (2015) using an economic geography framework reveals that regional benefits are formalized only under conditions of technology localization and low spatial mobility.

Technology localization through DCR based deployments also has superior backward linkages integrating well with in Indian economy. Further, there are substantial cross and circular linkages benefitting the economy. Household incremental income generation is higher, estimated distributive impacts of the income generation reveal greater spread into low income households for DCR categories. Thus, incentives for establishing the solar panel and BOS manufacturing in India has greater positive effect with respect to poverty alleviation and inclusive growth synergizing well with sustainable development goals for India.

The study also reveals that in-house solar manufacturing has higher environmental impacts in terms of embodied emission in manufacturing process, but it has the potential to generate more jobs per unit emissions for deployment. The results once again highlight the paradox between green growth and sustainability. The mechanisms of technology transfer for renewables into late mover economies largely focus on learning by using strategy circumventing a learning by doing curve which is known to create positive spill overs in terms of cleaner technology transfers and has a potential for economy wide improvement in process efficiency.

These results point to the fact that deployment of clean technologies may not trigger the expected innovation towards cleaner production processes leading to green growth. Further, it may not lead to expected positive developmental impacts needed for developing economies. Thus policies formulated for renewable energy scale up and deployment have to be scrutinized for their efficiency to meet multiple developmental goals.

7.3 Limitations & Future Work

The Green Growth – Sustainability paradox associated with Indian solar promotion was explored in this interdeciplinary study. The research boundary for empirical analysis restricts itself to the process of solar deployment not considering life cycle impacts in terms of energy transitions, emissions and overall greater energy security. The focus is on grid connected ground mounted solar PV installations so do not include other solar deployment categories like grid connected roof top solar,

solar stand alone, solar thermal which are an integral part of Indian solar innovation system. A static general equilibrium framework was used for analysis due to lack of data availability, however the existing dynamism in the solar sector would have been better captured by a dynamic modelling framework, further the economic segregation was only for 36 sectors due to unavailability of homogenized data on socio-economic and environmental accounts that may have led to better resolution and accuracy for results.

The thesis work only captures evaluation of expansive effects of solar deployment in India thus capturing only the input impacts of solar transitions in India in terms of cross-sectional short-term growth in economic activity for India focusing on the green growth prospects. Although sustainability impacts in terms of shift in security of energy supply, positive change in energy mix and reduction of energy linked GHG emissions are the predominant movers in the mainframe sustainability discourse. An addition of some of these indicators would provide an holistic view of the growth and development trajectory and provide the basis of further extension of the work.

The natural extension of the present research work can be in terms of expanding the research improving the resolution of the exiting models by using more dissociated IO tables. Further, as the availability of data improve a dynamic version of the modelling exercise will provide more representative results. The detailed life cycle assessment-based framework can be compiled to study overall all impacts of deployment process across time. Further a similar exercise can be performed various other technologically different renewable energy categories.

7.4 Conclusion

The study reveals that harnessing green growth potential of the solar scale up in India would be more effective if domestic localisation of technology manufacturing can be maintained. The greater benefits in terms of GDP , quantity and quality of employment generation occurs when solar panel manufacturing occurs with in India, as indicated by estimates of domestic content requirement based solar deployment. The incentives for homing the solar panel and BOS manufacturing in India has greater positive impacts on poverty alleviation and inclusive growth synergizing with global sustainable development goals. Inhouse solar panel and BOS manufacturing would lead to higher environmental impacts in terms of embodied emission in manufacturing process but it has the potential to generate more jobs per unit emissions for deployment.

However, execution of solar transitions has been a complex involving articulation across global green agendas and local brown agendas for India. The overarching expectation from international regime to focus mainly on learning by using and visible lacuna of effective vehicle for technology transfer from early movers to rapidly industrializing countries like India pose some fundamental challenges when studied from developmental perspective. Further objections of WTO on use of policy instruments like the domestic content requirement in solar policy further raise the concerns over developmental impacts of clean technology transitions in emerging economy like India. India’s National Solar mission (NSM) is a key initiative under the umbrella of its National Action Plan on Climate change (NAPCC). The evaluation of impacts associated with solar transitions should thereby transcend beyond the conventional industrial policy strategy and free trade obligations. This would be possible only when the transition process establishes itself as a developmental strategy fine-tuned for alleviating intrinsic climate change vulnerabilities and aspired developmental goals for India.

Appendix

Appendix A:1

Appendix A:2

Appendix A: 3

Appendix A: 4

Appendix B: 1

Appendix B: 2

Appendix C:1

Appendix C:2

Appendix C:3

APPENDIX A:1

Solar Block for DCR Projects

Products at purchasers' price	Intermediate Industries												Total Economy	Gross capital Formation	Total industry output at base price
	Solar Sector (36)	Basic & Fab Metal (12)	Paper (7)	Other non-Metals(C11)	Chemicals (C9)	Maintenance (19)	Electricity (17)	Construction (18)	Electrical & Optical equipment's (14)	Financial Intermediation (28)	Water travel (24)	Surface Travel (23)			
Solar Silicon wafers (Imported)	193.43	0	0	0	0	0	0	0	0	0	0	0	193.43	0	193.43
Back sheet, ribbon, Frame, Screen, metal paste	0	103.79	0	0	0	0	0	0	0	0	0	0	103.79	0	103.79
Hot Galvanized Steel Frames	0	21.9	0	0	0	0	0	0	0	0	0	0	21.9	0	21.9
Packaging	0	0	4.84	0	0	0	0	0	0	0	0	0	4.84	0	4.84
Glass	0	0	0	24.18	0	0	0	0	0	0	0	0	24.18	0	24.18
Chemicals	0	0	0	0	14.5	0	0	0	0	0	0	0	14.5	0	14.5
maintenance	0	0	0	0	0	29.01	0	0	0	0	0	0	29.01	0	29.01
Electricity	0	0	0	0	0	0	14.5	0	0	0	0	0	14.5	0	14.5
Ground Leveling & civil work	0	0	0	0	0	0	0	27.56	0	0	0	1.10	28.66	0	28.66
Wires & transmission, Switches charge controller infrastructure,	0	0	0	0	0	0	0	0	33.64	0	0	0	33.64	0	33.64
Invertors	0	0	0	0	0	0	0	0	26.50	0	0.55	0.34	26.84	0	26.84
Insurance	0	0	0	0	0	0	0	0	0	1.72	0	0	1.72	0	1.72
contingency	0	0	0	0	0	0	0	0	0	5.16	0	0	5.16	0	5.16
Interest during construction	0	0	0	0	0	0	0	0	0	17.20	0	0	17.20	0	17.20
Project Management	0	0	0	0	0	0	0	0	0	3.44	0	0	3.44	0	3.44
Financing Cost	0	0	0	0	0	0	0	0	0	3.44	0	0	3.44	0	3.44
pre operative cost	0	0	0	0	0	0	0	0	0	3.44	0	0	3.44	0	3.44
Water Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land Cost	0	0	0	0	0	0	0	0	0	0	0	0	0	10.32	10.32
VAT	0	2.28	0.106	0.531	0.319	0	0	0	0	0	0	0	3.232	0	3.236
Net Custom duty	0*	0	0	0	0	0	0	0	0.76	0	0	0	0.76	0	0.76
Subsidy	0	0	0	0	0	0	0	0	(-1.20)	0	0	0	-1.20	0	-1.20
Total Output at Base Price	193.43	127.97	4.95	24.71	14.82	29.01	14.5	27.56	59.7	34.4	0.55	1.44	533.04	0	542.81

Net custom duty 5.5% and subsidy on panel import 4.2%, VAT @ 2.2 % All values adjusted to Million USD (2011) exchange rate 46.42 (WIOD database), custom duty is wavered for solar grade semiconductors

APPENDIX A:2

Solar Block for Open Category Projects

Products at purchaser's price	Solar Sector (36)	Basic & Fab Metal (12)	Constructio n (18)	Electrical & Optical equipmen t's (14)	Financial Intermediat ion (28)	Water travel (24)	Surfac e Travel (23)	Total Economy	Gross capital Formatio n	Total industry output at base price
Solar Panel (Imported)	189.27	0	0	0	0	18.91	1.79	0	0	209.97
Hot Galvanized Steel Frames	0	21.94	0	0	0	0	0	0	0	21.94
Ground Leveling & civil work	0	0	27.56	0	0	0	1.10	0	0	28.66
Wires & transmission, Switches charge controller infrastructure	0	0	0	33.64	0	0	0	0	0	33.64
Invertors	0	0	0	26.50	0	.55	.34	0	0	27.39
Insurance	0	0	0	0	1.72	0	0	0	0	1.72
contingency	0	0	0	0	5.16	0	0	0	0	5.16
Interest during construction	0	0	0	0	17.20	0	0	0	0	17.20
Project Management	0	0	0	0	3.44	0	0	0	0	3.44
Financing Cost	0	0	0	0	3.44	0	0	0	0	3.44
pre-operative cost	0	0	0	0	3.44	0	0	0	0	3.44
Water Transport	0	0	0	0	0	0	0	0	0	0
Land transport	0	0	0	0	0	0	0	0	0	0
Land Cost	0	0	0	0	0	0	0	0	10.32	10.32
VAT	0	0.504	0	.76	0	-	-	-	-	1.264
Net Custom duty	11.37	0	0	1.58	0	-	-	-	-	12.95
Net Subsidy (-)	(-)9.27	0	0	-1.20	0	-	-	-	-	-10.47
Total Output at Base Price	191.37	22.444	27.56	61.28	34.4	19.46	3.23	359.744	10.32	370.064

Appendix A:3 Estimation of Demand, Employment & Labor Compensation Multiplier

Impacts of DCR and open category deployments are estimated in terms of total GDP output, household income, employment and distributive efficiencies of income generation. Introduction of a new sector (solar PV) in Indian economy is modelled. The IO analysis maps relationship between expenditure generated during project deployment and its impacts on 35 +1 sector Indian economy. The results are estimated in terms of either increased demand in the economy or total change in output of regional economy due to a final demand of the new sector j estimated using the equation:

$$\Delta X = OM_j \times \Delta FD_j$$

X = total output of the regional economy,

OM = output multiplier

FD = final demand

The relationship between expenditure generated by a certain project ΔFD and its impacts in the economy in terms of increased demand of good and services (ΔX) is depicted in following relation

$$\Delta X = (I - A)^{-1} \Delta D$$

Where I is the identity matrix, A is the matrix of technical coefficients (which reflects the percentage of production from each sector consumed by each of all productive sectors) and $(I - A)$ is Leontief inverse, that represents the total (direct & indirect) requirements per unit of final demand

Therefore change in output of total economy (35 sector, WIOD National Input Output table for India) where demand of n sectors change can be estimated as

$$\Delta X_{(1\times 1)} = \; n_{(1X35)} \times \left(OM_{(35\times 1)} \times FD_{(35\times 1)}\right)$$

The employment change in the economy due to given change in final demand of sector j is estimated as

$$\Delta E = TDIE \times \Delta FD_j$$

Where E is the sectoral employment and TDIE is employment total direct and indirect employment coefficient or simple employment multiplier of sector j. The total change in the employment of the economy in case where final demand of n sectors changes is estimated by

$$\Delta E_{(1\times 1)} = \; n_{(1\times 35)} \times \left(TDIE_{(35\times 1)} \times FD_{(35\times 1)}\right)$$

The total household income change in the regional economy due to given change in final demand of sector j is estimated as

$$\Delta I = TDII \times \Delta FD_j$$

Where I is household income and TDII is household direct and indirect income coefficient or income multiplier of sector. The total change in household income in the case where final demand of n sector changes is estimated by:

$$\Delta I_{(1\times 1)} = \; n_{(1\times 35)} \times \left(TDII_{(35\times 1)} \times FD_{(35\times 1)}\right)$$

The distributive efficiencies of employment generation between high, medium and low income jobs was estimated using year wise socio-economic accounts data made available by WIOD satellite accounts. The data base provides sectorwise low, high and medium skilled labor share in the total income generated. The estimations involves

$$\Delta I \quad = \Delta IHSL + \Delta IMSL + \Delta ILSL$$

Total income generated can be classified into high skilled income, medium skilled income and low skilled income generation. The distributive efficiency of income generation when final demand change of all the n sectors in the economy are considered

$$\Delta IHSL_{(1\times1)} = n_{(1\times35)} \times (TDIHSL_{(35\times1)} \times FD_{(35\times1)})$$

$$\Delta IMSL_{(1\times1)} = n_{(1\times35)} \times (TDIMSL_{(35\times1)} \times FD_{(35\times1)})$$

$$\Delta ILSL_{(1\times1)} = n_{(1\times35)} \times (TDILSL_{(35\times1)} \times FD_{(35\times1)})$$

Appendix: A: 4: Cost Input estimation

Selective Component Cost input estimation in the solar Block

Estimating total number of solar panel Requirement for 1 MW grid connected solar PV Deployment

Total Capacity of power plant	1 MW
Average sun Hours per day	5 hrs
Total watt hr/ day	5000000
Total Insolation (5-5.5)Kwh/m2/day	5.5
Divide total watt hr / day by total insolation	909090.91
Accounting by system inefficiency multiply by (1.2)	1090909.09
Divide by wattage (300W) of the panel for No of panels	3636.36
Approx	3636

Estimating total mounting structure requirement for 1 MW grid connected solar PV Deployment

Elements	Estimation	Units
Panel Dimension (LxBxH)	1956x992X35	mm
Galvanized steel plate @8.5 kg / m2	16.49	kg/ panel
24 panel in Each array	395.83	kg/array
Total no of steel Array @ 146	57791.44	kg/ MW
Total Galvanized Steel @ $1100/ Ton	3814235.30	INR/MW

APPENDIX: B1

	Sector	Rank	Gross Output	Rank	GDP Multiplier	Rank	Income Multiplier	Rank	Consumption Multiplier
	Estimated Multipliers for DCR Projects								
1	Agriculture, Hunting, Forestry and Fishing	**2**	3.416	**1**	1.271	**2**	0.655	**1**	4.215
2	Mining and Quarrying	**32**	1.236	**29**	0.116	**30**	0.050	**13**	1.339
3	Food, Beverages and Tobacco	**14**	2.205	**24**	0.187	**22**	0.076	**9**	1.676
4	Textiles and Textile Products	**24**	1.807	**20**	0.219	**20**	0.114	**11**	1.475
5	Leather, Leather and Footwear	**33**	1.137	**35**	0.034	**34**	0.020	**31**	0.112
6	Wood and Products of Wood and Cork	**15**	2.069	**15**	0.384	**12**	0.238	**30**	0.132
7	Pulp, Paper, Paper , Printing and Publishing	**16**	2.067	**22**	0.194	**19**	0.126	**27**	0.369
8	Coke, Refined Petroleum and Nuclear Fuel	**18**	2.016	**32**	0.075	**35**	0.018	**7**	1.904
9	Chemicals and Chemical Products	**27**	1.729	**23**	0.189	**28**	0.053	**15**	1.070
10	Rubber and Plastics	**30**	1.436	**31**	0.081	**32**	0.036	**26**	0.384
11	Other Non-Metallic Mineral	**20**	1.921	**18**	0.248	**18**	0.126	**23**	0.529
12	Basic Metals and Fabricated Metal	**12**	2.384	**21**	0.204	**23**	0.076	**4**	2.533
13	Machinery, Nec	**29**	1.503	**27**	0.125	**27**	0.054	**20**	0.747

14	Electrical and Optical Equipment	**25**	1.806	**26**	0.156	**24**	0.067	**22**	0.653
15	Transport Equipment	**19**	1.957	**25**	0.185	**26**	0.059	**18**	0.898
16	Manufacturing, Nec; Recycling	**28**	1.697	**28**	0.119	**29**	0.052	**12**	1.469
17	Electricity, Gas and Water Supply	**23**	1.843	**19**	0.229	**21**	0.114	**19**	0.856
18	Construction	**4**	2.820	**10**	0.602	**8**	0.327	**2**	3.048
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	**35**	1.072	**34**	0.040	**33**	0.025	**29**	0.157
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	**5**	2.698	**3**	0.940	**5**	0.440	**10**	1.536
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	**3**	3.170	**2**	1.251	**1**	0.661	**5**	2.445
22	Hotels and Restaurants	**31**	1.422	**30**	0.107	**25**	0.066	**17**	0.969
23	Inland Transport	**10**	2.465	**14**	0.429	**14**	0.193	**3**	3.028
24	Water Transport	**36**	1.036	**36**	0.016	**36**	0.007	**33**	0.066
25	Air Transport	**17**	2.030	**16**	0.365	**16**	0.166	**32**	0.072
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	**9**	2.508	**9**	0.604	**10**	0.275	**28**	0.225
27	Post and Telecommunications	**7**	2.635	**6**	0.798	**7**	0.385	**24**	0.469

28	Financial Intermediation	**6**	2.661	**5**	0.851	**6**	0.403	**8**	1.792
29	Real Estate Activities	**22**	1.851	**13**	0.479	**17**	0.158	**6**	2.190
30	Renting of M&Eq and Other Business Activities	**13**	2.330	**8**	0.671	**11**	0.257	**14**	1.238
31	Public Admin and Defence; Compulsory Social Security	**8**	2.542	**4**	0.932	**3**	0.483	**36**	0.001
32	Education	**21**	1.893	**12**	0.501	**9**	0.291	**16**	1.001
33	Health and Social Work	**26**	1.761	**17**	0.358	**15**	0.186	**21**	0.673
34	Other Community, Social and Personal Services	**11**	2.439	**7**	0.795	**4**	0.451	**25**	0.425
35	Private Households with Employed Persons	**34**	1.132	**33**	0.069	**31**	0.039	**34**	0.034
36	Solar PV Deployment	**1**	5.541	**11**	0.537	**13**	0.206	**35**	0.005

APPENDIX: B2

Estimated Multipliers for Open Category Projects

	Sector	Rank	Gross Output	Rank	GDP Multiplier	Rank	Income Multiplier	Rank	Consumption Multiplier
1	Agriculture, Hunting, Forestry and Fishing	**10**	2.272	**9**	0.559	**18**	0.089	**1**	3.736
2	Mining and Quarrying	**33**	1.222	**31**	0.100	**30**	0.035	**13**	1.160
3	Food, Beverages and Tobacco	**8**	2.400	**19**	0.270	**14**	0.136	**10**	1.462
4	Textiles and Textile Products	**27**	1.609	**32**	0.096	**34**	0.016	**9**	1.602
5	Leather, Leather and Footwear	**34**	1.200	**34**	0.062	**27**	0.041	**30**	0.119
6	Wood and Products of Wood and Cork	**18**	2.091	**13**	0.346	**11**	0.198	**31**	0.113
7	Pulp, Paper, Paper , Printing and Publishing	**22**	1.904	**33**	0.087	**28**	0.039	**26**	0.346
8	Coke, Refined Petroleum and Nuclear Fuel	**17**	2.097	**29**	0.114	**24**	0.047	**7**	1.663
9	Chemicals and Chemical Products	**26**	1.691	**25**	0.159	**32**	0.028	**15**	1.006
10	Rubber and Plastics	**30**	1.528	**28**	0.121	**20**	0.064	**27**	0.344
11	Other Non-Metallic Mineral	**13**	2.141	**14**	0.335	**12**	0.185	**24**	0.416
12	Basic Metals and Fabricated Metal	**9**	2.376	**22**	0.185	**21**	0.058	**5**	2.090
13	Machinery, Nec	**31**	1.474	**30**	0.100	**31**	0.033	**20**	0.645
14	Electrical and Optical Equipment	**25**	1.797	**27**	0.140	**23**	0.052	**22**	0.580

15	Transport Equipment	**21**	1.971	**23**	0.181	**22**	0.054	**18**	0.764
16	Manufacturing, Nec; Recycling	**24**	1.817	**24**	0.170	**19**	0.088	**12**	1.288
17	Electricity, Gas and Water Supply	**5**	3.757	**4**	1.195	**3**	0.838	**19**	0.735
18	Construction	**12**	2.235	**20**	0.239	**29**	0.039	**3**	2.383
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	**32**	1.300	**26**	0.152	**16**	0.108	**29**	0.130
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	**2**	5.298	**1**	2.191	**1**	1.362	**11**	1.379
21	Retail Trade, Except of Motor Vehicles s	**20**	2.021	**11**	0.536	**17**	0.092	**4**	2.196
22	Hotels and Restaurants	**23**	1.848	**15**	0.310	**9**	0.215	**17**	0.910
23	Inland Transport	**16**	2.120	**21**	0.215	**33**	0.023	**2**	2.492
24	Water Transport	**36**	1.036	**36**	0.014	**36**	0.006	**34**	0.066
25	Air Transport	**6**	2.927	**6**	0.790	**5**	0.478	**33**	0.067
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	**4**	4.000	**3**	1.310	**4**	0.793	**28**	0.208
27	Post and Telecommunications	**3**	4.696	**2**	1.793	**2**	1.119	**23**	0.422
28	Financial Intermediation	**11**	2.270	**8**	0.578	**13**	0.180	**8**	1.609
29	Real Estate Activities	**19**	2.063	**10**	0.558	**10**	0.211	**6**	2.082

30	Renting of M&Eq and Other Business Activities	**7**	2.898	**5**	0.925	**6**	0.440	**14**	1.137
31	Public Admin and Defence; Compulsory Social Security	**14**	2.132	**7**	0.633	**8**	0.235	**36**	0.001
32	Education	**29**	1.572	**16**	0.284	**15**	0.115	**16**	0.951
33	Health and Social Work	**15**	2.126	**12**	0.516	**7**	0.297	**21**	0.639
34	Other Community, Social and Personal Services	**28**	1.601	**17**	0.280	**26**	0.042	**25**	0.392
35	Private Households with Employed Persons		1.066	**35**	0.028	**35**	0.006	**35**	0.031
36	Solar PV Deployment	**1**	5.789	18	0.274	**25**	0.042	**32**	0.091

Annexure C: 1

Solar Panel Industry: Firm Level Certifications

Certifications	Details
ISO 9001	Specifies requirements for quality management systems where an organization • needs to demonstrate its ability to consistently provide product that meets customer and applicable statutory and regulatory requirements • aims to enhance customer satisfaction through the effective application of the system, including processes for continual improvement of the system and the assurance of conformity to customer and applicable statutory and regulatory requirements
ISO 14001	Family of standards related to environmental management that exists to help organizations • minimize how their operations (processes, etc.) negatively affect the environment (i.e., cause adverse changes to air, water, or land); • comply with applicable laws, regulations, and other environmentally oriented requirements, • continually improve in the above
OHSAS 18001	An internationally-applied British Standard for occupational health and safety management systems. It exists to help all kinds of organizations put in place demonstrably sound occupational health and safety performance. It is a widely recognized and popular occupational health and safety management system

Annexure C2 : Solar Panel Manufacturing : Quality Standards

Manufacturing Standards	Details	Certifying Agencies
*IEC 61215	Crystalline silicon PV modules performance capability under prolonged exposure to standard climates	TUV Rheinland
IEC 61701	Quality and functionality of PV modules in high salt mist and humid conditions	TUV Rheinland
IEC 61730	Standard certification for Class A fire safety	TUV Rheinland
*UL 1703	American National standard of safety for flat plate PV modules and panels	Underwriter Laboratory USA
UL 4703	Construction and performance requirements of photovoltaic wire in photovoltaic electrical energy systems	Underwriter Laboratory USA
CE standards	European marking of conformity that indicates a product complies with the essential requirements of the applicable European laws or directives with respect to safety, health, and environment and consumer protection.	TUV Rheinland
JET PVm	Certification for reliability and the safety of Photovoltaic (PV) modules. Certificates are granted to each model of products after the successful completion of applicable tests based on the IEC/IEC harmonized JIS standards and the factory inspection of the quality management system at the manufacturing location	Japan Electrical Safety and Environment Safety laboratory

Appendix C3 MNRE Concept Note on Solar PV manufacturing scheme (2017)

i. Support to promote DCR:

MNRE had initiated various schemes to promote Domestic Content Requirement (DCR). The details are as given below:

Programme	Domestic Content Provision
1. Phase-I	
a) Solar Grid connected power projects (capacity 150 MW) – Batch-I	Crystalline silicon technology - to use modules manufactured in India Thin film and CPV technology – allowed to be imported
b) Solar Grid connected power projects (capacity 350 MW) – Batch-II	Crystalline silicon technology - to use cells and modules manufactured in India Thin film and CPV technology – allowed to be imported.
2. Phase-II	
a) Solar Grid connected power projects – Batch-I (375 MW with DCR content out of total allocated capacity of 750 MW)	Cells and Modules to be of indigenous origin of 375 MW. Cells and Modules in open category of 375 MW.
b) Batch-II, Tranche-I (Bundling scheme)	MNRE shall intimate the capacity to NTPC before announcement of State Specific Bid. Under DCR, the solar cells and modules used in the solar PV power plants must both be made in India.
c) Batch-III (2000 MW VGF scheme)	250 MW is kept for DCR category. Cells and Modules to be of indigenous origin.

d) Batch-IV(5000 MW VGF scheme)	Cells and Modules to be of indigenous origin. As per scheme, out of total capacity of 5000 MW, MNRE may allocate some capacity under DCR depending on availability and price. With the approval of Hon'ble Minister, 15 % is kept for DCR.
e) 1000 MW CPSU scheme	i) 1 Cr/MW for Cells & modules ii) 50 Lacs/MW for Modules
f) 300 MW Defence Scheme	Cells and Modules to be of indigenous origin.
g) Grid connected Rooftop	Only Module needs to be of indigenous origin under MNRE scheme

i. Present Status of DCR:

As on date around 1436 MW has been commissioned under DCR under various schemes of MNRE and around 1000 MW are under construction stage.

In view of WTO ruling, the provision of DCR has been stopped in future tenders which are not for Government/ PSU manufacture. Domestic manufacturers are solely dependent upon proposed CPSU scheme and Defence scheme, which has a target of only 300 MW.

ii. Impact of WTO decision on supporting DCR in solar manufacturing:

a) Due to recent ruling by WTO on DCR, 5 solar projects of capacities of 450 MW were cancelled under VGF scheme.
b) Around 400 MW solar projects under DCR under VGF scheme which were scheduled for tendering, could not take off.
c) Future DCR solar projects can be set up only by Govt. organisations and not by private developers.
d) Domestic solar manufacturers are discouraged in taking any initiatives for any expansion in existing capacity due to low market sentiments.

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