IIIEE Theses 2020:33

Profitability of Utility-Scale Solar Power in India

Analysis of six states, possible future scenarios and implications for the 2030 solar power target

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Thesis for the fulfilment of the
Master of Science in Environmental Sciences, Policy & Management (MESPOM)
jointly operated by Lund University – University of Manchester -
University of the Aegean – Central European University

Lund, Sweden, June 2020

Erasmus Mundus Masters Course in Environmental Sciences, Policy and Management

MESPOM

This thesis is submitted in fulfilment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean (Greece), Central European University (Hungary), Lund University (Sweden) and the University of Manchester (United Kingdom).

Published in 2020 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
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ISSN 1401-9191

Acknowledgements

First and foremost, I would like to thank my supervisor Prof. Aleh Cherp, for his continuous support, guidance and encouragement. Thank you for helping me conceptualise the topic and also setting a realistic scope, pushing me to do better when I lost motivation, giving me your valuable time in all those long skype calls (even on weekends), and for teaching me to write analytically yet succinctly.

Second, I express my deep and sincere gratitude to my parents for their incredible patience, wisdom and unconditional love and support, especially throughout the course of this thesis. Thank you for pushing me to be and do better each day. I must also thank my six-year old cousin for reminding me every day to appreciate the little things in life and have fun irrespective of circumstances.

Last but not the least, I thank my fellow MESPOMers for this remarkable two-year journey and the entire MESPOM family, including the faculty and staff at Central European University in Hungary, University of Aegean in Greece and Lund University in Sweden, for giving me the opportunity to learn and garner some of the most valuable and unforgettable experiences in life. I would also like to thank Erasmus+ for providing me the financial support needed to take on this opportunity in the first place.

The work for this thesis took me through a journey of excitement, doubt, frustration, hard work and ultimately accomplishment. I recognise the extraordinary circumstances that the global pandemic has put everyone in, and I acknowledge the good fortune I have had in completing this thesis on time. I have discovered strength in faith and that doing the work anyway despite fear is the only way to go and grow.

Abstract

The success of energy transitions in India depends on the feasibility of rapid expansion of solar power. How fast solar power can be expanded depends on its profitability, which has not been systematically analysed in prior literature. This paper answers three questions – (i) What is the profitability of utility scale solar power in six selected states in India (Karnataka, Tamil Nadu, Maharashtra, Chhattisgarh, Bihar and Jharkhand) and what explains its variations, if any? (ii) Under what conditions can solar power in these states be profitable without government subsidies? (iii) In light of existing profitability and the need for government subsidies, are India's 2030 solar targets feasible? This thesis conducts simple economic modelling based on discounted cashflow analysis and measures profitability using Internal Rate of Return, Discounted Payback Period and Profitability Index. The study finds that the profitability of utility scale solar power varies across Indian states due to variance in solar radiation, land availability, income levels, capital costs, the costs of competing conventional energy sources, and power sector governance. It also finds that profitability of solar power is most sensitive to the wholesale electricity price. Second, the study finds that if the capital cost declines by 2% c.a. per year (as is currently forecasted based on the cost dynamics of solar PV panels) and the wholesale price of electricity stays at 0.03 €/kwh, investments in solar projects in Maharashtra will breakeven without government subsidy by 2029, Tamil Nadu by 2032, and Karnataka by 2033. However, by then investments in Chhattisgarh and Bihar would still need more than 30% of capital cost subsidy to be profitable. Finally, this thesis argues that the feasibility of India's utility scale solar targets will depend on political capacity and motivation in addition to the profitability of solar PV installations. A more general contribution of the thesis is in expanding the focus from a widely used Levelised Cost of Electricity (LCOE) to profitability as a measure of economic viability of energy technologies.

Keywords: Utility-scale solar, Solar power in India, IRR, Discounted Payback Period, Profitability Index, LCOE

Executive Summary

India must transition its power sector from carbon-intensive to low-carbon energy sources while extending electricity to 100 million people who currently lack access to modern energy, providing for a growing population and increasing incomes. In its effort to navigate to a low-carbon future, the Indian government has set ambitious targets of installing 100 GW grid-connected solar power by 2022 (IBEF 2015), 200 GW by 2027 (Ministry of Power 2018) and 300 GW by 2030 (Ministry of Power 2019, p 15). The techno-economic feasibility of such a massive and rapid uptake of a new energy technology would require that it is economically viable or profitable. Most current arguments concentrate on achieving grid parity of solar power through lowering the Levelised Cost of Electricity (LCOE). This assumes that once the cost of generating solar power is lower than other energy sources, it will prevail. This argument has recently been forwarded specifically with respect to solar energy becoming increasingly cheap globally and particularly in India and China due to decreasing technology cost (IRENA 2019, Carbon Tracker 2016). This thesis expands the concept of economic viability of new energy technologies by arguing that for a new technology to expand it has to be profitable for investors.

This thesis aims to contribute to assessing the feasibility of reaching India's solar power targets by answering the following questions.

- *What is the profitability of utility scale solar power projects in selected Indian states and what explains its variations, if any?*
- *Under what conditions can utility scale solar power in these states be profitable without government support?*
- *In light of the existing profitability of solar PV and government spending required, are India's 2030 solar targets feasible?*

This thesis defines profitability using Internal Rate of Return, Discounted Payback Period and Profitability Index. These parameters are calculated through discounted cashflow analysis using data from 57 all-India utility-scale solar PV auctions for six Indian states – Karnataka, Tamil Nadu, Maharashtra, Chhattisgarh, Bihar and Jharkhand. The thesis estimates the effect of tax benefits, subsidies, electricity prices, solar module prices, and Weighted Average Cost of Capital (WACC) on profitability.

Key findings

Profitability of solar power in India and its variations.

Profitability of utility scale solar power projects varies across Indian states (PI ranging between -0.86 in Bihar to 1.43 in Chhattisgarh). This variability reflects differences in solar radiation, land availability, capital costs, competitiveness with conventional sources of electricity and power sector governance. Profitability is most sensitive to change in the wholesale electricity prices. Government capital subsidies are more essential for ensuring profitability than tax benefits. Within realistic ranges, the effect of change in cost of capital on profitability was not very strong. Finally, once IPPs have entered into a Power Purchase Agreement (PPA), profitability is sensitive to risks arising from change in capital costs and operation and maintenance costs, financial parameters and solvency of the DISCOMs.

Can solar power be profitable without subsidies?

If module cost declines by 34% until 2030 (as forecasted by BNEF 2019) and the electricity tariff stays at 0.03 €/kWh under the same financial parameters, solar projects in Maharashtra will not require government subsidy beyond 2028, Tamil Nadu by 2032 and Karnataka by 2033 for investments to breakeven. Investments in Chhattisgarh and Bihar would still need more than 30% of subsidy to breakeven in 2033.

Are India's solar targets for 2030 feasible?

Feasibility of achieving the 2030 solar targets is constrained by capacities of and costs for three key actors. For solar project developers, the main constraints are risks related to techno-economic, financial and policy changes especially after PPA has been signed. For DISCOMs, it relates to their continued ineptitude and threats to financial solvency, thereby requiring not only heavy bailouts from the government but also negatively impacting the health of financial institutions in the country and raising the risk of investments. Finally, for the federal government, the study finds that the size of required spending will depend on which state/s undergo the bulk of solar installations. The range of total subsidies required based on different state parameters is significant - ranging from €4.5 billion under the conditions of Maharashtra to €32.6 billion under the conditions of Bihar.

Recommendations to Policymakers

Should political motivation continue to be the most significant driver for solar expansion in India, policies should follow the following recommendations: First, there should be more clarity on solar targets by prescribing a clear and stable roadmap stating year-wise solar targets beyond 2022 and making state-wise allocations, which are congruous with existing characteristics and capacities of the respective states. Second, the power sector must be reformed in a way to enhance the efficiency of transmission and distribution companies especially with regards to increase efficiency of collection of bills and PPA negotiations. Third, electrifying the remaining households by increasing affordability will increase demand. Fourth, removing risks by improving certainty relating to tax and fluctuating interest rates will attract more investments. Finally, existing policies must be disentangled to provide better clarity to developers in terms of benefits available.

Academic contribution and scope for future research

The main contributions of the study has been to (i) show that merely looking at generation costs or LCOE may not be sufficient to analyse economic viability of solar power; (ii) the empirical demonstration that profitability of solar power varies greatly across Indian states and is not universally conductive to investments; and (iii) identification of the role of different factors and their evolution, in particular wholesale electricity prices, capital costs and government subsidies on this profitability of solar power in the future in India.

More should be done to understand the profitability of solar PV now and in the future and more broadly the feasibility of India's solar targets. First, it is recommended for future analyses to include solar rooftop, off-grid solar power, other policy instruments like renewable purchase obligations and renewable energy certificates, and more if not all Indian states. Second, compiling a clear practitioner's perspective of what is deemed profitable would improve all analysis on profitability. Third, it would be crucial to examine the operation of the state transmissions and distribution companies (DISCOMs) as well as political processes in the federal government that affect its commitment to solar power. Finally, socio-technical aspects of feasibility of rapid and massive solar power deployment such as land availability and land-related conflicts, broader social acceptability and the presence of the necessary technical innovation potential must be identified and examined.

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Abbreviations

AAPC	Average Power Purchase Cost
AC	Alternating Current
AD	Accelerated Depreciation
BI	Bihar
BNEF	Bloomberg New Energy Finance
BP	Beyond Petroleum
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CH	Chhattisgarh
CoC	Cost of Capital
CoD	Cost of Debt
CoE	Cost of Equity
CREDA	Chhattisgarh Renewable Energy Development Agency
CS	Capital subsidy
CSO	Central Statistical Organization
DC	Direct Current
DISCOM	Distribution Companies
DPBP	Discounted Payback Period
ESOPB	Economical and Statistical Organization of Punjab
GEA	Global Energy Assessment
GOI	Government of India
GW	Gigawatt
IBEF	India Brand Equity Foundation
IEA	International Energy Agency
IEEFA	Institute for Energy Economics and Financial Analysis
IISD	International Institute for Sustainable Development
IPCC	Intergovernmental Panel for Climate Change
IREDA	Indian Renewable Energy Development
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
ISA	International Solar Alliance
JH	Jharkhand
JNNSM	Jawaharlal Nehru National Solar Mission
KERC	Karnataka Electricity Regulatory Commission
KN	Karnataka
kWh	Kilowatt hour
LCOE	Levilised Cost of Electricity
MCLR	Marginal Cost of Fund based Lending Rate
MH	Maharashtra
MNRE	Ministry of New and Renewable Energy (India)
MNRE	Ministry of New and Renewable Energy (India)
MoP	Ministry of Power
NDC	National Determined Contribution
NPV	Net present Value
NREL.	National Renewable Energy Laboratory
NTPC	National Thermal Power Corporation
NVVN	NTPC *Vidyut Vyapar* Limited
OECD	Organisation for Economic Cooperation and Development
PI	Profitability Index
PPA	Power Purchase Agreement
PV	Photovoltaics
R&D	Research and Development
REC	Renewable Energy Certificate
ROI	Return on Investment
RPO	Renewable Purchase Obligation
RQ	Research Question
SBI	State Bank of India
SECI	Solar Energy Corporation of India Limited
SERC	State Electricity Regulatory Commission
TEDA	Tamil Nadu Renewable Energy Development Agency
TN	Tamil Nadu
VGF	Value Gap Funding
WACC	Weighted Average Cost of Capital
WEC	World Energy Council

1 Introduction

With a population of 1.4 billion, India is the third largest producer and consumer of electricity behind China and the United States. Today over 70% of its power generation comes from fossil fuel sources and around 20% from renewables, where solar accounts for merely 1.7% (IEA 2020). BP estimates that owning to strong population growth and economic development, India's share in global primary energy demand will increase to 11% by 2040. 42% of this new energy demand is projected to still be fueled by coal leading to a doubling of India's CO_2 emissions by 2040 (BP Energy Outlook 2019, p 64-75). Therefore, the first challenge that stands before India's power sector is to decrease its impact on the climate. The second challenge is with regards to the strong population growth and the lack of access to electricity. Currently, the industrial sector remains the largest consumer of electricity followed by the service sector (including agriculture), residential and finally transport. Over the last decade India had an annual electricity consumption growth rate of 6% (IEA 2020). In 2018, the Government of India (GOI) announced that India has reached 100% electrification (The Times of India 2018). However, the reality looks different. The International Energy Agency (IEA) notes that despite India's good progress in electrification, nearly 100 million people still today do not have access to electricity (IEA 2020).

The current literatures on global energy transition (WEC 2019, GEA 2016, Riahi et al. 2012, etc.) as well as the 1.5° IPCC Report (2018) are of the opinion that renewables are likely to play a crucial role in low-carbon energy transition. In fact, it has the potential to supply two-thirds of the global energy demand, which will contribute to reductions in greenhouse gas emissions needed between now and 2050 to limit average surface temperature below 2° Celsius (Gielen et al. 2019). In order to reduce greenhouse gas emissions, meet its climate pledges and enhance access to modern energy, India plans to increase the share of renewables in its energy mix through both grid-connected and off-grid power systems. In 2015 Union Budget, India set a target to install 100 GW of solar PV capacity by 2022 (IBEF 2015), 200 GW by 2027 (Ministry of Power 2018) and 300 GW by 2030 (Ministry of Power 2019, p 15). 60% of its short-term 2022 goal is to be met from utility scale solar power projects and 40% through solar rooftop (IBEF 2015).

As of 31 January 2020, India's grid connected solar installed capacity is at a little over 34 GW. Around 32 GW accounts for ground mounted utility scale projects and 2 GW from rooftop solar power. From 2013, solar capacity grew 10-fold within 6 years. However, the growth rate over the last 2 years have been slow (inferred from IEA 2020, p 154). Currently majority of the Indian states are far from realising their 2022 goals and Wood Mackenzie warns that these targets are under risk (Lal 2019). The Ministry of New and Renewable Energy (MNRE) has insisted that its 2022 solar target is still "well within reach" (Economic Times 2019). There has been even less systematic analysis of the feasibility of achieving longer term - 2027 and 2030 targets. So, the question is why does solar energy in India expand as fast as it does? And is it feasible to expand it sufficiently fast to meet India's national climate targets?

1.1 Problem definition

Economic viability is a key determinant for techno-economic feasibility of a broad and rapid uptake of new energy technologies. Most current arguments relating to economic viability concentrate on achieving grid parity (or the point at which the cost of generating electricity is the same as the price of electricity at the grid) and having a low Levelised Cost of Electricity (LCOE). It essentially means that if the cost of generating solar power is lower than for other energy sources, the former will prevail. This argument has recently been made across sectors of business (Zhai and Lee 2019, Wood Mackenzie 2019), government (IRENA 2019) and non-government organisations (Gabbatiss 2019, IEEFA 2019a). They have been forwarded specifically with respect to solar energy becoming increasingly cheap globally and particularly in countries like India and China due to decreasing technology cost (IRENA 2019, Carbon Tracker 2016). Consequently, the Government of India (GOI 2019) has claimed that it is profitable to not only invest more in solar energy but also increase the pace of these investments. However, in order to determine whether investments will flow to solar, or renewables in general, one needs to analyse not (only) the cost of power generation but also the rate of return to private investments over time.

According to literature, the rate of return depends on a multitude of factors which are political, social, economic and technological in nature. Therefore, identifying the key factors of influence and their sensitivity to the rate of return is essential to not only analyse the current level of profitability but also determine what they mean in terms of achieving India's climate goals. For example, solar power has reached grid parity in India with solar auctions in early 2019 recording tariff as low as 0.03 €/kWh, while thermal power was sold at around 0.04 €/kWh (The Economic Times 2019). On one hand, this is extremely promising and has ushered in a turning point in the sector. However, in 2019 the country witnessed a slow-down in solar capacity addition. Non-participation, undersubscribed tender capacity, extension of deadlines to submits bids, cancellation of tenders after bidding were some of the experiences faced by the solar power industry. Developers claimed that the price ceilings set by the government were too low and not promising for investments (Chandrasekharan 2018a). There were further instances where DISCOMs failed to pay developers and wanted to re-negotiate the electricity tariff (Sudarshan 2019). Additionally, the solar sector in India is heavily subsidised with both direct capital subsidies and tax breaks. This means solar power is unable to stand without significant government support against conventional power sources. Therefore, question is - Has solar in India truly achieved grid parity in the first place (Hall 2019)? And how long will GOI need to subsidise solar to keep it profitable?

1.2 Aim and research questions

To this end, my thesis aims to contribute to assessing the feasibility of reaching India's solar power targets by answering the following questions.

RQ1: What is the profitability of utility scale solar power projects in selected Indian states and what explains its variations, if any?

RQ2: Under what conditions can utility scale solar power in these states be profitable without government support?

RQ3: In light of the existing profitability of solar PV and government spending required, are India's 2030 solar targets feasible?

1.3 Scope and delimitations

In this thesis, profitability is calculated using a discounted cashflow analysis and is defined by using basic concepts from finance and economics like Internal Rate of Return, Discounted Payback Period and Profitability Index (Rodrigues et al 2016). Six Indian states were selected for the study – Karnataka, Tamil Nadu, Maharashtra, Chhattisgarh, Bihar and Jharkhand - following systematic criteria that are explained in *Section 3.1.2.1*. Nevertheless, there no strong evidence that the results of this thesis can be directly extrapolated to other Indian states. The study only looks at grid-connected utility-scale solar photovoltaic installations. Although the methodology used can be applied to rooftop and off-grid installations, the results of the analysis may be different.

Another limitation is that the findings of the thesis cannot be projected into the future with 100% confidence, simply because the different factors are ever-changing. However, the results of the thesis can be used as baseline data to monitor the development of solar power profitability in India over time.

With regards to the type of data used, the study is based on the latest generic data published by the State Electricity Regulatory Commissions (SERCs) due to both unavailability of project-level information and the lack of time. What this means is that project level outcomes may be different. The actual return on equity may be more or even less than that of the SERC's required rate of equity (Shrimali et al 2013). However, for the purposes of this thesis ballpark aggregated values should suffice for deriving meaningful conclusions.

1.4 Implications of Covid-19

Originally this thesis was planned to include interviews with solar PV developers, authorities and other stakeholders in India, (besides other things) specially to take stock of how much return is considered profitable. Due to disruptions imposed by COVID-19 pandemic, such interviews were not possible. Instead, a broader and deeper analysis of documents and data has been undertaken.

1.5 Ethical considerations

This thesis is an output of individual work with routine support and collaboration with the supervisor and was not exposed to any form of external influence. The research design for the thesis has been reviewed against the criteria for research requiring an ethics board review at Lund University and has been found to not require a statement from the ethics committee.

1.6 Audience

The method and findings of the research can be useful to two groups of audience. It can be relevant for academic researchers studying profitability of solar power and other renewables in India and also globally. Secondly, it can be applicable to policymakers in terms of determining the effectiveness of existing policies and identifying areas of potential policy developments for the purpose of increasing economic viability of solar and more generally renewable projects.

1.7 Disposition

The rest of the thesis is organised as follows. *Chapter 2* takes stock of the literature landscape relevant to the three research questions. *Chapter 3* describes the theories and methods used to answer each research question. *Chapter 4* systematically presents all findings. *Chapter 5* explains what the findings mean in the broader Indian context while systematically addressing the aim of the paper. Finally, *Chapter 6* offers final conclusions along with applicability of findings for policymakers and future research.

2 Literature review

This chapter takes stock of the literature relevant to the three research questions. The chapter is divided into four sections. The first section reviews the literature on profitability of solar power and how it is measured. The factors that affect solar profitability and the existing research on the profitability of utility-scale solar power projects globally are also reviewed. The second section summarises India's solar strategy, what policies exist to meet this strategy and what institutions are in place to implement them. In the third section, the drivers of and barriers to solar power profitability in India are explored. The final section summarises the available literature landscape and identifies the knowledge gap that the thesis seeks to address.

2.1 Profitability of solar power and what influences it

The last decade witnessed a widespread deployment of solar PV globally. Most of the expansion has been visible in high-latitude countries receiving lower levels of sunshine thereby making it abundantly clear that the uptake of solar technology requires way more than sunshine (Ondraczek et al 2015). This solar uptake has been attributed to increasing government support, falling technology costs and improved performance and social acceptance. In 2018, the cost of generating solar power from utility scale solar PV declined by 77% from 2010 levels, with a year-on-year decrease of 13% (IRENA 2019). This also led to the largest yearly installed capacity addition of 94 GW.

2.1.1 Metrics of profitability

Most studies on the economics of solar power calculate the Levelised Cost of Electricity (LCOE): the lifetime average cost of producing electricity. LCOE is often used for determining grid parity, i.e., the point at which the cost of generating electricity is the same as the price of the electricity in the grid (Yan et al 2019, Yang 2010). If the LCOE is lower than grid price, then the given technology is commonly considered economically competitive (Nissen and Harfst 2019). Achieving grid parity was thus interpreted as solar power becoming competitive with other energy sources.

Another angle on the economic performance of solar power is to look at its profitability. Profitability is "the ability of an investment to earn a return from its use" (Howard and Upton 1961). If solar power is profitable it means it will attract investment, which is crucial for solar power uptake. In finance, the most common indicator to measure profitability is the Internal Rate of Return (IRR). IRR is calculated for the discount rate, which yields a net present value (NPV) equal zero for a stream of positive and negative cashflows during the lifetime of a project (Mellincamp 2019). IRR provides a different metric of competitiveness of solar power than LCOE which takes into account not only the costs of production but also potential revenue flows over the lifetime. Return on Investment (or ROI) is a similar metric used to analyse the short-term performance of an investment. It is generally used to calculate the first-year return to the initial investment made (PVsell, Accessed on February 10, 2020).

Focusing on LCOE, IRENA argues that lower module prices and decreasing balance of system costs have been the main drives for reduction in cost of electricity from solar. However, in 2010, Talavera et al. conducted a discounted cost-based analysis for PV-grid connected systems, to analyse the return of investments in three different developed and highly liberalised electricity markets in the world- USA, EU and Japan. The study found that in addition to cost of technology, return on investment is most sensitive to existing interest rates, initial investment subsidy, annual electricity production (dependent on the capacity factor of the plant), electricity price and initial investment in increasing order of magnitude. Cash outflows in all three of these cases include capital costs, financing costs, costs for operation and maintenance, and an assumed utilization rate of a given plant. Cash inflows, on the other hand, include revenue earned from the sale of electricity.

2.1.2 Factors affecting profitability

Being a very capital-intensive technology, cost of capital (CoC)[1] is one of the key variables determining the cost of solar power (Bogdanov et al 2019). It is also a "major factor of uncertainty" when making future global cost analysis (Egli et al 2019). Inter-governmental organisations like the IEA and IRENA have been criticised for making uniform cost of capital assumptions in their analysis. IEA use a uniform CoC of 7% (Egli et al 2019) and IRENA uses 7.5% for OECD countries and 10% for the rest of the world (IRENA 2018). Literature suggests that while uniform estimates can be made for the discount factor (or the time value of money), uniform CoC assumptions lead to biased LCOE estimates (Egli et al 2019). This is because financing conditions for long term investments vary across countries due to differences in macroeconomic stability, political uncertainty and maturity of financial markets (Steffen and Schmidt 2019). One visible example for this is the large difference of CoC required to finance solar PV projects in eastern and western European countries.

Ondraczek et al (2015) conducted a study for analysing the effect of financing cost on the LCOE of solar PV and found that expansion of PV installation in developing countries require policies that allow wider availability of low-cost finance while "de-risking" low-carbon investments. Another study evaluating renewable deployment policies for the last two decades found that the most effective policies around specific design elements like feed-in-tariffs, auctions and renewable portfolio standards are those that address both investment risk and investment return simultaneously (Plozin et al 2019). Additionally, Egli et al (2018) analysed 133 utility scale solar PV and onshore wind power projects in Germany and found that changes in financing conditions like a rising interest rate may lead to a higher cost of solar power generation. The study further found that technological learning leading to a reduction in unit and operational expenditures are often overestimated as factors for cost reduction. Cumulatively general interest rates and experience effects accounted for only 5% of cost reductions visible in the last 18 years for solar PV in Germany. Mir-Artiguez et al (2018) conducted a study to analyse the effectiveness of lifting of government support on the renewable electricity and found that IRR in renewable projects depends most on the cost of capital, level of initial borrowing and changes in government support.

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[1] Cost of capital is the cost of a company's funds or cost of debt plus cost of equity. In simple words, it is the amount of money a developer needs to have both from loans and investments to finance a given project.

Another group of researchers focused on the nature of policies that surround renewables influence their profitability. Jenner et al (2013) in an effort to find the strength and effectiveness of policy efforts for renewable energy expansion calculated the Return on Investments (ROI), a metric similar to IRR. They found that in European and American electricity markets, economic viability is affected by a combination of factors including amount of investment or subsidies allocated by pro-renewable policies, timeframe of these investments, expected lifetime of technologies, average cost of producing electricity and the price of electricity injected into the grid. They conclude that the interaction of policy designs dealing with renewables, electricity price and LCOE or the cost of electricity generation is more important that enacting a policy for renewables itself.

2.2 India's solar strategy

As of 2017, India had a total electricity generation of 1532 TWh, where solar accounted for 1.7% and renewables accounted for 21%. According to its NDC targets, India aims to increase the share of non-fossil fuel in primary electricity production to around 40% by 2030. Therefore, in order to achieve its climate pledges, reduce GHG emissions, and also enhance energy access, India plans to increase the share of renewables in its energy mix through both grid-connected and off-grid power systems. India has set a target to achieve 175 GW of grid-connected renewable power capacity by 2022. 100 GW of this goal is to be met by solar power, 60% through utility scale solar power projects and 40% through rooftop solar power (MNRE 2020a). Last Retrieved on 31 May 2020). Out of 60 GW utility scale solar target and 40 GW solar rooftop target, the country has achieved 32GW and 2 GW respectively to-date. (Table 2-1).

Table 2-1 Historical and nationally planned installations of utility scale solar PV in India

	2014-2015	**2015-2016**	**2016-2017**	**2017-2018**	**2018-2019**	**2019-2020**	**2020-2021**	**2021-2022**
Cumulative solar capacity addition (in GW)	3	4.8	12	22	32	42	51.5	60

Source: Rathore et al 2018, p 8

2.2.1 Existing policies

Owing to its geographical location, India has good solar potential with most of the country receiving an average 8 hours of sunlight daily and an average of 300 sunny days annually. The daily average solar insolation lies between 4-7 kwh/m^2/day (Mahtta et al 2014, JNNSM 2014). 58% of the total land area can be accounted as hotspots or regions characterised as "exceptional solar power potential for decentralised commercial exploitation" (Ramachandra et al 2011). However, this potential is dispersed unevenly across the country. Deshmukh et al conducted a geospatial and techno-economic analysis and found that the country has a cumulative solar potential of 1300-5200 GW for utility-scale solar PV and 160- 620 GW for concentrated solar power (with 6 hours storage). But most of this potential fall within the southern and western states of the country (Deshmukh et al 2019). See *Figure 1*.

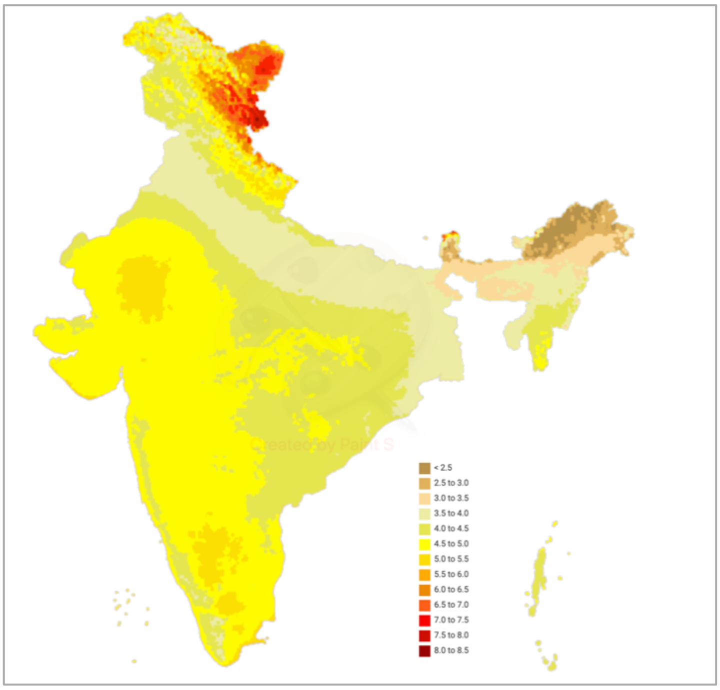

Figure 1 Direct Solar Irradiance in India (in kWh/sq.m/day)

Source: NREL. Retrieved on 20th May 2020.

To meet its 2022 goal, GOI has allocated targets for all states and union territories. In order to conform to the national target, most state governments and union territories have adopted their own solar policies to reach the allocated targets in the same ratio as the central government (60% utility scale installations and 40% solar rooftop). For example, the state of Tamil Nadu has been allocated a target of 8884 MW. The state's solar policy aims to achieve 9 GW installed capacity by 2023, 5.4 GW will come from utility scale projects and 3.6GW from solar rooftop. (TEDA 2019).

Over the last decade GOI has taken several initiatives to incentivise the development of a large-scale solar power sector in India. The first and most notable among them was launching the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010 under the National Action Plan on Climate Change. The primary goal was to establish India as a global leader in solar energy, promote ecologically sustainable growth by setting up favourable environment for solar technology penetration in the country, achieve grid parity by 2022, while addressing India's energy security challenges (MNRE 2020). Initially it targeted to set up 20 GW of grid-connected and 2 GW off-grid solar power 2022 but in 2014 this was revised for a new target of 100 GW. JNNSM unfolds in a three-phased approach today in India, each phase evaluating progress and experience from the previous and incorporating findings to the next. The first phase (extended until 2013) focused on (i) capturing low hanging fruits in solar thermal, (ii) promoting off-grid systems for consumers without access to commercial electricity and (iii) made modest capacity addition for grid interactive systems. The key focus of Phase 2 (2013-2017) was aggressive capacity addition to attain economies of scale and competitive solar developments. Finally, the focus of Phase 3 (2017-2022) is to cumulatively achieve 100 GW of grid connected and 2 GW of off grid solar power (MNRE 2020).

However, solar analysts from consultancies like Wood Mackenzie claim that even though long-term developments of solar power in India look promising, India will miss its 2022 targets because of “imposition of various taxes and levies on various solar products, the cancellation of tenders and tariff re-negotiations” (Economic Times 2019). Even scholars have previously argued that India’s 2020 target even when accomplished may jeopardise its energy security given the current lack of domestic solar technology innovation and production of low-cost solar modules, cells and other supporting equipment (Hairat and Ghosh 2017).

Under JNNSM, several schemes and policy instruments have been adopted to extend financial support to producers of solar power and also consumers in case of captive production. Viability Gap Funding (VGF) allows developers to supply power at a pre-determined rate and bid for a capital subsidy. VGF is limited to 30% of capital cost or 2.5 crore INR/MW (300,480 €/MW), whichever is lower. (IISD 2018). As the renewable sector continues to grow in India, government support is shifting from feed-in tariffs towards competitive bidding (Bose and Sarkar 2019). The profitability of solar power generation in India is affected by a large number of fragmented policies. Developers have several options to choose from. For example, on the demand side, developers can sell electricity to distribution companies (DISCOMs) at a feed-in tariff or at the rate determined in the competitive reverse bidding process. They can also sell electricity to large open access consumers at a negotiated rate. Developers may even trade Renewable Energy Certificates (RECs) in Central Electricity Regulation Commission (CERC) approved platforms and claim benefits while selling electricity to DISCOMs at a price lower than the average purchase cost. On the supply side, until 2017, solar developers enjoyed tax breaks on excise and custom duty. However, this has been replaced by a lower GST and custom duty to prevent a cascading tax effect. Other indirect tax break benefits involve those in the form of accelerated depreciation[2] (AD) where developers, not availing VGF can claim tax benefits by depreciating their fixed assets at a higher rate at the initial years of the project. The scheme was introduced for solar projects in 2014 at an 80% depreciation rate later revised to 40% from April 2017. (IISD 2018)

2.2.2 Institutional framework and market structure

(*This section has been summarized after consulting Murthy 2014, Rathore et al 2018, IEA 2020, MNRE p 7-9)*

India has synchronised its five regional grids into one national grid at one frequency. Based on the 2003 Electricity Act power generation, transmission and distribution has been separated. It has also unbundled power generation by allowing independent power producers into the market. Today most renewable generation is privately owned. However, unbundling of electricity transmission and distribution remains incomplete. Both retail and wholesale markets in the country remain fragmented. Around 90% of power trading still today are reached through bilateral long-term contracts. This prevents efficient price discovery in the market and leads to stressed assets and renewable energy curtailment (IEA 2020). As a result, it falls on the

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[2] Essentially a tax break that developers enjoy during the initial years of operation. However, the total amount of tax paid by the developer at the end of the project remains the same.

government and electricity regulatory commissions to take necessary steps to promote renewables in the country.

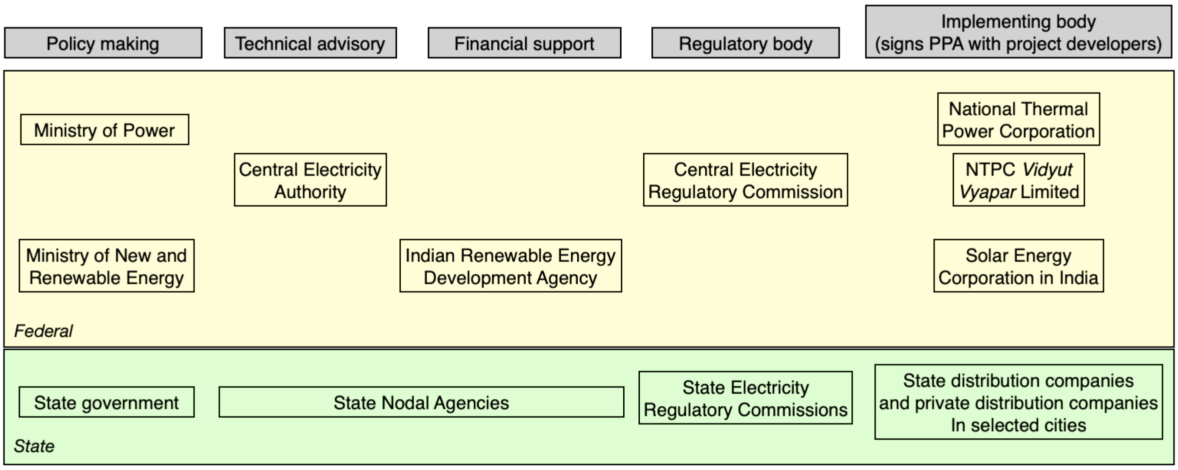

Figure 2 Institutions governing for solar power generation in India

Source: Murthy 2014, IEA 2020, MNRE p 7-9, Rathore et al 2018

The Ministry of Power (MoP) is the highest central governing body that is in charge of formulating and administering policies for the electric power sector in India. MoP is responsible for the formulation and administration of the Electricity Act of 2003 (hereon referred to as "The Act"), which acts as the legal framework that guides all activities within India's National Solar Mission. National Thermal Power Corporation Limited (NTPC) is a state-owned enterprise under the MoP and is the largest power producer and distribution company in India. NTPC *Vidyut Vyapar* Limited (NVVN) supported by NTPC financially, managerially and technically facilitates power trading in the country. NVMM signs Power Purchase Agreements (PPA) with project developers. Central Electricity Authority (CEA) is the technical subsidiary of MoP that advises the government and commissions on technical matters of electricity generation transmission, distribution, trading and utilisation. State governments and companies are also directed by CEA on technical issues of grid connectivity and maintenance.

Ministry of New and Renewable Energy (MNRE) is a scientific ministerial body that is in charge of solar energy development, application and realisation of India's national solar mission. Indian Renewable Energy Development Agency Limited (IREDA) is a state-owned company administered by MNRE responsible for providing financial support for the development of renewable power. Solar Energy Corporation of India (SECI) is another public sector undertaking by MNRE, established in 2011, is responsible for the developmental, commercial implementation of the National Solar Mission (SECI webpage). MNRE works in close proximity with Central Electricity Regulatory Commission (CERC), MoP, its technical subsidiary Central Electricity Authority, and NTPC to manage the offtake of solar power and minimise the government's financial burden.

The CERC issues guidelines for setting central tariffs, licenses for power transmission for solar power purchase. It is an independent regulatory authority and acts as an advisory body to the government during the formulation of national electricity and tariff policy. Tariffs set by CERC are revised annually based on current technology costs and market trends. The State Electricity Regulatory Commission (SERC) acts as the regulatory body at the state level and sets guidelines and regulations with regards to tariff for power purchases, grid connectivity, etc. The National Tariff Policy, enacted in 2006, mandates that State Electricity Regulatory Commissions (SERCs) will issue RECs and along with the CERC will set up Renewable Purchase Obligations (RPOs) depending on solar potential and other regional determinants. The National Tariff Policy was amended in 2011 and mandated that solar-specific RPOs are to be increased from a minimum of 0.25% in 2012 to 3% by 2022. MNRE acts as monitors the fulfillment and implementation of REC framework and compliance of RPOs (Rathore et al 2018). State Nodal Agencies such as Tamil Nadu Energy Development Agency (TEDA) or Chhattisgarh State Renewable Energy Development Agency (CREDA) provide financial and technical assistance to solar and other renewable energy projects at the state level.

2.3 Drivers and barriers to solar power profitability in India

India has experienced an exponential growth in solar energy over the last decade (IEA 2020). India today records the lowest installation cost of solar in the world, making it attractive to investors (Wood Mackenzie 2019). Or has it? Before answering that question, it is important to understand what has driven solar energy growth in India so far.

2.3.1 Drivers

2.3.1.1 Availability of resources

By now this has been already established that India has a very high solar potential both in terms of solar insolation and land resources. According to NREL, it receives a global horizontal irradiance of 5.0–5.5 kwh/m2 per day, recording sunshine for an average of 300 days annually. This puts India among the top 5 countries in the world, having a potential to produce over 6 million TWh/year (Rathore et al 2018). Secondly, being capital intensive, solar power deployment especially for the utility sector requires large availability of land. According to the CERC, setting up of 1 MW power plant based on crystalline silicon technology requires a land area or approximately 5 acres and 9 acres for Thin-Film technology (CERC 2019). According the National Remote Sensing Centre, India has around 115 million acres of available wasteland (Department of Land Resource 2011) thereby making the availability of land resource significantly abundant.

2.3.1.2 Techno-economic motivations

By 2018, the decline in country-specific generation cost of utility scale solar PV globally ranged from 62-80% from 2010-2018. India alone witnessed a year-on year decline of 21% with an LCOE accounting for USD 0.067/kwh (0.06 €/kWh) (IRENA 2019). Therefore, unit cost reductions have been significant globally. However, that may not have been the primary factor motivating solar investments in India. Thapar et al (2018) conducted a regression analysis of 11 variables (including among others, policy, economic, commercial and energy) across 32 solar auctions between 2014-2017, in order to identify the key determinants that influenced an investor's decision. They found that cost of solar modules and cost of funds were marginally important factors. On the other hand, solar targets set by the central and state governments, utilities' financial credentials and level of bid subscriptions showed significant relation. A significant part of available literature also ascribes the growing competitiveness of solar power, and hence its expansion, to the adoption of e-reverse[3] auctions in place of feed-in-tariffs to grant solar contracts (Shah 2018, Thapar 2018 etc). This was initiated by GOI in order to reduce its financial burden. E-reverse auctions allows solar developers to submit their bids electronically for building a certain capacity of solar power to be sold to the utilities at a certain price for the lifetime of the project. At the end of the auction only the lowest bid gets disclosed and the bidders are allowed to revise their bids. Recently, due to this competitive bidding the cost of solar power generation has been brought down below the Average Power Purchase Cost (APPC). But this has raised doubts over the economic viability of solar projects. Such low tariff may not be attractive in India because developers have to pay a high cost of debt and risk premium (Shah 2018).

2.3.1.3 Political motivations

Shidor and Busby (2019a) conducted a very comprehensive study to conclude that even though techno-economic factors may have helped increase competitiveness of solar power in India recently, political motivation of the current government has been the key driver for India's exponential solar growth. This merely were reiteration from one conclusion derived from Thapar et al 2019 and several others. For the study 23 elite practitioners across sectors were interviewed and 9 plausible drivers that usually shape government's decision for energy transition were tested. The results shed light on how the Modi government has formulated its domestic and foreign policy from the very start. Shidor and Busby found that (i) India's initial national solar 2020 target was revised from 20 GW in 2010 to 100 GW in 2014 as soon as the current government came to power. In fact, solar acted as one of the imageries out of Modi's election campaign which surrounded on modernizing and digitalizing India. In other words, there was a motivation to assert political distinction and power domestically by the ruling elite and solar was a way to do so; (ii) Second, the Modi government has reformed India's foreign policy significantly in order to develop its global image and engender partnerships. This was visible in 2014 when Indo-US released a joint statement, followed by India making commitments to phase out the usage of Hydrofluorocarbons (HFC), ultimately followed by India's announcing of Paris pledges in 2015 and forming the International Solar Alliance (ISA) with France the same year. The authors further reported that India had both a defensive and an offensive strategy at place. While it did not make any commitments to peaks its carbon emissions recently, it also didn't want to come off as doing too little for the climate, all this time carefully positioning itself in a way to lead climate action with partnership payoffs; (iii) Third, as a developing nation, India has often relied on foreign investments for development in the country. Solar acted as a way to attract investors. In 2015, the government initiated RE-invest a high-profile event in the country. In 2017, 28% of all global solar finance went to India. This amounted to 3.6 billion USD (around 3.2 billion €) (Mercom India 2018). Through ISA, India

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[3] In a normal (or forward) auctions, buyers bid to buy certain goods and services. In a reverse auction, the roles of buyers and sellers are reversed. Here, for example, buyers of elelctricity put out tenders for sellers of electricity to bid on. Sellers usually outbid each other, and the buyer buys electricity from the seller who puts the lowest price on offer. An e-reverse auction is when a reverse auction is held electronically.

aims to mobilise 1 trillion USD (around 900 billion €) worth of foreign investments (Shidore and Busby 2019b, Stothard 2015). (iv) Finally, one of the key goals of the government has been energy sovereignty or self-sufficiency by reducing dependence on previously imported fuels (like high-quality coal) and overcoming persistent current account deficits. Fascinatingly, the study found very little evidence for drivers that would have seemed plausible like concerns about energy supply security, environmental concerns (it was seen as an international issue and could be included in the second driver), reductions in generation costs or concerns about energy access.

Given the above motivations, now the question is what barriers stand in the way of profitability of solar power and simultaneously solar expansion in India?

2.3.2 Barriers

Rathore et al (2018) interviewed a group of large-scale solar power developers in India and found critical barriers that can be broadly grouped under the following categories.

2.3.2.1 Policy and regulatory

As stated in an earlier section, India does not have a single comprehensive solar policy. For example, no single policy affects the cost of solar power generation in India. Rather developers have several options to choose from (IISD 2018). On top of that there are multiple institutions in charge of the administration process characterised by excessive regulations, complicated tax and licensing systems and bureaucracy, monopoly of government and therefore ability to exercise discretionary power. This makes obtaining benefits and subsidies cumbersome and time consuming. Solar developers are mainly selected on a basis of minimum and maximum solar capacity instead of the companies' financial track records. This prevents newer companies to enter the market. Additionally, lack of transparency and corruption is a major issue. According to Transparency International Corruption Perception Index India ranks 80 out of 198 countries with a score below average (Transparency.org Last accessed on 20 April 2020). 28% of developers interviewed by Rathore et al agreed that they have to pay bribes from the singing a contract to commissioning of the project.

2.3.2.2 Techno-economic

When it comes to solar energy, India has been more of a technology-taker than a technology-maker or innovator (Shidore and Busby 2019a). This comes with additional shortcomings like low maturity of the solar industry and lack of domestic R&D. Developers have complained about unavailability of short interval radiation data and if available, abundance of incongruous data. Other complaints have been with regards to sharp upscaling of solar energy with imported solar modules (Behuria 2020). 90% of the solar modules used in India are imported. There are policies in place that support domestic manufacturing, but these are not very effective. For example, Indian manufactured modules are not efficient and often have low capacity. The average size of a Chinese module produces around 6 GW per annum while those manufactured in India have a capacity of only 69-86 MW (Rathore et al 2018). This further raises questions about the government's drive towards energy security (Behuria 2020).

2.3.2.3 Financial

Being a capital-intensive energy system, solar power requires that most of the lifetime cost has to be paid upfront by the developer. This adds to the amount of capital cost needed to fund the project. The financial aspects come into play because 70% of the capital cost in India accounts for debts or loans taken from commercial banks. Therefore, shorter payback periods and higher or variable interest rates significantly affects the rate of return and payback from a solar project. In 2013, Shrimali et al financially modelled actual renewable projects in India and found that higher cost of debt and inferior terms of loans can raise power generation cost by 24-32% when compared with the United States. Even when cost of the debt goes down, terms of loan can add 13-14% to generation cost. However unlike in the US or Europe, India has a very high cost of debt and hence policies like "duration of revenue-support, revenue-certainty, investor-risk-perception, and completion/cost-certainty are not likely to be effective." The most optimal way to reduce the cost of debt[4] would therefore be to give interest rate subsidies. These are likely to reduce LCOE by 13%-16%. Moreover, Rathore et al (2018) adds that technically feasible options like non-recourse financing is unavailable in India. This raises profitability because lenders have to repay loan from revenue earned from the solar project and not from the company asset. Another barrier comes with poor bankability of PPAs. Mostly PPAs are signed with DISCOMs in India and most DISCOMs are not in the best financial health and need government bailouts to pay developers (IISD 2018). Finally, and this also links to the regulatory framework, the time for financial closure or the time taken to finance the project after signing the contract is long.

2.3.2.4 Infrastructural

Historically land acquisition has been contentious and the legal process surrounding it is extremely complicated in India (Bajaj 2019). Solar developers say that their first hurdle is to acquire land. Most of the times, the land that is acquired is usually located in remote areas and far from power substations or grid injection infrastructures. This leads to transmission and distribution losses. According to the World Bank, Transmission & Distribution losses and Aggregate Technical & Commercial losses have been one of the major impediments to renewable power sector in India (Pragal and Banerjee 2014). Besides lack of proper transmission investments and planning, Deshmukh et al (2018) added that 80% of solar PV resources are located in high water stress areas and this can negative influence on solar deployment unless water requirements are reduced. Therefore, overall development of the energy system is important and still lacking in the country.

2.3.2.5 Socio-cultural

Padmanathan et al (2019) conducted surveys in order to understand people's perception of solar energy systems and calculate the level of technological acceptability in different sections of population in India. They found: (i) high income groups readily purchase solar systems as a status symbol rather than climate concerns and their knowledge about the energy system is very low. Middle- and low-income groups are the least informed; (ii) Overall there is very little

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[4] India's current interest rate is over 10% for solar projects which is a lot higher when compared to those allocated for loans given to infrastructure or real estate development in the country

awareness and clarity of government policies and subsidies, their clearer benefits or even detailed benefits of the system in general. For example, solar installations at the residential level has a high upfront cost and is profitable only to households consuming over 600 kwh of electricity per month. However, there is very little clarity for consumers or knowledge about it. Because of this, the public attribute solar technology as immature in India; (iii) Because of lack of clarity and proper dissemination of information, policies like Accelerated Depreciation (AD) have not penetrated all levels of the society. While large scale solar project developers are motivated to avail tax exemptions benefits like AD, small and medium enterprises remain unaware of its benefits. Finally, it is important to point out that utility scale developers equate solar technology with "social responsibility." They also believe that the technology is viable in the long run.

2.4 Knowledge gap in the literature and the contribution of this thesis

After analysing the literature, few key conclusions can be made. First, and more generally, there is a lack of in-depth inter-disciplinary studies of solar energy systems in India compared to countries in Europe and North America. Padmanabhan et al. 2019 comes the closest to this when analysing socio-cultural factors contributing to solar adoption. Second, a large number of intertwined factors influence profitability of solar power in general but the significance of some of the factors in the Indian context is unique. Third, the analysis of economic viability in this sector is also limited and dated like in Rodriguez et al 2016, extremely localised like in Maheshwari and Jain 2017 and primarily focused on solar rooftop rather than utility-scale projects. This thesis contributes to closing this gap by analysing the profitability of utility-scale solar installations in several states with diverse characteristics. Its other contribution is the analysis of the role of different factors, in particular government subsidies on this profitability and estimation of how the evolution of these factors can affect the profitability of solar power in the future.

3 Theory and methods

This chapter is divided into three sections corresponding to the three research questions. The first section explains the concept of profitability and how I calculate it using basic ideas from economics and finance such as Net Present Value, Internal Rate of Return, Discounted Payback Period and Profitability Index. I also state all my data sources and explain how and why I choose specific Indian states. I also construct an analytical framework based on my literature review, in order to differentiate and visualise the causal mechanisms influencing profitability of solar investments in India. In the second section, I identify the key factors of influence that I use to test conditions under which solar power will be profitable without government support. Finally, in the third section I highlight how I interpret and aim to analyse feasibility of reaching solar targets based on findings from the first two research questions.

3.1 What is the profitability of utility scale solar power projects in selected Indian states and what explains its variations, if any?

In order to answer RQ 1, I interpret profitability using basic concepts from economics and finance like Net Present Value, Internal Rate of Return, Discounted Payback Period and Profitability Index. I conduct simple economic modelling based on discounted cash flow (DCF) analysis to measure profitability. DCF is based on the idea that value of any business endeavour is in its ability to generate cashflows. In other words, the value of a business project is the present value of a stream of expected cashflow projections. It is forward-looking and is used to estimate the potential for investments in a project (Kumar 2016). I use Microsoft Excel to define the relationship between a developer's expected cash inflow and outflow and selected policy and non-policy parameters based on the latest generic data published by the Central Electricity Regulatory Commission (CERC) and the respective State Electricity Regulatory Commissions (SERCs) for solar tariff determination. The primary objective is to understand how changes in the operating variables affect overall performance and valuation of investments (DePamphilis 2010, p281). To this end, the methodology adopted for this part of the thesis has been inspired by Rodriguez et al (2016) who determine the economic feasibility of 1kw and 5kw small scale solar PV projects in 16 countries around the world.

3.1.1 Calculating net annual cashflow, NPV, IRR, DPBP and PI

Net annual cashflow (C_y) for year y is calculated as the difference between all after-tax cash inflows and cash outflows during each year for the lifetime of the project.

$$\mathrm{Cy} = \text{Cash inflow}_y - \text{Cash outflow}_y$$

Cash outflows, for each year y, calculated by adding the annual maintenance and operation costs $O\&M$, loan repayments at the existing interest rates LR, insurance costs IN and income tax T payable depending on asset depreciation. Cash inflows, on the other hand, for utility scale projects account for the amount of electricity exported to the grid (total electricity generation E_g minus auxiliary consumption A_c) at the determined grid injection tariff T_g reached through a Power Purchase Agreement (PPA) between the developer and the utility. Y denotes the lifetime of the solar project. Therefore,

$$Cash\ inflow_y = \sum_{y=1}^{y} ((E_g - A_c) \times T_g)_y$$

$$Cash\ outflow_y = \sum_{y=1}^{y} (O\&M + LR + IN + T)_y$$

After the net annual cashflows (C_Y) are determined, these are discounted at the given discount rate r to discounted net annual cashflow (DCF_y). The concept of discount rate relies on the fact that present value of money is always higher than in the future simply because at any point money can be put in a bank to earn interests (Kumar 2016). Therefore, the net annual cashflows are discounted in order to include the time value of money and to avoid overestimation of future returns.

$$DCF_y = \frac{C_Y}{(1 + r)^y}$$

Thereafter, the net present value (or NPV) is calculated by subtracting the initial investment, or the amount of equity from the total discounted net cashflow. Equity represents shareholders' stake in the project. This can be either the amount that the developer invests from company funds or from selling company shares. The purpose for calculating NPV is to determine if a project records positive or negative future cashflows. Symbolically,

$$NPV = \sum_{y=1}^{y} \frac{C_Y}{(1 + r)^y} - C_o$$

Here, C_Y is annual net cashflows and C_o accounts for initial investment or outlay minus any subsidy that might be available for the project and r is the discount rate. So, if i) NPV> 0, investment will be economically viable, i.e., the developer makes a profit; ii) if NPV = 0, investment will be economically viable, the developer does not make a profit but recovers the initial investment; and, iii) NPV < 0, investment will not be economically viable. Finally, for sake of comparison, if the NPV of two projects are positive, the project with the highest NPV is ideally selected because it has a higher present value.

Finally, IRR is calculated for the discount rate, which yields an NPV equal zero for a stream of positive and negative cashflows during the lifetime of a project (Mellincamp 2019). Therefore, symbolically,

$$0 = NPV = \sum_{y=1}^{y} \frac{C_Y}{(1 + IRR)^y} - C_o$$

The size of the IRR directly corelates to the attractiveness of the project in percentage form. In other words, it tells what percent discount rate or (Weighted Average Cost of Capital) WACC is needed to fully recover initial investments. Therefore, the higher the IRR, the more favourable are the available investment opportunities and vice versa.

The Discounted Payback Period (DPBP) is simultaneously calculated from analysing the yearly discounted cashflows. It is the amount of time taken to repay the initial investment/outlay of the project.

$$DPBP = \frac{Initial\ investment\ (eur)}{DCF\ (eur/year)} = years$$

Finally, the Profitability Index (PI) is calculated to get a clearer indication of how much profit or loss the project makes during its lifetime.

$$PI = \frac{NPV}{C_o} + 1$$

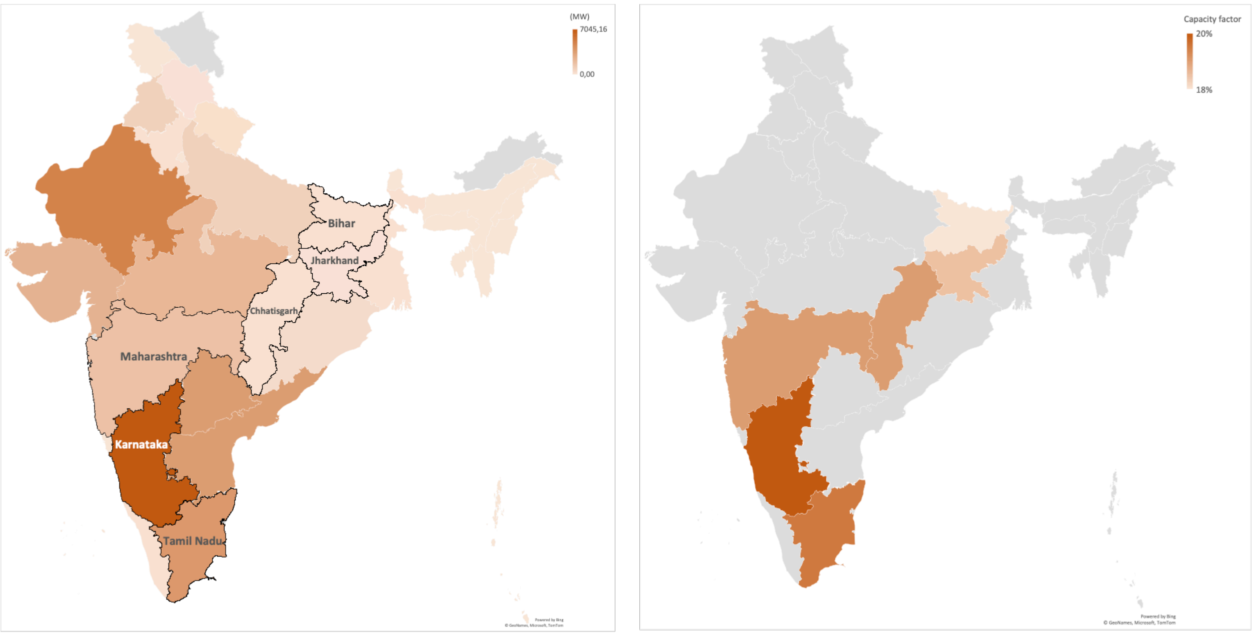
Where, if PI = 1, it means the returns breakeven with initial investment; if PI = 2 the profit is doubled on the investment and so on.

It is important to note that a project can have a positive IRR but a negative PI. This is a typical example of an unprofitable investment. A negative PI is indicative of a negative NPV. In this case, it is important to understand what IRR and NPV represent. IRR shows the rate of annual returns after cashflows are discounted. NPV on the other hand, represent the absolute value of an investment after the end of the term under a certain discount rate. Therefore, if IRR is positive and NPV is negative, it means that the cost of capital needed to fund the project each year is more than the annual returns derived from it.

3.1.2 Scope and data sources

3.1.2.1 Selection of states

Utilisation of solar PV in Indian states is shown in *Table 4-1*. I compare solar investments in the states of Karnataka, Tamil Nadu, Maharashtra, Chhattisgarh, Bihar and Jharkhand. These states were selected through reviewing each state in India according to the following selection criteria: (i) They had significantly different solar installed capacity as of March 2020; (ii) They were not significantly further away from one another in order to be largely affected by geophysical parameters; (iii) A solar tariff regulation has been passed by the respective SERC post 2014; (iv) The state must represent at least 2% of the land area and 2% of the population of the country; and finally (v) there is availability of reliable data. Data regarding state-wise solar installed capacity has been sourced from the MNRE website for grid-connected solar PV (last accessed on 31 March 2020). Information with regards to tariff regulation has been sourced from respective SERC websites and IREDA's data archives. Finally, information with regards to land area and population has been sourced from GOI 2011 census data. See *Figure 3 (a)* and *Appendix 1*: Data sources *Table 1*.



(a)

(b)

Figure 3 (a) Selected states and state-wise solar installed capacity; (b) State-wise capacity factor

Source: (a) Adapted from MNRE 2020b physical progress database (as of 31.03.2020) (b) Adapted from Deshmukh et al 2019

3.1.2.2 Solar PV specifications

The lifetime of a solar system is assumed to be 25 years having a 10% salvage value after operation. I assume solar performance based on the highest and lowest annual capacity factor as found during a geospatial and techno-economic study conducted by Deshmukh et al 2019. This study assumes a DC: AC ratio of 1:1, an azimuth of 180o and a ground cover ratio of 0:4. It also assumes a south facing fixed tilt system, where the tilt is equal to the latitude of the location, inverter efficiency loss of 4% and wiring, soiling and availability loss of 14%. (Deshmukh et al 2019). Based on these assumptions, I calculate profitability of utility scale solar projects having a capacity of 100 MW. See *Figure 3 (b).*

3.1.2.3 Financial parameters

All cost values used in this paper have been converted into euro at the exchange rate of 1 EUR = 83.2 INR (Reserve Bank of India, March 2020). I calculate profitability from the developer's perspective. I use latest generic data published by the respective SERCs for these calculations. These are ballpark figures published by the SERCs and are revised after a determined control period due to market changes.

The capital cost determination in the tariff orders is inclusive of cost of modules, land costs, cost of general and civil works associated with mounting structures, connecting transmission lines and other preliminary and preoperative expenses are accounted for. It also includes estimations on excise duty and tax payable for import of modules. Given that 90% of solar modules used in India are imported this is a safe assumption to make. With regards to interest rates, some states denote them in terms of State Bank of India (SBI) basic points. For these cases, 1-year average from January 2019- January 2020 of SBI Marginal Cost of Funds based Lending Rate (MCLR) is taken. Therefore 8.28% represents 100 SBI basic points (*Appendix 1*: Data sources *Table 2*). With regards to payable income tax, I assume 29.12% as the cost of debt, according to CERC tariff order, unless specifically stated otherwise by respective SERCs. Finally, in order to test the sensitivity of financial parameters I calculate the Weighted Average Cost of Capital (WACC) and assume it as the discount rate *r*. Symbolically,

$$WACC\ (or\ r) = \frac{d}{d+e}(R_d) * (1-T) + \frac{e}{d+e}\ (R_e)$$

Where, d is the amount of debt, R_d is the existing interest rate, T is the applicable tax, e is the amount of equity and R_e is the rate of equity. (Stephen 2020, Shrimali et al 2013)

3.1.2.4 Electricity tariff

In order to determine the grid injection tariff, I consulted 57 auction results from July 2015 until February 2020 (Appendix 1: Data sources Table 3). The average of last year auction results for respective states is taken as the grid injection tariff. Where unavailable (like Bihar never had a solar auction) the average of last year all India auctions is considered. See *Appendix 2*: Auction Data

3.1.2.5 Subsidies and taxes

As previously indicated, there are a number of schemes through which both federal and state governments provide subsidies for solar power production. The most common among them are Accelerated Depreciation (AD) and Viability Gap Funding (VFG). Accelerated Depreciation is a form of tax break, which allows producers to depreciate their asset faster during the initial phase of their project. Under section 32 of the Income Tax Act, from April 2017, solar plants that are operational for more than 180 days a year are eligible for a 60% depreciation in the first year. While those working for less than 180 days a year will be eligible for 30% depreciation in the first year and the 30% in the following year. The benefit for this is that the developer has to pay significantly less income tax during the initial years of the project. For my calculations, I assume the best-case scenario, i.e., 60% depreciation in the first year.

VFG, on the other hand, is a capital subsidy. The federal government covers a maximum of 30% of the capital cost depending on various eligibility criteria (IISD 2018). However, when tested against the actual amount of yearly capital subsidies given by GOI for utility scale solar capacity addition, it was found that subsidies for each state on an average vis-a-vi their then capital costs ranged between 2% - 12% See *Table 3-1*. Therefore, for the sake of first analysis I use the 5-year average of public expenditure made in the form of capital subsidies by the GOI from 2014-2018, compiled by IISD (2018) (p. 7 accompanying spreadsheet in report) in order to avoid overestimations. There are several small subsidies given by the state governments as well, but these have not been well documented for all states and hence not considered in the analysis. (See *Table 3-1*).

Table 3-1 Percentage of capital subsidy given by GOI

	2014	**2015**	**2016**	**2017**	**2018**	**5-year average**
Total capital subsidy (in €)	56 346 154	95 108 173	193 906 250	410 588 942	349 759 615	249 154 447
Total utility installed capacity (in MW)	943	2 682	4 970	8 364	4 852	4 362
Total capital subsidy per MW (€/MW)	59 752	35 462	39 015	49 090	72 086	57 117
Karnataka	6%	4%	4%	5%	7%	5%
Tamil Nadu	10%	6%	6%	8%	12%	8%
Maharashtra	8%	5%	5%	7%	10%	7%
Chhattisgarh	5%	3%	3%	4%	6%	4%
Bihar	4%	2%	3%	3%	5%	3%
Jharkhand	8%	5%	5%	7%	10%	7%

Source: Compiled by author after consulting IISD 2018, IREDA 2020 (previous)

3.1.3 Categorising factors affecting profitability

The factors affecting profitability of solar power in India can be investigated by tracing the causal links between critical economic and financial characteristics of utility-scale solar power (as dependent variables) and various socio-political and geophysical factors and conditions that influence these characteristics (as independent variables). Ideally, tracing the causal links would involve statistical or other quantitative analysis, but for my thesis I will rely on logical reasoning and simple economic models supported by the analysis of published statistics and literature. According to the existing literature, the factors affecting profitability of solar PV include the interplay of mechanisms shown in *Figure 4*. While each of these factors alone can directly influence profitability, it is important to note that interactions within factors can also affect profitability. For example, a policy to allocate more resources to solar R&D can lead to technology learning and innovation. This will eventually reduce the capital cost and thereby increase returns.

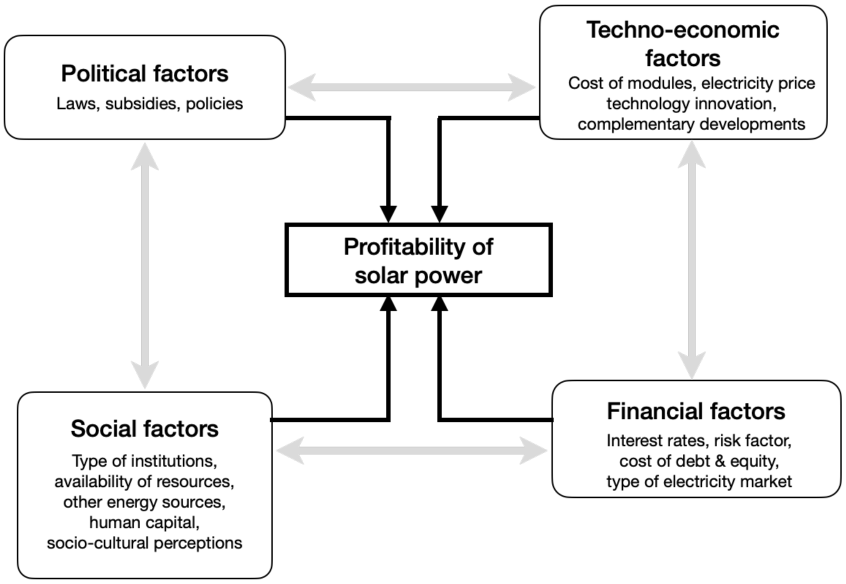


Figure 4 Factors affecting profitability of solar power

Source: Developed by author

(I) **The techno-economic** – these represent the factors like cost and efficiency of solar modules, technological innovation and complementary developments like storage potential, inverter efficiency etc. The economy of scale in solar power module production together with technology learning make power production cheaper and profitability higher. The profitability also depends on the price that the solar power producers can sell electricity at. This, in turn depends on the structure and dynamics of electricity market, including changing demand for electricity, competition from other sources, regulations and any specific schemes such as solar power auctions held in India, where the tariffs for utility-scale solar projects are agreed. Finally, techno-economic factors also include geophysical conditions such as availability of land and solar radiation.

(II) **The political** – these represent factors that are influenced by governing actors structured by capacity defined in terms of available resources, and motivation defined by political pursuits both domestically and internationally. These are visible in the form of laws enacted, adoption of policies, setting up of targets, forming institutions and forming international partnerships. The primary idea is that government support helps create demand in the form of purchase obligations, promotes supply by various production side incentives and helps take off the burden and uncertainties of initial investments allocating projects to developers with a given level of RoE.

(III) **The financial** – these represent factors that are pre-existing in the economic domain and are innate to the national market. They essentially include variables that influence the ease of doing business like cost of debt, cost of equity, prevailing exchange rates, inflation rates, payable corporate and income taxes. The primary idea here being, the financial characteristics determine how easy it is to access capital, invest in a business and finally earn returns. On a broader spectrum it influences how cash flows in given market conditions.

(IV) **The social** – these represent parameters that are pre-existing in the social domain. They may be in the form of socio-technical variables, representing pre-existing energy sources, technologies, availability of knowledge and suitable resources; socio-political variables, representing pre-existing institutions for policy disseminations; or socio-cultural variables, representing perception of different groups in the society. The primary idea being that social conditions provides the context in which profitability can be explored and interpreted. They essentially will help answer broader questions like- what should be the threshold of profitability? Profitability for whom? Profitability against what?

3.1.4 Sensitivity analysis

I calculate profitability of utility scale solar projects given their respective techno-economic, financial and policy parameters. For the scope of this paper, I only choose 1 or two variables within the three broader categories, based on their expectedly high level of influence. So, for instance, I look at tax benefit and subsidies under policy parameters, change in electricity price and capital cost change due to module prices under techno-economic parameters, and change in WACC under financial parameters. First, I calculate the IRR, DPBP and PI for all the states. Then I conduct a sensitivity analysis to see which of the four parameters affect profitability the most. I do so by assuming that critical economic characteristics of utility-scale solar power as dependent variables and various social and geophysical factors and conditions that influence these characteristics as independent variables.

3.1.5 Limitations

The most significant limitation is the use of generic data due to both unavailability of company level information and also lack of time. What this means is that project level outcomes may be different, the actual return on equity may be more than that of the SERC's required rate of equity, or capital cost for larger installations may be different due to economies of scale, or even the actual electricity price agreed to between the developer and the distribution company while entering the PPA may be slightly different than the auction results. However, my goal is to not only see the level of profitability for large scale projects in India but to also analyse the sensitivity of the key parameters that affect it. In other words, does the Indian market and available policy provide a suitable condition for the solar energy expansion that it targets to achieve. In this case ballpark values of key financial parameters should suffice for deriving meaningful conclusions (Shrimali et al 2013). Moreover, most of the tariff order documents have been very recently (2018 or 2019) updated in order to incorporate latest policy developments and mirror the latest market trends.

Secondly, there are no strong evidence that the results of this thesis can be directly extrapolated to other Indian states. The study only looks at grid-connected utility scale solar photovoltaic installations. Although the methodology used can be applied to rooftop and off-grid installations, the results of the analysis may be different. Finally, the findings of the thesis cannot be projected into the future with 100% confidence, simply because the different factors are ever-changing. However, the results of the thesis can be used as baseline data to monitor the development of solar power profitability in India over time.

3.2 Under what conditions can utility scale solar power in these states be profitable without government support?

To answer this research question, I follow a logical course of analysis as per the method described in the previous section. I see under realistic assumptions of future electricity price, capital cost and financial parameters, how long and how much government spending will be needed to make utility scale solar power profitable in the particular states. Due to absence of a definite roadmap from the GOI beyond 2022, I assume the following capacity additions for the solar sector for meeting its 2030. I also assume that utility scale capacity additions per 100 GW will be in the same ratio as is it now – meaning, 60% of the targets will be met by utility scale solar power while 40% through solar rooftop.

Table 3-2 Assumed utility scale solar capacity addition in GW from now to 2030

Years	2019-2020	2020-2021	2021-2022	2022-2023	2023-2024	2004-2025	2025-2026	2026-2027	2027-2028	2028-2029	2029-2030
Capacity addition (in GW)	10	9.5	8.5	12	12	12	12	12	20	20	20

Source: 2019-2022 values derived from MNREa (See Table 2-1) 2022-2030 values assumed based on 2030 solar targets as in Ministry of Power 2018 and Ministry of Power 2019

3.3 In light of existing profitability and the need for government subsidies, are India's 2030 solar targets feasible?

In order to answer the final research question, I use Jewell and Cherp's (2020) framework for evaluating the feasibility of energy transitions based on the capacities of key actors involved in transitions to bear the relevant costs. In this thesis, I focus on three major actors: solar project developers, DISCOMs and the federal government. This means that the feasibility of India reaching its solar targets depends on costs to and capacities of these two actors, which can be expressed as economic viability and political feasibility. Namely:

- First, there should be continuous availability of capital and the investments in solar power should be profitable, i.e., incur positive returns within shorter payback periods. In other words, solar power must be economically viable and thus developers should obtain benefits rather than incur costs. This can be answered drawing from conclusions in RQ1.
- Second, public authorities and political actors should have sufficient capacity to support solar energy development. In other words, providing support solar power must be politically feasible. This can be answered drawing from conclusions in RQ2.

While economic viability and political feasibility are necessary, they are not sufficient conditions for the feasibility of reaching India's solar target. The required rapid build-up would also need to be feasible in the concrete socio-technical context of Indian states, involving issues ranging from land availability and planning permissions to potential local opposition and the availability of qualified labour. This aspect of feasibility is outside of the scope of the current thesis but should be researched in future work.

4 Results and analysis

This chapter reports the findings on RQ1 and RQ2 in the following order. First, the typical characteristics of both cash inflows and outflows for solar capacity installation are identified. In the second section, the profitability of investments based on the state-wise gathered data on *Table 4-1* is calculated. Third, profitability based on changes in four key factors is calculated. In the final section, how much government spending is required to meet India's 2030 utility scale solar targets, under realistic assumptions of the key factors, is determined.

For the purpose of convenience, hereafter the six selected states are referred to as follows:

States	**Initials**	**States**	**Initials**
Karnataka	KN	Chhattisgarh	CH
Tamil Nadu	TN	Bihar	BI
Maharashtra	MH	Jharkhand	JH

Table 4-1 The main parameters of investments in solar installations in the selected Indian states

	Karnataka	**Tamil Nadu**	**Maharastra**	**Chhattisgarh**	**Bihar**	**Jharkhand**
Last amendment	2019	2019	2019	2019	2018	2016
Control period	-	2	-	3	3	4
Capacity factor	20%	19,5%	19%	19%	18%	18,5%
Capital cost (in eur/MW)	408 654	402 644	314 904	540 865	531 466	728 185
O&M cost (% of Capital cost)	1,32%	1,40%	2,29%	1,56%	1,67%	1,95%
O&M escalation rate	5,72% pa	5,72% pa	5,72% pa	5,72% pa	5,72% pa	5,72% pa
Insurance cost**	0,35% of net asset value	0,35% of net asset value	0,35% of net asset value	0,35% of net asset value	0,35% of net asset value	0,35% of net asset value
Debt-Equity ratio	70 30	70 30	70 30	70 30	70 30	70 30
Term of debt	13 years	10 years	12 years	13 years	10 years	12 years
Interest rate	10.50%	10.55%	11.31%	10.28%	10.28%	11.28%
Required return on equity	14%	17.60%	16%	16%	14%	20% (first 10 years) 24% (next 15 years)

	Karnataka	Tamil Nadu	Maharastra	Chhattisgarh	Bihar	Jharkhand
Depreciation	5.81% on 90% of asset for first 13 years the remaining spread equally over lifetime	3.6% on 95% of capital cost	5.83% on 90% of asset for first 12 years the remaining spread equally over lifteime	5.28% on 90% of asset for first 13 years the remaining spread equally over lifetime	7% for 10 years on 90% of capital, the remaining spread equally over lifetime	5.83% on 90% of asset for first 12 years the remaining spread equally over lifteime
Salvage value	10%	10%	10%	10%	10%	10%
Income tax rate	27.28%	27.28%	29.12%	27.28%	34.61%	27.28%
Discount factor	11.55%	9.53%	10.41%	10.02%	8.22%	11.87%
Auxiliary consumption	0.25%	NA	-	0.25%	0.25%	0.25%
Grid injection tariff (eur/kw)***	0.04	0.04	0.03	0.06	0.03	0.06
5-year average capital subsidy rcvd*	5%	8%	7%	4%	3%	7%

Exchange rate (1 EUR) = 83.2 INR (RBI March 2020)
* See *Table 3-1*
**assumed the same as in TN
***based on last available auction data in the state in *Appendix 2*: Auction Data

Source: Compiled by author after consulting KERC 2019, TERC 2019, MERC 2019, IREDA 2019

4.1 Typical cashflow of solar power projects

Figure 5 shows the characteristics of typical cash inflow and outflow for solar utility projects in India. Cash inflow is dependent on two key factors: grid injection price (or the price as which developers sell electricity to the DISCOMs), hereafter referred to as the electricity tariff, and the capacity utilisation factor of solar power plants, which determines the amount of electricity that is produced by a given power plant in a given state. Due to the differences in geographical locations, the capacity factor is different for the selected states and falls between 18% - 20% annually. The electricity tariff has been determined based on last auction results held in the states. These range between 0.03-0.06€/kWh. The higher prices are more representative of the earlier auctions, for example CH and JH both had their last auctions in 2016 with the tariff of 0.06€/kWh, while there was never a state level solar auction in BI. Hence, the latest tariff from February 2020 all-India auction is used as a proxy for BI, where the tariff was 0.03€/kWh (see also *Figure 10*).

While capacity factor and electricity tariff influence cash inflow, the variables influencing cash outflow include the initial investment at the start (also referred to as the equity), operation and maintenance costs, insurance costs, loan repayments and income tax payments for the lifetime of the project. The total grey area in the *Figure 5* represents the cash inflow from the sale of electricity while only the shaded portion represents the part of the income for which taxes have to be paid. The level of taxable income depends on the amount of depreciation allowed for the asset. See *Table 4-1* for allowed limits in the selected states.

The amount of payable income tax and insurance cost decline gradually, while operation and maintenance costs increase over the years. This is because the value of a fixed asset reduces due to general wear and tear over time. The debt tenure in the selected states ranges between 10-13 years, after which generation costs decline significantly. Although spanning for less than half of the lifetime of the project, the cost of debt (inclusive of loan repayment and interests paid) accounts for the largest share in the total cash outflow, closely followed by payable tax. See *Figure 6*.

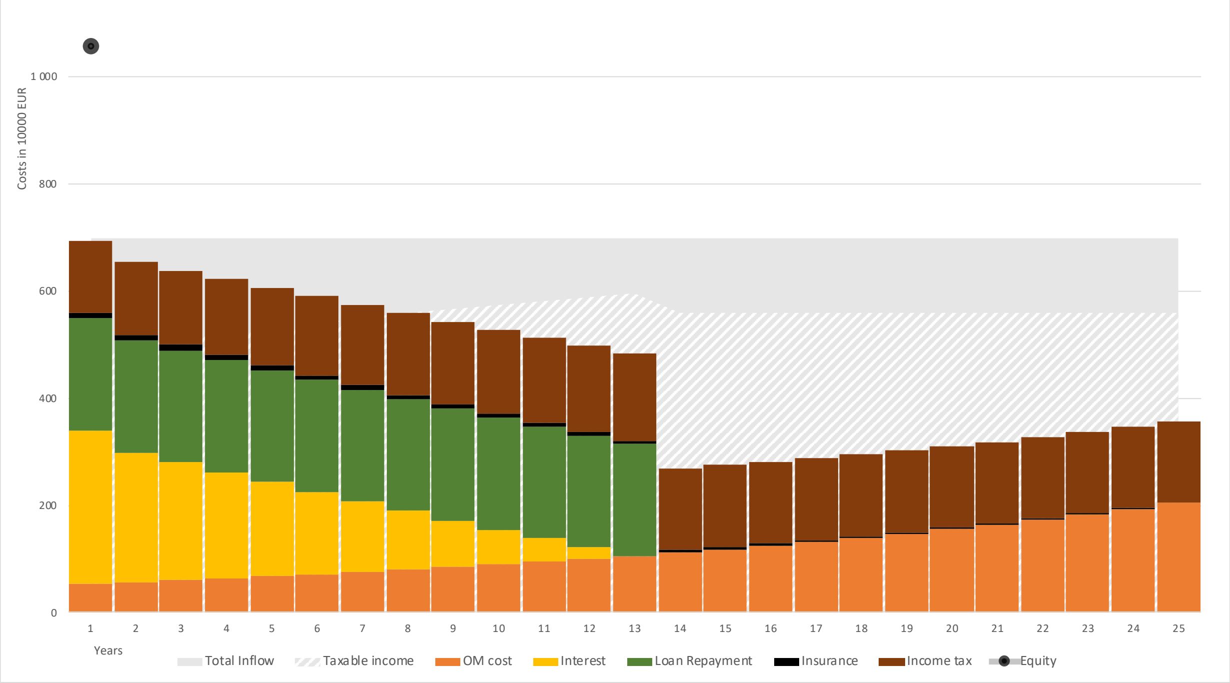


Figure 5: Typical cash inflows and outflows in a solar project (KN, 100 MW)

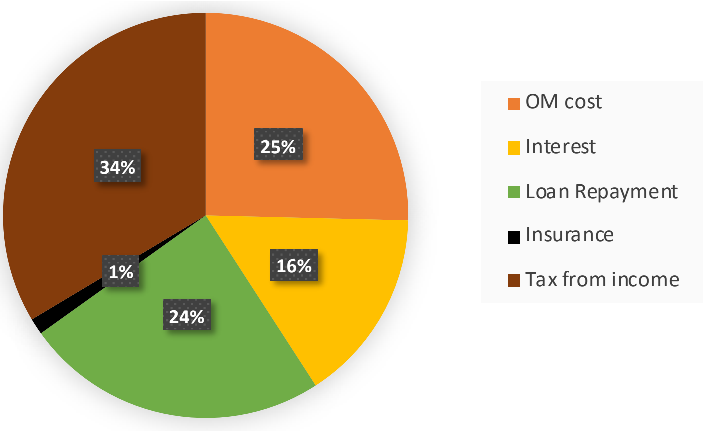


Figure 6: Share of costs in cash outflow (KN, 100 MW)

4.2 Profitability of solar projects in selected Indian states

Table 4-2 shows the profitability of solar utilities in the six selected Indian states. Although all states, except BI record a positive IRR, returns only breakeven in KN, TN (*Figure 7*) and CH, in the order of increasing level of profitability. It is important to point out that CH's high level of profitability is only owed to its latest tariff order being from 2019 (where capital costs already takes into account technology development) and high electricity tariff (based on its last solar auctions held in 2016).

MI records a positive IRR, but returns do not breakeven (*Figure 8*). JH too records a positive IRR but a negative PI (*Figure 9*). This is another typical example of a no-go investment, where expected returns cannot be delivered. It happens when the net present value (NPV) of all future cashflows is negative because the cost of capital needed to fund the project would be higher than the rate of return derived from it annually (Refer to *Section 3.1.1* for a detailed theoretical explanation). Such a result is due to very high capital cost in JH as its tariff order document was last updated in 2016. Because of this significant discrepancy in available data, hereafter, JH has not been included in my analysis. BI, on the other hand, records both a negative IRR and a negative PI thereby representing a negative NPV. Very low profitability of solar investments in the state is representative of high capital cost, high interest rate coupled with low capacity factor and low electricity tariff.

Table 4-2: Profitability of solar utilities in the six selected Indian states

	IRR	**DPBP**	**PI**
Karnataka	12%	< 21 years	1.07
Tamil Nadu	11%	< 16 years	1.30
Maharashtra	5%	-	0.39
Chhattisgarh	13%	< 14 years	1.43

	IRR	DPBP	PI
Bihar	-6%	-	-0.86
Jharkhand	0.4%	-	-0.28

Note: rows shaded in green designate the states where solar power is profitable

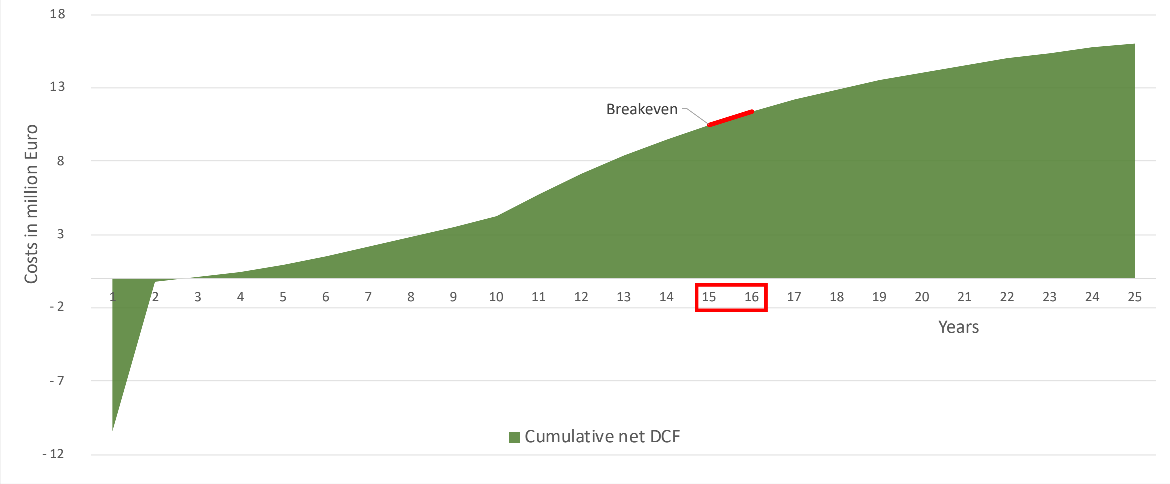


Figure 7: Cash outflow, positive net income and breakeven in Tamil Nadu for a solar investment of 100 MW

Note: Investment is profitable and returns breakeven between the 15th and 16th year

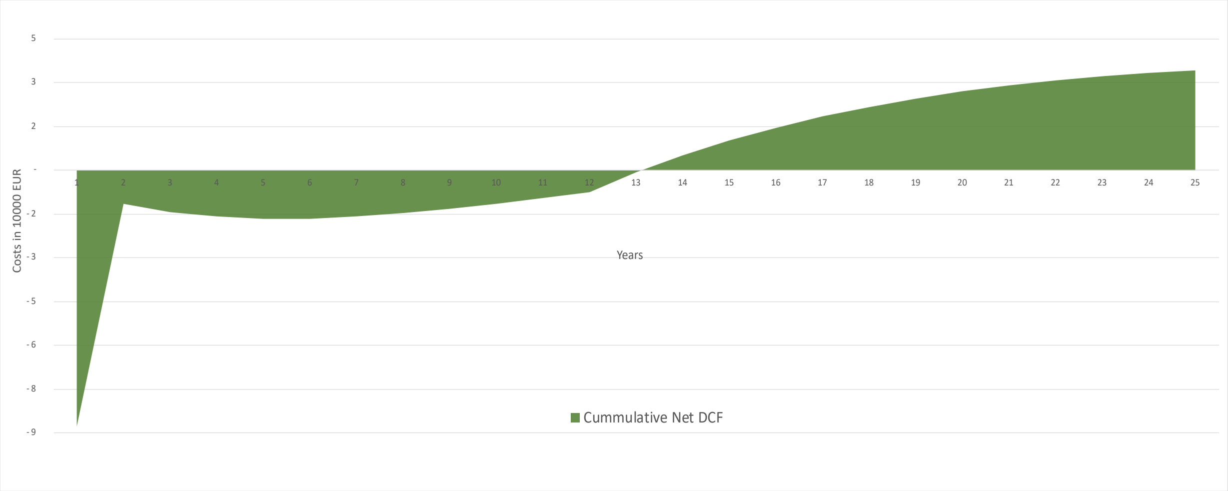


Figure 8: Positive net income but no breakeven in Maharashtra for a solar investment of 100 MW

Note: Investment is unprofitable

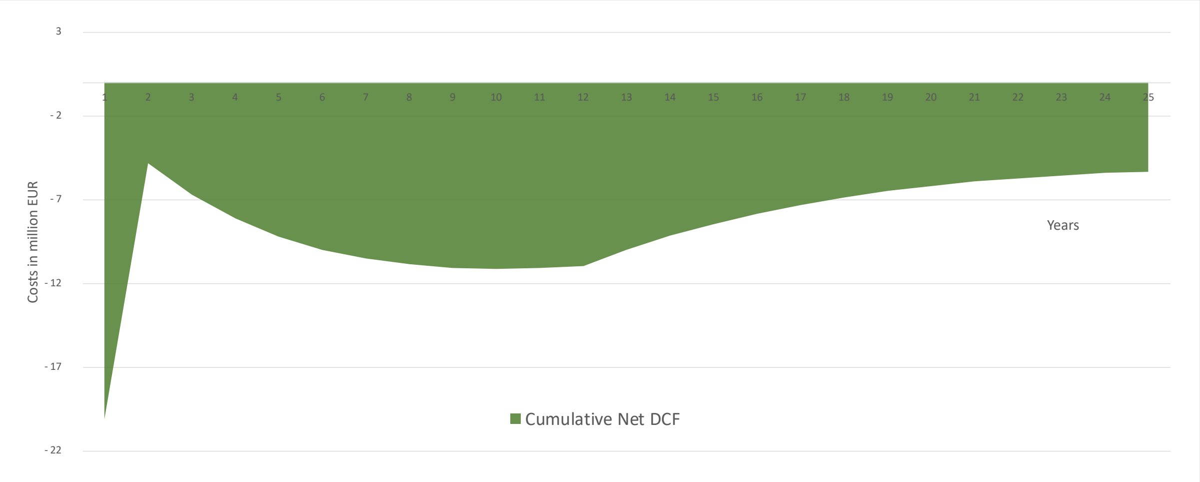


Figure 9: Negative net income and no breakeven in Jharkhand for a solar investment of 100 MW

Note: Negative returns throughout the lifetime. Investment is highly unprofitable

4.3 Factors affecting profitability

In the previous sections, we see that profitability is being affected by a multitude of factors. Under this section, a few major ones are explored. The following subsections explore how electricity tariff, subsidies and taxes, capital costs and financial parameters impact profitability of solar power in the selected Indian states.

4.3.1 Electricity tariff

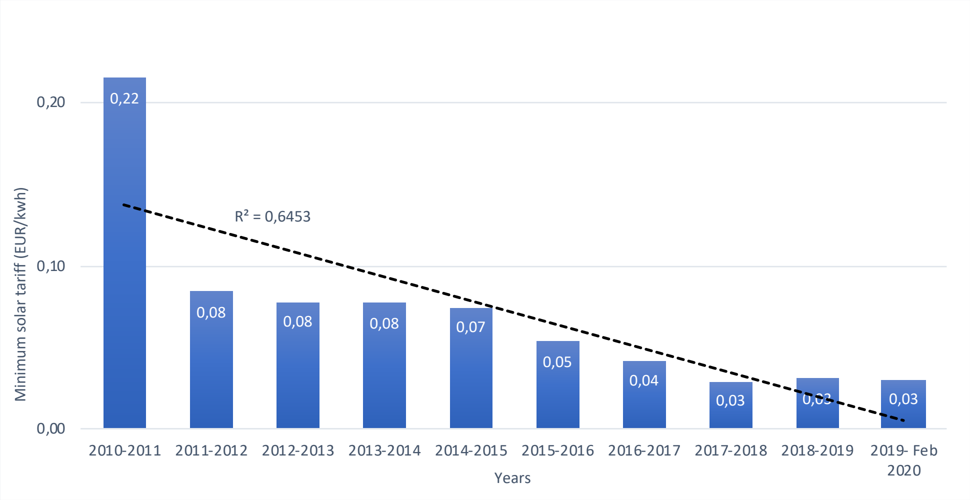


Figure 10: Year-wise minimum national solar electricity tariff in India

Source: Adapted from Thapar et al 2018 and auction data gathered (Available in Appendix 2: Auction Data*)*

While installed solar capacity in India has rapidly expanded in the last decade, competitive bidding has led to a drastic decline in the electricity tariff. *Figure 10* shows that the national electricity tariff has declined by 86% within the last 10 years. In the five states the tariff varied between 0.06 and 0.03 €/kWh. This begs the question, how profitable are solar investments under the current and potentially lower electricity tariffs?

If all other things remain the same (including the five-year average subsidy as calculated in *Table 3-1*) and the electricity tariff for all states is at 0.03 €/kWh, investments in solar power would not be profitable in any of the states, although IRR in KN, TN and MH would still be positive (*Table 4-3*). Should tariffs rise to 0.04 €/kwh, solar power would be profitable in three of the five states. Under this tariff, investment would become so profitable, that the money invested in solar power in MH would close to double in 25 years. However, for the investments to break even in CH and BI, electricity tariff would need to rise to 0.05 EUR/kwh. This proves that profitability of solar power is highly sensitive to the electricity tariff at which it is sold to the distribution companies.

Table 4-3: Effect of change in electricity tariff on profitability

Electricity tariff	**0.03 €/kWh**			**0.04 €/kWh**		
	IRR	**DPBP**	**PI**	**IRR**	**DPBP**	**PI**
Karnataka	5%	-	0.19	12%	< 21 years	1.07
Tamil Nadu	4%	-	0.24	11%	< 16 years	1.30
Maharashtra	5%	-	0.39	15%	< 14 years	1.57
Chhattisgarh	-4%	-	-0.68	3%	-	0.03
Bihar	-6%	-	-0.86	0%	-	-0.17

Note: Profitable scenarios are highlighted with green.

4.3.2 Subsidies and taxes

This section explores the profitability of solar investments at different electricity tariffs, under different combinations of subsidies and tax benefits to solar producers.

In India, the two main types of solar power support policies include a capital subsidy (CS) up to 30% of capital cost and a tax break in the form of accelerated depreciation (AD) of 60% in Year 1 or distributed equally between Year 1 and Year 2 depending on the number of days the plant operates. For this analysis, different policy combinations for 30% CS and 60% AD in Year 1 are explored. A combination of 60% AD and the average CS calculated is also explored. *Table 4-4* represents profitability under different policy combinations, under the current electricity tariff (a) and a lower electricity tariff (b). *Table 4-4 (a)* suggests that investments in KN, TN and MH are only profitable when there is a 30% CS. Across all policy combination, investments in CH and BI remain unprofitable. Finally, from all policy combinations tested, 30% CS and 60% AD in Year 1 offers the most attractive incentive with a breakeven before 15 years for the three profitable states.

Table 4-4: Profitability under (a) different policy combinations but with 0.03 EUR/kwh electricity tariff and (b) at best case scenario but lower electricity tariff

	(a) Current tariff (0.03 €/kWh)								(b) Lower tariff (0.02 €/kWh)	
	30% CS		**60% AD**		**60% AD and 5-year avg CS for each state**		**30% CS and 60% AD**		**30% CS and 60% AD**	
	DPBP	**PI**	**DPBP**	**PI**	**DPBP**	**PI**	**DPBP**	**PI**	**DPBP**	**PI**
KN	< 25 years	1.01	-	0.36	-	0.49	< 14 years	1.42	-	0.22
TN	< 24 years	1.04	-	0.41	-	0.65	< 14 years	1.57	-	0.19
MH	< 17 years	1.27	-	0.50	-	0.71	< 10 years	1.69	-	0.12
CH	-	-0.09	-	-0.45	-	-0.38	-	0.32	-	-0.64
BI	-	-0.28	-	-0.62	-	-0.56	-	0.15	-	-0.82

Note: Profitable combinations are highlighted with green. For the sake of easier representation, the IRR values are not added to this table. Please refer to Appendix 3:

However, this begs the question, does this best-case scenario guard developers against a fall in electricity tariff in KN, TN and MH? *Table 4-4(b)* shows that profitability falls if electricity tariff is lowered. KN and TN still make positive annual returns, but these returns do not breakeven with the initial investments. Electricity tariff must be 0.027 €/kWh and 0.026 €/kWh for KN and TN respectively for returns to breakeven. While for MH, CH, and BI the tariff must be 0.026 €/kWh, 0.038 €/kWh and 0.04 €/kWh respectively in order for returns to breakeven.

Table 4-5 represents the minimum subsidy requirements for returns to breakeven in each state under current and lower electricity tariff. This shows that solar investments will only be profitable in KN, TN and MH under existing policies available.

Table 4-5: Subsidies required for returns to breakeven under current and lower electricity tariff with and without accelerated depreciation (AD)

States	Current tariff (0.03 €/kWh)		Lower tariff (0.02 €/kWh)	
	Without AD	**60% AD**	**Without AD**	**60% AD**
Karnataka	28%	21%	57%	48%

States	Current tariff (0.03 €/kWh)		Lower tariff (0.02 €/kWh)	
	Without AD	**60% AD**	**Without AD**	**60% AD**
Tamil Nadu	30%	18%	59%	48%
Maharashtra	25%	16%	58%	49%
Chhattisgarh	54%	45%	75%	66%
Bihar	57%	48%	77%	68%

Note: subsidy is expressed as % of capital costs; cells where the required subsidy exceeds the current ceiling of 30% of capital costs are highlighted with green

4.3.3 Capital costs including module prices

Another key variable affecting profitability is capital cost, which is closely linked to the price of PV modules. The costs of PV modules have been steadily falling following economies of scale and global technology learning. Wright's law specifies that the cost of technology decline by a fixed percentage (e.g. 10-15% for airplanes) with doubling of production (Wright 1936). According to IRENA, after every doubling of the global cumulative installed capacity, module prices declined by 20-22% during the last decade (IRENA 2020). Between 2013-2018, PV module prices in India declined by 57%, indicating a 10-15% decrease on a year-on-year basis (IRENA 2019, p 43). Around this time installed capacity in India doubled at least thrice from 2.6 GW to 28 GW. This means that the relationship between the prices of solar PV modules in India and the growth in capacity roughly followed the same relationship as at the global level. This section evaluates the effect of declining capital costs on profitability under different electricity tariffs.

The amount of subsidy (as % of capital cost) is calculated, which would be needed to ensure break-even of solar power projects under the current tariff and the assumption that module costs will decline 10-15% per year. It is important to bear in mind that according to the SERC of KN (KERC 2019), module costs only account for 53% of the total capital cost. In the following calculation, the study assumes that module costs account for the same proportion of capital costs in all states. *Figure 11* shows that under this assumption, KN, TN and MH will not require subsidies by 2022-2024. However, CH and BI, owing to their currently high capital cost will only be able to break even without subsidies by 2025-2028.

Table 4-6 shows that in order for returns to breakeven without a subsidy under current electricity tariff, capital cost must decline by 27% in KN, 25% in TN, 20% in MH, 47% in CH and 49% in BI from current levels. This would correspond to 36%, 35%, 27%, 65% and 68% respectively required decline in solar module prices. Under the assumption that solar module prices in all states are the same as in Karnataka, they would make a smaller share of capital costs in more 'costly' states of BI and CH, which means that decline in these costs will have less impact on profitability, so it may take longer to achieve profitability and require a larger decline of solar module costs.

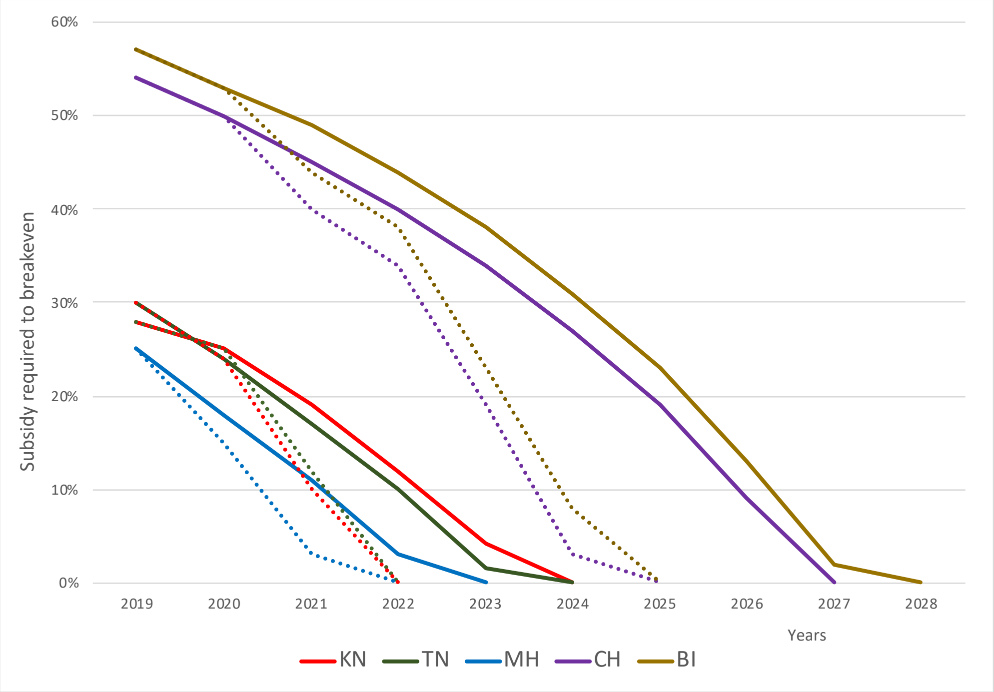


Figure 11: Subsidy required for returns to breakeven if electricity tariff remains at 0.03€/kWh and (a) module prices decline by 10% per year (represented by bold lines); (b) module prices decline by 15% per year (represented by dotted lines)

Table 4-6: The required decline in capital costs and in solar PV module prices to achieve profitability without subsidies at 0.03€/kWh

States	(a) Current capital cost (in €/100MW)	(b) Capital cost required to breakeven without subsidy (in €/100 MW)	(c) Percentage decline	(d) Percentage decline in module costs required
Karnataka	40 865 385	29 792 697	-27%	-36%
Tamil Nadu	40 264 423	30 024 721	-25%	-35%
Maharashtra	31 490 385	25 127 268	-20%	-27%
Chhattisgarh	54 086 538	28 747 340	-47%	-65%
Bihar	53 146 635	27 000 867	-49%	-68%
Decline forecasted by BNEF for the next decade				**-34%**

However, a fall in electricity tariff to 0.02 €/kWh will have drastic impact in terms of both rate of return and required government spending. For sake of reference, MH, which has the lowest capital cost would currently require 58% of its capital cost as subsidy (more than double) for returns to breakeven (*Figure 12*) and subsidies will have to be paid for 3-4 more years and this will cause government spending will rise by 4-6 times. Therefore, it is evident that investments are promising should module prices decline by 10-15% on a year-year basis. However, benefits are overruled should this be accompanied by a decline in electricity tariff.

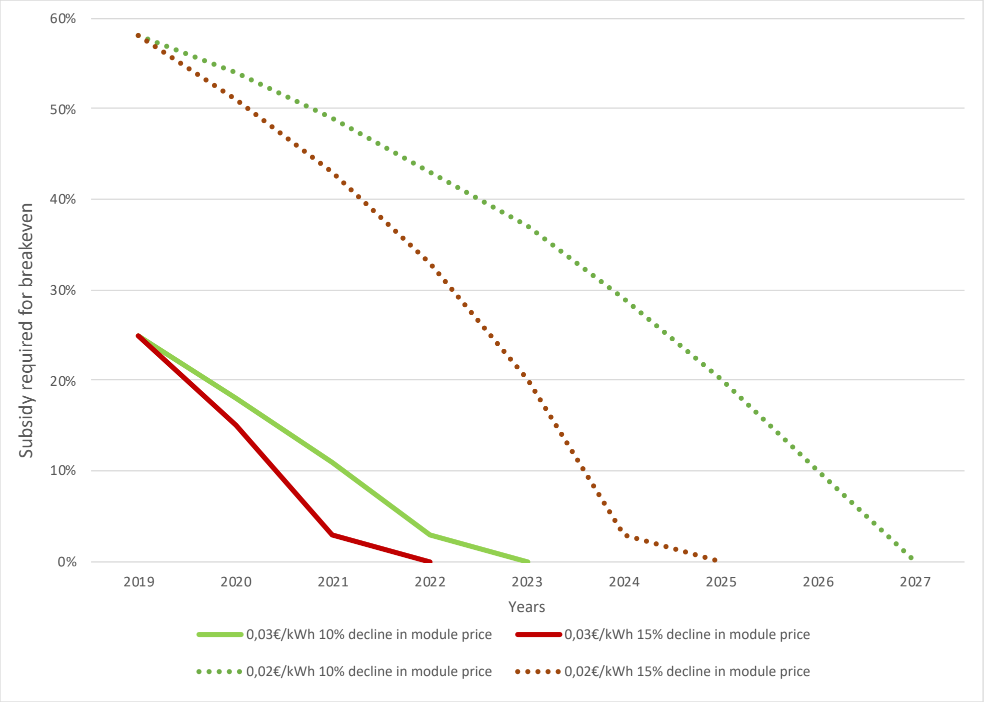


Figure 12: Change in subsidy requirement when electricity tariff falls to 0.02€/kWh in MH

Moreover, major financial analysts claim that module price decline during the next decade is unlikely to be as drastic as in the past. BNEF in their 2019 New Energy Outlook predicted a 34% decline from 2019 levels. This would indicate a 3-4% decline on a year-on-year basis. Although this would mean that the current amount of subsidy required for solar investment to break-even in the selected states would be the same as in *Table 4-5 (a)* and *Figure 11,* subsidy would have to be paid for a longer period of time – 2029-2033 for KN, TN and MH and until 2047 and 2049 for CH and BI respectively (*Figure 13*). Clearly these results would be further magnified should the electricity tariff reduce at the same time.

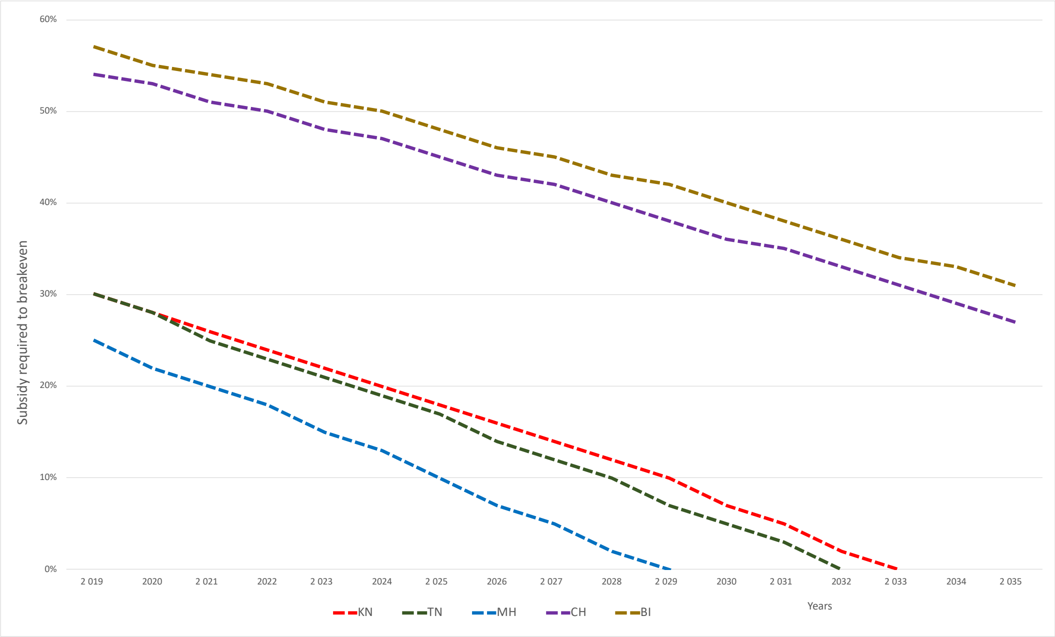


Figure 13: Subsidy required for returns to breakeven if electricity tariff remains at 0.03€/kWh but module prices decline by 34% in the next decade

4.3.4 Financial parameters

Another set of key factors that affect profitability are the financial parameters. These mainly include the cost of debt, cost of equity (assumed same as the SERC's required rate on equity) and the tax rate - all three contributing to determine the after tax WACC or discount factor. For this section, a sensitivity analysis is conducted in order to see how (i) the three individual factors- i.e., changes in the cost of debt (assuming unchanged debt tenure), cost of equity and tax rate influence the WACC and thereby profitability, while all other things remain the same as in *Table 4-1*; and (ii) how much WACC is required for investments to breakeven without subsidies.

First, it was found that WACC arrived based on the given financial parameters do not add up to the discount rate assumed by the respective SERCs. It is lower in case of TN and BI and higher in case of KN. Although the difference is minimum and does not cause any significant change in the profitability of investments, the reason for such discrepancies is not certain but could be credited to fluctuating interest rates.

Table 4-7 WACC allocated by SERCs and calculated WACC

	WACC allocated by SERCs	**Calculated WACC**
Karnataka	11.55%	9.54%
Tamil Nadu	9.53%	10.61%
Maharashtra	10.41%	10.41%
Chhattisgarh	10.02%	10.03%
Bihar	8.22%	8.91%

Second, it was found that profitability is most sensitive to the cost of capital - debt and equity combined. And among these two variables, profitability is most sensitive to the cost of debt as has been already found in an earlier study on influence of financial parameters on profitability of investments in renewables in India (Shrimali et al 2013). The study finds that profitability in solar investments in the selected states changes significantly that is PI increases or decreases by at least 1 point with 5% increase or decrease in the cost of debt. The study also finds that lower interest rates may make investments more profitable. However, it does not guard against a fall in electricity tariff. (See *Table 4-8*). In which case, government support in the form of subsidies has to be increased. For example, 60% AD and 30% CS would make solar investments in KN, TN and MH profitable under 0.02€/kwh electricity tariff but interest rates have to be as low as 0-5% and term of debt higher than 20 years. For sake of comparison, the minimum lending rate for a home loan in India is 7.2% currently. Finally, *Table 4-8* shows the required WACC for breakeven under different electricity tariff and subsidy combinations. Should subsidies be lifted, WACC is significantly low meaning debt has to be extended at very low or even negative interest rates.

Table 4-8 WACC required for investments to breakeven

	Cetrirus Paribus	**0.03€/kwh**	**0.02€/kwh**	**0.03€/kwh (without subsidy)**
Karnataka	12%	4%	-3%	3%
Tamil Nadu	11%	4%	-5%	3%
Maharastra	5%	5%	-7,5%	4%
Chattisgargh	13%	-4%	-18,5%	-4%
Bihar	-6%	-6%	7000% (for only PI to be zero)	-6%

4.4 Government spending required for achieving solar targets in India

Having explored the four key policy and non-policy factors, under this section aims to see how much of government spending is required under-realistic assumptions of best case scenario– which is the module costs decline by 34% (BNEF 2019) in the next decade to meet India's 2030 solar target under the current all-India electricity tariff 0.03 €/kWh, which is assumed to be fixed as solar has already reached grid parity in India. It also assumes that financial parameters remain the same. Going by different state parameters, required government spending is likely to be between €4.5 billion (going by MH parameters) and €32.6 billion (going by BI parameters). For sake of comparison, in the past 5 years, GOI has spent €3.2 billion for utility scale solar power projects and €9.1 billion for coal power projects and €62.3 billion for subsidizing and bailing out transmission and distribution companies between 2013-2018. (IISD 2019, p. 7 accompanying spreadsheet in report).

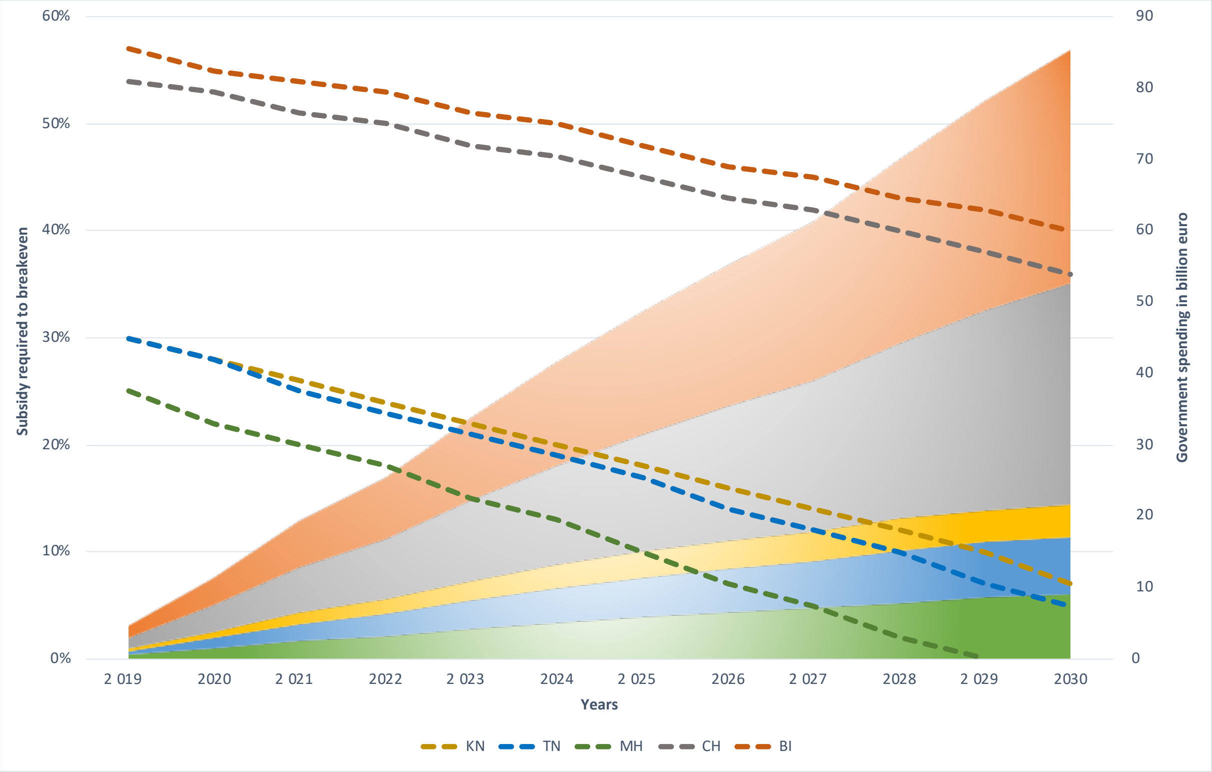


Figure 14: Government spending required to meet India's 2030 targets, when module prices decline by 34% from 2019-2030, electricity tariff stays at 0.03€/kwh and financial parameters remain unchanged

Note: Under these conditions Tamil Nadu would no longer require subsidies beyond 2032, Karnataka beyond 2033, Chhattisgarh beyond 2047 and Bihar beyond 2049. (The methodology adopted for year-wise capacity delineation is explained in Section 3.2)

5 Discussion

In this chapter, the findings from Chapter 4 and literature reviewed in Chapter 2 are sifted to see how far one can come to answer the three initial research questions and what they mean in the broader Indian context.

5.1 What is the profitability of utility scale solar power projects in selected Indian states and what explains its variation, if any?

Figure 4 and *Figure 15* show that factors affecting profitability of solar power in India can broadly be grouped into four categories - techno-economic, political, financial and social – and that factors belonging to these broad categories interact. Policies may affect seemingly 'non-policy' factors. For example, electricity tariff determination is a result of the e-reverse bidding mechanism adopted by a government policy aiming to stimulate solar power adoption. For the scope of this thesis, only a few selected factors from the first three categories have been examined. Among the policy factors, this thesis looks at subsidies and taxes and on the non-policy spectrum, it looks at the electricity tariff, capital costs, especially module prices and finally financing conditions as factors affecting profitability.

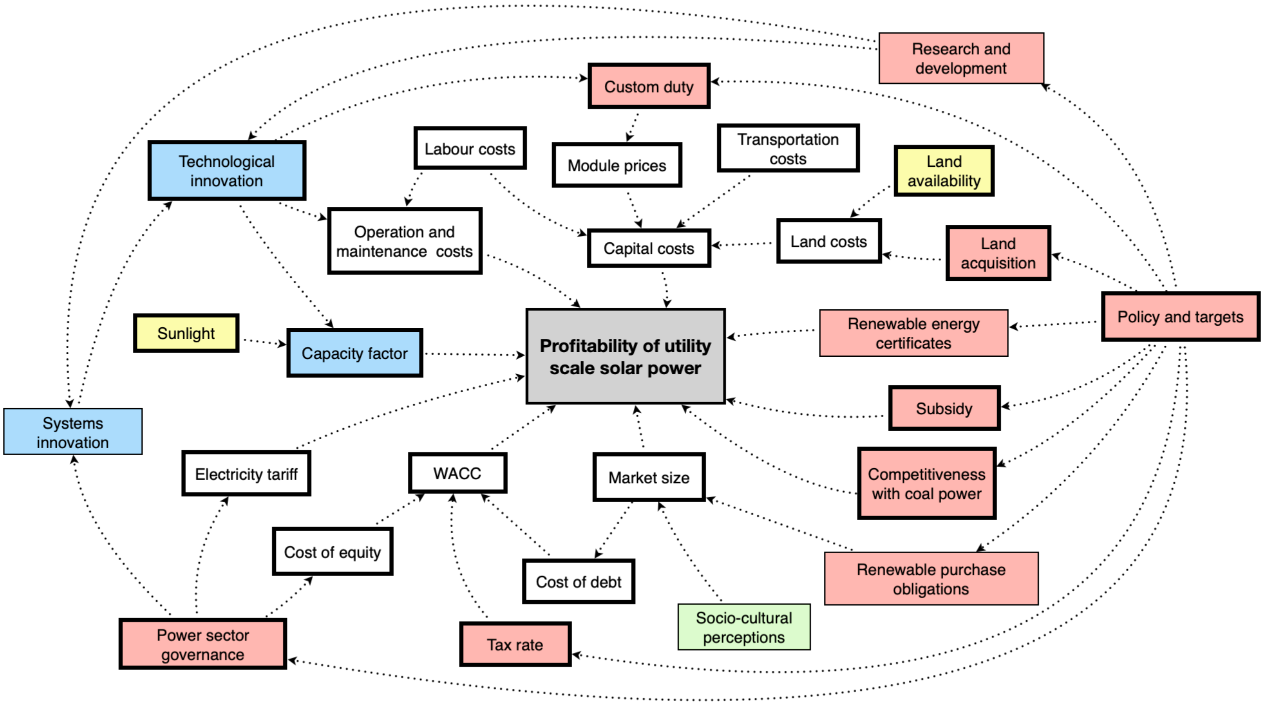


Figure 15 Factors affecting the profitability of utility scale solar power in India

Notes: The yellow blocks indicate geophysical, red blocks – policy, white blocks – techno-economic and financial and blue blocks - indicate socio-technical factors affecting profitability of utility scale solar power in India. The socio-cultural factor is highlighted in green is outside of the scope of this thesis. Also factors only in bold have been addressed in this thesis in varying degrees. While all factors influence solar at the national level, it is important to bear in mind that technological and system innovations can also be influenced by global developments.

Chapter 4 showed that the profitability of utility scale solar power varies across Indian states. In section 4.2 (Table 4-2) solar power is only seen to be profitable in three of the six examined states: Karnataka, Tamil Nadu and Chhattisgarh. The profitability in all six states varies widely (with PI ranging between -0.86 in Bihar to 1.43 in Chhattisgarh). This variability reflects differences in availability of resources, capital costs, competitiveness with conventional sources of electricity and power sector governance, which are discussed further below.

5.1.1 Availability of sunlight and land

A very obvious assumption would be that it is because some states receive higher solar irradiance than others. Chapter 4 showed that solar power projects are currently profitable in states having an average capacity factor of 19% or higher (See *Table 5-1*). However, capacity factor may not be the most significant factor of influence. For instance, solar projects in Karnataka which has the highest capacity factor among the selected states of 20% would not be profitable if it had the same capacity factor as Bihar (18%). But solar projects in Bihar would not be profitable if it had the same capacity factor as Karnataka. In fact, solar projects in Bihar would still not be profitable if it had the all India highest capacity factor of 25% (Deshmukh et al 2019), while all other things stayed the same.

Second, profitability of solar power projects is seen to be higher in states with greater suitable land availability for solar PV constructions. Availability of more land could mean lower land costs, somewhat decrease capital costs, of which land constitutes 5%. Third, while land acquisition continues to be a common barrier for solar power developers across all Indian states, land acquisition laws in India fall under the domain of state governments and therefore easy accessibility and timely approvals are exclusive to the respective states. For example, it takes developers 24 months to obtain necessary approvals associated with acquiring land for large scale installations while the time allocated to commission a project is only 18 months. In case of solar park projects land is pre-acquired and is provided by the government but these are getting increasingly competitive. Moreover, the government itself is running into several difficulties with regards to acquiring land and transmission infrastructures (Bajaj 2019). See *Table 5-1*.

Moreover, settlement patterns within the states are different. Size of the market for grid-connected solar power may vary and indirectly influence profitability. Typically, larger markets are associated with economies of scale, which help bring down costs and with higher investor confidence, lowers the cost of capital thereby increasing profitability. In more constrained markets, economies of scale would take longer or even harder to reach. For example, over 80% of population of Bihar does not have access to electricity and these households are mainly in remote areas far flung from transmission lines (World Bank 2014), thereby decreasing the applicability of grid connected large scale solar power on the whole. This means the on-grid solar power market in Bihar is smaller and as observed in Chapter 4 the profitability in the state is lower.

5.1.2 Differences in capital cost

Another significant difference that can be spotted in *Table 4-1* is that capital costs differ between states. Capital costs generally include, in addition to land costs, module costs, safeguard or import duty, costs related to civil and general works, mounting structures, power conditioning unit, evacuation lines, all preliminary and preoperative expenses, all applicable goods and service taxes (GST) (KERC 2019). Land charges and labour charges are likely to vary in different parts of India due to differences in socio-economic conditions. In addition, capital costs also include transportation and delivery charges. Given that 90% of the solar modules used in India are imported, states on the coast are likely to have an added advantage with low costs inland transportation and delivery. This could explain lower capital costs for Karnataka, Tamil Nadu and Maharashtra. On the other hand, Chhattisgarh, Bihar and Jharkhand are inland states meaning that higher charges have to be borne for transporting modules to them. It is also significant to point out that developers in some of the states like Tamil Nadu have indicated that the capital cost determination by the SERC is lower than in reality. They have also indicated that capital costs per MW for lower capacity installation is always higher than for higher capacity installation (TNERC 2019, p 47). This is essentially because of economies of scale as the fixed cost (comprising of grid connection, transportation etc.) per MW is smaller in case of large installations. Operation and maintenance charges also vary but the difference is not very big. However, there remains one discrepancy. From the available data, it is not very clear why operation and maintenance costs are distinctly higher in Maharashtra as compared to the other states. This is possibly due to a higher cost of labour in this 'richer' state, but the direct information confirming this hypothesis could not be identified. Research for this study also found that richer states have been able to make higher solar capacity installations over the last decade. 8 out of the top 10 states in terms of solar installed capacity today fall among the top 10 states contributing to the nations GDP. This aspect- whether richer states, with higher profitability build more solar power projects - has not been explored as a part of this thesis and could be a scope for future research.

5.1.3 Competitiveness with conventional sources

The third difference is the availability and competitiveness of solar vis-a-vi thermal power plants in the states. For instance, coal power generation is more expensive in Karnataka and Tamil Nadu than in the other states. Jharkhand (1st), Chhattisgarh (3rd), Maharashtra (7th) and Bihar (9th) house few of the largest coal reserves in the country (Ministry of Coal 2018). Closer proximity to coal mines makes generation of thermal power cheap, allows easy accessibility and has already helped build a strong power sector and thereby employment dependency in some of the states. For example, due to excess power supply in Chhattisgarh, the state also exports electricity to nearby provinces through the interconnected state transmission lines (Rao et al 2014). In contrast, Karnataka and Tamil Nadu lack in-state mining capabilities and therefore rely on imported coal from few of the above states (Buckley and Shah 2018c, Buckley and Shah 2018b). This means that coal has to be moved over large distances through the interstate railway lines. Rail costs along with the mine-mouth Indian coal charges make power generation expensive (Buckley and Shah 2018b). Situations are further grim in Karnataka because coal power plants operate at a capacity factor of 35% making thermal power production not only expensive but also inefficient. Furthermore, Buckley and Shah have fond that building base load gas power plants has also remained financially unviable here (Buckley and Shah 2018c). With imposition of a coal cess (a form of tax on coal), cost of thermal power generation has increased in general and is reported to rise further (Buckley and Shah 2018b). This would mean a higher electricity tariff will be required to make coal profitable in some of the states.

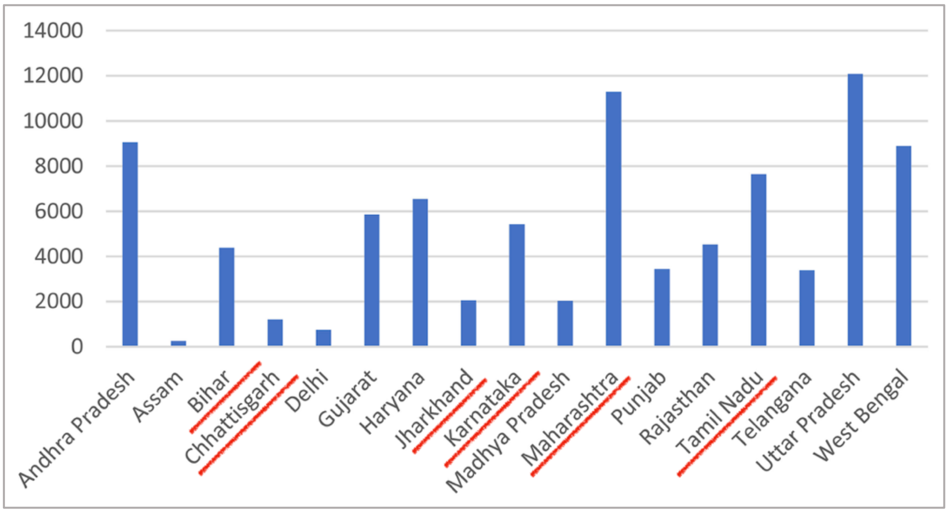


Figure 16 Distribution of expensive brown coal power plant capacities in India (in MW)

Source: Shrimali 2020. Fg 2

After passing the Electricity Act in 2003, which allowed independent power producers (IPPs) to participate in the power generation, India started adding coal power plants very rapidly. Although in 2017, India for the first time became a net power exporter, adding capacities did not equal to the amount of power produced. Existing coal power plants remained under-utilised and stranded due to various reasons. IEEFA reviewed 12 non-performing solar power plants in India. The report found that a coal power plant in Nasik, Maharashtra remained stranded for using "outdated technology, the lack of viable long-term power purchase agreements, and unresolved land acquisition issues resulting in the absence of the final mile of rail linkage, meaning no access to coal supplies" (Buckley and Shah 2020). Capital waste and un-utilised assets have been reported for Tamil Nadu, Karnataka, Maharashtra and Chhattisgarh. This has also been a leading contributor to India's bank loan problems, as due to inadequate revenue debt remained unpaid (The Economic Times 2018). Probably this just proves the shortcomings of the power sector in general in India and warns of solar even running into similar problems? But this begs further question, if underutilizing available resources is the right thing to do and is it profitable or adds to the government expense?

5.1.4 Power sector governance

Solar power is less profitable in Indian states with poorer electricity sector governance, where DISCOMs experience higher aggregate technical and commercial (AT&C) losses. (See *Table 5-1*).

After passing the 2003 Electricity Act, India has unbundled part of its power sector by allowing IPPs to participate in the generation of electricity. However, transmission and distribution companies still continue to be owned by respective state governments. Currently one of the major challenges to the power sector in India are the shortcomings of these companies. Recently they account as the major recipient of the total government subsidies allocated for the power sector as form of bailouts for selling electricity at below market rates (IISD 2018). This is caused by under-recoveries and delays in disbursements to generation companies. This has also been recently highlighted by Sumant Sinha, CEO of ReNew Power Ltd., India's leading solar power generator. According to Sinha, state-owned DISCOM's failure to make timely payments in Andhra Pradesh has posed one of the main challenges to both attracting and making profitable investments in the state. DISCOMs have periodically curtailed its public procurement and have increasingly put pressure on the company to renegotiate supply contracts. This raises questions from lenders and developers with regards to certainty of payback and also reduces the credit profile of the DISCOMs. Additionally, despite accounting for about a 10th of India's renewable energy capacity, Sumant claims that the state of Andhra Pradesh still owes renewable power generators USD 353.5 million (around € 316.3 million) (Sudarshan 2019).

Another example would be Jharkhand. Although the state is one of the richest in terms of mineral availability, access to electricity is very low. DISCOMs have failed to "curb power theft and improve billing and collection efficiency. They fail to send electricity bills to households on time, let alone actually collect the money." Without additional revenue, DISCOMs simply lack adequate resources to make improvements. However, raising the electricity tariff is politically unpopular and even then, it would not address the problem unless billing and collection efficiency is increased (Urpelainen 2019).

Table 5-1 Variability across the selected Indian states

	Karnataka	**Tamil Nadu**	**Maharashtra**	**Chhattisgarh**	**Bihar**	**Jharkhand**
PI (*Table 4-2*)	1.41	1.55	0.75	1.72	-0.73	-0.26
Installed capacity (in MW)	7278	3916	1802	231	152	38
2022 target allocation by GOI (in MW)	5697	8884	11926	1783	2493	1995
Average capacity factor	20%	19.5%	19%	19%	18%	18.5%
Land availability (in sq.km)	4700	3500	20400	Not available	750	1500
GSDP/capita (€ current price 2018-2019)	2535	2329	2305	1165	527	914
Capital costs (in €/MW)	408 654	402 644	314 904	540 865	531 466	728 185

	Karnataka	Tamil Nadu	Maharashtra	Chhattisgarh	Bihar	Jharkhand
O&M cost (% of capital cost)	1.32%	1.40%	2.29%	1.56%	1.67%	1.95%
Cost of coal power generation	High	High	Very high	Very low	High	Low
AT&C losses	16%	18%	19%	18%	33%	36%

Source: Deshmukh et al 2019, p 6; MNRE 2020b (last accessed in May 30, 2020), energysector.in (2018), KERC 2019, TNERC, 2019, MERC 2019, CERC 2019, BERC 2018, JERC 2016, IREDA 2020, ESOPB and CSO 2020

5.2 Under what conditions can solar power in these states be profitable without government support?

At the moment, government support is essential for profitability of solar power in all of the six states with, **capital subsidies** being more important than **tax breaks**. If these subsidies were removed, tax breaks alone would not make solar power profitable in any of the six states (*Table 4-4*). On the other hand, without tax breaks, subsidies needed to ensure profitability would increase from the current 16-48% to 25-57%.

So, the question is- can non-policy factors evolve in such a way that the subsidies are no longer necessary? The non-policy factors shown on *Figure 15* have different effects on profitability. The findings of this study show that of the economic factors: the electricity tariff and the capital cost have the strongest effects, whereas the financial parameters (within the realistic ranges of their variation) have a relatively weak effect.

In order to make solar power profitable in all states without government subsidies, **the electricity tariff** would need to increase from current 0.03€/kWh (all-India level) to 0.04-0.06€/kWh. If it declines to 0.02€/kWh, solar PV will not be profitable across all the six states even with the existing subsidies and tax benefits. Are such increases or decreases in the tariffs likely? The all-India electricity tariff has stayed at 0.03€/kWh for the last 3 years and probably will remain the same for some time, as solar power has already reached grid parity in India. Indian solar auction history shows that as solar power became cheaper over the years, the electricity tariff at which IPPs were willing to sell power to the DISCOMs have significantly declined. While this means solar power at 0.03€/kWh in some states can compete with coal power sold at 0.04€/kWh, solar investments are less profitable or even unprofitable in others. A significant increase in the tariff prices are therefore not likely.

This paper establishes that **capital costs,** are strongly affected by module prices. Using Karnataka's benchmark, the study assumed that module prices account for 53% of the capital cost in all states[5]. If these costs decline, the profitability of solar power, all other things being equal, will increase. More specifically, if solar PV module price decreases by 10-15% annually (as in the last decade), and all-India electricity tariff remain at 0.03€/kWh, solar investments in the examined states would be profitable, at the latest by 2028 without government support. However, the rate of cost decline in the future may not be as fast as in the past. Should module prices decline by 3% annually during the next decade (as projected by BNEF 2019), only investments in Maharashtra would be profitable by 2030 without any government support. Moreover, should electricity tariff fall to 0.02€/kWh investments would require higher subsidies to be paid over for a longer time period. Therefore, as appealing as it may sound to say that solar is profitable in India because of decline in module price, one can see that they would not be favourable under lower electricity tariff.

Finally, with regards to **financial parameters**, it was found that cost of debt accounts for the largest share in the WACC required to fund the project as has been highlighted in the majority of the existing literature (Prakash 2018, Shrimali et al 2013, etc). Should the electricity tariff remain at 0.03€/kWh, WACC must fall from the current 8-12% to at least 4% in the best performing state (Maharashtra) for solar power investments to break even without government subsidies (See Table 4-8). However, this decline in WACC is unlikely, because it would mean that loans have to be given at very low or even negative interest rates in order to meet the required rate of equity.

Table 5-2 Change in non-policy factors that can make utility-scale solar power profitable without government subsidies

Factors	Needed change	Likelihood of this change
Electricity tariff	To 0.04€/kWh – 0.06€/kWh from current 0.03€/kWh (all India)	Unlikely, because the tariffs have not changed over last 3 years and has never increased during the last 10 years
Solar module prices	Decline by at least 3% per year (If tariffs are lower, higher decline is needed)	Likely by 2030 according to BNFL projections or earlier if past rates are maintained
WACC	Range between -6% in Bihar to 4% in Maharashtra	Unlikely, because then loans have to be given at very low or even negative interest rates

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[5] It must be borne in mind that states where transportation, land or even labour charges are higher this may vary. However, as a rule of thumb, module prices in general account for around 50% of the capital costs in solar power projects.

5.3 In light of the existing profitability of solar PV and government spending required, are India's 2030 solar targets feasible?

Jewell and Cherp (2020) argue that the feasibility of energy transitions depends on the capacities of key actors to bear the relevant costs. In this thesis, I focus on several major actors: solar project developers, DISCOMS, and the federal government. For the energy transition to be feasible, it should not incur unbearable costs for any of these actors. For solar project developers, it means that their investments should be profitable, DISCOMS should be economically solvent and the government should not bear an excessive burden of subsidies[6].

My findings show that at the moment the first condition (the profitability of solar investment) is not universally met across all the examined Indian states, however it may be met in the future if the prices of solar module further decline. However, even when investments in solar power are nominally profitable, they still involve significant risks related to potential market and policy changes. Once the bids are completed and the IPP has agreed to sell electricity at a given price for a given period of time, profits become highly sensitive to the capital cost and even operation and maintenance charges. In this regard, adopting newer policies for instance imposing a custom duty, increases costs and decreases the proportion of expected return of the developers. In fact, developers have claimed module prices even increased intermittently for short durations even though it falls in the long run (The Hindu 2018). Rahul Munjal, Managing Director of Hero Future Energies in an interview, explained as most of the solar module manufacturing is located in China, this happens only when short term demand increases (for instance companies from Europe, US and China want solar modules at the same time) but these are correctable by adjusting delivery dates (Munjal et al 2018). This further implies any changes in policies, techno-economic developments or financial parameters after PPA has been signed will significantly affect profitability.

The second and most significant part of the investment risk arises because of the current ineptitude of the DISCOMs: developers constantly run into the risk of not being paid in time or not being paid at all. Because of this some states like Tamil Nadu never had a state solar auction beyond 2017 (*See Appendix 2: Auction Data*). Although the state distribution company was recently under discussion to float a 500 MW tender for an approximate 0.03 €/kWh price ceiling (Rajan 2020). In general, India has witnessed a shift from state-based auctions to federal auctions (inferred from *Appendix 2: Auction Data* and IRENA 2017, p 64). Electricity tariffs arrived to in state-based auctions are generally higher and hence attractive than those centrally tendered by SECI or NTPC. However, the latter provide lower risks. Moreover, due to falling electricity tariff, and imposition of the safeguard duty and fluctuating interest rates in 2019 auctions went without participation, deadlines were extended, tenders remained under-subscribed, and tenders were even cancelled after the bidding process (Chandrasekaran 2019a). Developers claimed that the price ceilings set by the government were too low and not promising for investments while the government has shunned such arguments saying, "If developers feel the upper cap is not viable, they should stay away from bidding" (Chandrasekaran 2018). Others claimed that "the safeguard duty imposed neither decreased

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[6] Although it should be borne in mind that feasibility would also depend on the concrete socio-technical context of Indian states, this aspect is outside of the scope of the current thesis.

imports nor increased manufacturing. It simply increased the cost of solar power production" (Rathi 2019, Parikh 2020). This signals the second constraint to feasibility: insufficient capacity of DISCOMs and threats to their financial solvency. Between 2014-2018, the Indian government spent more than €62 billions on bailing out insolvent DISCOMs (inferred from accompanying spreadsheet in IISD 2018), and even though their financial problems were not entirely related to solar power, the institution in such dire financial straits cannot be relied on in reliably reimbursing tariffs to solar power to IPPs.

The final constraint to feasibility is the size of required subsidies. The Indian federal government between 2014-2018 has spent around €4 billion for utility scale solar power in different form of subsidies. This was 51% of what it spent on coal, 10% on what it spent on oil and gas and 7% of what it spent on developing and bailing out DISCOMs (inferred from IISD 2018). In *Figure 14*, one can find that going by different state parameters, if modules decline by 3% ca per year and electricity tariff remain at 0.03€/kWh, in order for returns to at least breakeven government spending required would be between €4.5 billion (MH parameters) and €32.6 billion (BI parameters) for utility scale solar. Therefore, if India follows the trajectory of the leading states - Karnataka, Tamil Nadu and Maharashtra – where capital cost is low, solar is already seen as profitable, government spending is comparable and even lower to that in the past. However, achieving the targets under the conditions of Chhattisgarh and Bihar or even Jharkhand for that matter would require four times higher subsidies, as compared to Maharashtra. Moreover, under all these conditions, returns to investments would only breakeven. In reality investors and developers venture on projects where investments are multiplied. This would therefore require higher subsidies or a comparable form of government support or even faster decline in module prices and stable electricity tariff and financial parameters. However, solar developers are already witnessing fluctuating interest rates and higher module costs due to the imposition of a safeguard duty which has thereby resulted in slowing down of yearly capacity additions (Rathi 2019).

Finally, the scale of the government expenditure which may be required to meet India's 2030 targets must be considered in the relation to the government's commitment to solar power, which was originally motivated by political, rather than economic considerations. Historically, the Modi government has embraced solar as its flagship climate strategy. The government's motivation for solar power has been aligned to its domestic and foreign policy. This was visible in how the country was able to bring about a dramatic growth in solar energy even when solar was not cheaper than conventional power sources (Shidore and Busby 2019). According to the authors the government made a deliberate choice of supporting more expensive solar power instead of increasing the use of under-utilised and cheaper coal power plants. In 2014-2017, a fifth of the coal power plants remained under-utilised, which accounted for a 38 GW of unused generation. If utilised fully, this would have generated more electricity than the entire 100 GW solar target slated to be achieved by 2022. In short, political motivation above all led to the dramatic growth of solar energy in India during the initial years. GOI even today routinely sets targets and prioritises solar growth to meet its goals. Some state governments have also followed suit. Recently Gujarat and Chhattisgarh have decided not to build new coal power plants other than the ones already under construction, in order to follow the country's renewable target. The Chhattisgarh government has decided that any excess demand in the state will now be addressed by adding solar (Rathi and Singh 2019). However, even though share of solar in the energy mix will rise, it is unlikely to be the largest in these states. (Parikh 2019b). The political commitment made at the initial stages of solar power introduction in India would increase the feasibility of achieving the 2030 targets. However, it should be kept in mind that sustaining such a commitment would become increasingly difficult if the financial burdens of subsidising solar power do not come down. So far, the GOI supported only a minor fraction of the solar capacity that is projected to be constructed by 2030. Unless the need for subsidies significantly decreases, the financial burden may jeopardise the feasibility of this long-term target.

6 Conclusions

This final chapter is divided into three sections. Section 1 summarizes the key findings of this research by answering the three research questions succinctly. Based on the findings, recommendations are offered to two field of practitioners – policymakers in Section 2 and academia in Section 3.

6.1 Key findings

The aim of this thesis has been to contribute to assessing the feasibility of reaching India's solar power targets by answering three questions- (i) What is the profitability of utility scale solar power projects in selected Indian states and what explains its variations, if any? (ii) Under what conditions can utility scale solar power in these states be profitable without government support? (iii) In light of the existing profitability of solar PV and government spending required, are India's 2030 solar targets feasible?

To this end, this thesis conducts a discounted cashflow analysis and assesses profitability using concepts like Internal Rate of Return, Discounted Payback Period and Profitability Index. With regards to the first question, it finds that profitability of utility scale solar power projects varies across Indian states (PI ranging between -0.86 in Bihar to 1.43 in Chhattisgarh). This variability reflects differences in availability of resources, capital costs, competitiveness with conventional sources of electricity and power sector governance, mainly in terms of efficiency of transmission and distribution companies. Thereafter, profitability is calculated, and its sensitivity tested against a group of key factors: electricity tariff, availability of subsidies and tax benefits in the form of accelerated depreciation, changing capital cost due to change in module prices and change in the WACC required to finance projects. The findings show that profitability is most sensitive to change in the electricity tariff. The findings also suggest that between the two types of policy instruments tested, capital subsidies are more effective in increasing profitability than tax benefits in the form of accelerated depreciation. Finally, it was seen that profitability is sensitive to capital costs. With regards to the financial parameters, it was seen that more relaxed financing conditions especially in terms of lower interest rates and longer terms for loan repayment increase the profitability of solar investments. However, within realistic ranges the impact of change in cost of debt or tax rates on profitability were not very strong. Finally, the thesis finds that once IPPs have entered into a PPA, profitability would become sensitive to risks arising from change in capital costs and operation and maintenance charges, financial parameters and ineptitudes of the DISCOMs.

With regards to the second question, the results suggest that if capital cost declines by 34% until 2030 (as forecasted by BNEF 2019) and the electricity tariff stays at 0.03 €/kWh under the same financial parameters, solar projects in Maharashtra will not require government subsidy beyond 2028, Tamil Nadu by 2032 and Karnataka by 2033. While investments in Chhattisgarh and Bihar would still need more than 30% of subsidy to breakeven in 2033. Jharkhand has not been included in this analysis as its tariff order document was last updated in 2016 and the data pertaining to the capital cost was found to be not reflective of the current market trends.

With regards to the third question, the thesis finds that currently there are constraints to feasibility from the perspective of the three key actors - solar project developers, DISCOMS and the federal government. In order to ensure feasibility these key actors must necessarily have the capacities to bear the relevant costs towards the required transition. For solar project developers, it is seen that profitability of solar investment is not universally met across all the examined Indian states, but it may be met in the future if the prices of solar module further decline. However, even when investments in solar power are nominally profitable, they still involve significant risks related to techno-economic, financial and policy changes especially after PPA has been signed. For DISCOMs, it is seen that their continued ineptitude and thereby threats to financial solvency not only require heavy bailouts from the government but also impact developers and the health of financial institutions in the country by increasing the risk of investments. Finally, for the federal government, the findings indicate that size of required government spending depends on which state/s undergo the bulk of solar installations. In this regard, the thesis finds that the range for total subsidies required based on different state parameters is significant - ranging from €4.5 billion in Maharashtra and €32.6 billion in Bihar. While it is seen, historically, GOI's commitment to solar power was motivated by political pursuits rather than economic considerations, it must be borne in mind that past installations constitute only a minor fraction of the solar capacity that is projected to be constructed by 2030. Therefore, sustaining long-term commitments would become increasingly difficult if the financial burdens of subsidising solar power do not come down.

6.2 Recommendations to policymakers

Should political motivation continue to be the most significant driver for solar expansion in India, policies adopted, and their designs are likely to play the most crucial role to drive India's low-carbon transition. In this regard, this thesis offers the following recommendations.

For starters, the government must provide more clarity on its solar targets. This would entail prescribing a clear and stable roadmap with regards to stating year-wise solar targets beyond 2022 while making state-wise allocations, which are congruous with existing characteristics and capacities of the respective states. This would increase visibility from the investors point of view and provide more clarity on the size of the market and the demand to be met. Second and most crucial would be to reform the power sector in a way to enhance the efficiency of transmission and distribution companies especially with regards to increase efficiency of collection of bills and PPA negotiations. Currently there are around 100 million people without access to electricity. Electrifying these households by increasing affordability and will likely to increase demand. Uncertainty of tax and interest rates must also be protected especially for developers who have entered a PPA.

And finally, policies should be disentangled to provide better clarity to all developers in terms of benefits available. For example, the study found that with regards to the two types of policy instruments studied, profitability is most sensitive to direct capital subsidy. Therefore, investments in states would be profitable with different magnitude of direct subsidies even without any tax benefits but not otherwise. However, from the government's perspective, accelerated depreciation is preferred as it reduces public spending and does not change total tax revenue from the project. For states already having low capital costs shifting from capital subsidies to accelerated depreciation may be economically viable for the government and the developer. However, investments would not be profitable without capital subsidies in states exposed to higher capital costs. Therefore, policies should be designed in a way which is congruous with existing characteristics and capacities of the respective states and are not universal.

6.3 Broader implications, limitations and recommendations for future research

The main contributions of the study has been to (i) show that merely looking at generation costs or LCOE may not be sufficient to analyse economic viability of solar power; (ii) the empirical demonstration that profitability of solar power varies greatly across Indian states and is not universally conductive to investments; and (iii) identification of the role of different factors and their evolution, in particular wholesale electricity prices, capital costs and government subsidies on this profitability of solar power in the future in India.

The findings of this thesis highlights that merely looking at generation costs or LCOE may not be sufficient to analyse economic viability of solar power and that profitability of investments also plays a role. However, more should be done to understand the profitability of solar PV now and in the future and more broadly the feasibility of India's solar targets. Although my research contributes to understanding the profitability of utility-scale solar it is essential to also include solar rooftop in future studies especially because it accounts to 40% of India's solar target and so far, only 0.05% of its 2022 short-term goals have been achieved. Equally, the economic viability of off-grid solar power should be evaluated. Another limitation of this analysis is that it only looks at two policy instruments. A further comprehensive analysis must include to the effect of renewable purchase obligations and more importantly, renewable energy certificates, in order to include wheeling and bankability benefits enjoyed by the developers. Finally, despite careful selection, six states may not be representative of all of India. Careful analysis of all states and union territories will provide greater clarity.

To evaluate more broader aspects of feasibility, I consider it important to examine the operation of the state transmissions and distribution companies (DISCOMs) as well as political processes in the federal government that affect its commitment to solar power. It is also important to identify and examine socio-technical aspects of feasibility of rapid and massive solar power deployment such as land availability and land-related conflicts, broader social acceptability and the presence of the necessary technical innovation potential.

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Appendix 1: Data sources

Table 1 Selected Indian states

States	Total installed capacity (in MW)	Population representation (in %)	Area representation (in %)
Karnataka	7278	5.05	5.83
Tamil Nadu	3916	5.96	3.96
Maharashtra	1802	9.28	9.36
Chhattisgarh	231	2.11	4.11
Bihar	152	8.6	2.86
Jharkhand	38	2.73	2.42

Table 2 SBI 1-year MCLR

Year	MCLR
January 2019	8.55%
February 2019	8.55%
March 2019	8.55%
April 2019	8.50%
May 2019	8.45%
June 2019	8.45%
July 2019	8.40%
August 2019	8.25%
September 2019	8.15%
October 2019	8.05%
November 2019	8%
December 2019	7.90%
January 2019	7.90%
1 year avg for 100 SBI basic points	8.28%

Source: SBI 2020

Appendix 2: Auction Data

The first 50 auction data were compiled from Thapar et al 2018 (1-27) and Bose and Sarkar et al 2019 (28-49). The remaining 8 were updated from (Chandrasekaran 2019a, Saurabh 2019, Chandrasekaran 2019b, Prateek 2019a, Prateek 2019c, Bajaj 2019, Prateek 2019b)

	Year	Month	State	Tender issuing agency	Capacity (MW)	Winning developer	Alloted capacity (MW)	Minimum tariff (INR/kWh)
1	2014	April	Chhattisgarh	State	100	NA	100	6,44
2	2014	August	Karnataka	State	500	NA	500	6,71
3	2014	September	Telengana	State	500	NA	500	6,45
4	2014	October	Andhra Pradesh	State	500	NA	500	5,25
5	2015	July	Madhya Pradesh	State	300	NA	300	5,05
6	2015	August	Telengana	State	2000	NA	2000	5,17
7	2015	September	Punjab	State	500	NA	500	5,09
8	2015	October	Uttrakhand	State	170	NA	170	5,57
9	2015	December	Andhra Pradesh	Federal	150	NA	150	5,13
10	2015	December	Haryana	State	150	NA	150	5,08
11	2016	January	Rajasthan	Federal	420	NA	420	4,34
12	2016	January	Uttar Pradesh	Federal	100	NA	100	4,78
13	2016	January	Maharastra	Federal	380	NA	380	4,81
14	2016	February	Karnataka	Federal	50	NA	50	4,43
15	2016	March	Andhra Pradesh	Federal	500	NA	500	4,63
16	2016	March	Andhra Pradesh	Federal	350	NA	350	4,63
17	2016	March	Karnataka	State	860	NA	860	4,69
18	2016	March	Jharkhand	State	1200	NA	1200	5,08
19	2016	April	Karnataka	Federal	500	NA	500	4,78
20	2016	June	Maharastra	Federal	450	NA	450	4,41
21	2016	June	Chhattisgarh	Federal	100	NA	100	4,88
22	2016	June	Telengana	State	350	NA	350	4,67
23	2016	July	Gujarat	Federal	225	NA	225	4,96
24	2016	July	Rajasthan	Federal	130	NA	130	4,35
25	2016	August	Odissa	Federal	270	NA	270	4,81
26	2016	August	Uttar Pradesh	Federal	100	NA	100	4,81
27	2016	September	Maharastra	Federal	450	NA	450	4,58
28	2017	February	Madhya Pradesh	Federal and State	750	Mahindra Renewables	250	3,31
						ACME solar	250	3,3
						Solerenergi Power	250	3,3
29	2017	April	Andhra Pradesh	Federal	250	Solairedirect Energy India 250 Pvt. Ltd.	250	3,15
30	2017	May	Rajasthan	Federal	400	Phelam Energy Group	50	2,62
						Avaada Power	100	2,62
						SBG Cleantech	100	2,63
31	2017	May	Rajasthan	Federal	500	Avaada Power	200	2,44
						SBG Cleantech	300	2,45
32	2017	September	Tamil Nadu	State	1500	Rassi Green Earth Enenrgy	100	3,47
						NLC	709	3,47
33	2017	September	Gujarat	State	500	GRT Jewellers Pvt. Ltd	90	2,65
						Gujarat State Electricity corp	75	2,66
						Gujarat Industries power	75	2,67
						Azure Power	260	2,67
34	2017 (Cancelled)	October	All India	Federal	250	Azure Power	250	3,14
35	2018	February	Karnataka	State	191	ACME solar	20	2,94
						Asian Fab tec	20	3,24
						Ekialde	20	3,15
						Emmvee	20	3,52
						Greenko	20	3,3
						Max Planck Solar Farms	15	3,12
						Rays Power Infra	15	3,16
						ReNew Power	2	3,15

						Shapoorji Pallonji	20	2,94
						Svarog Global	20	3,54
						TEP Rooftop Solar	19	3,04
36	2018	March	Karnatka	State	550	ReNew Power	300	2,91
						Avaada Power	150	2,92
						Azure Power	100	2,93
37	2018 (Cancelled)	April	Gujarat	State	500	Kalthia Engineering and Construction	50	2.93
38	2018	May	Andhra Pradesh	Federal and State	750	Sprng Energy Pvt Ltd	250	2.72
						Ayana Renewable Power	250	2.73
						SB Energy Solar	250	2.73
39	2018	May	Maharastra	State	1000	JLTM Energy India	200	2.71
						Mahoba Solar	250	2.71
						ReNew Power	250	2.72
						ACME solar	250	2.72
						Tata Power REL	150	2.72
40	2018	June	Assam	State	100	Azure Power	75	3.37
						Maheswari Mining and Energy Pvt. Ltd	10	3.37
41	2018	June	Uttar Pradesh	Federal	275	ACME solar	75	3.32
42	2018	July	Uttar Pradesh	State	1000	ACME solar	150	3.48
						Adani	250	3.55
						ACME solar	150	3.55
						Azure Power	160	2.44
43	2018	July	All India	Federal	2000	ACME solar	250	2.44
						Shapoorji Pallnji Group	250	2.52
						Hero Future Energies	250	2.53
						Mahindra Susten	250	2.53
						Azure Power	600	2.53
						Adani	50	2.54
44	2018	July	Andhra Predesh	Federal	750	SB Energy Solar	250	2.70
						Sprng Energy Pvt Ltd	250	2.70
						Ayana Renewable Power	250	2.71
45	2018	July	All India	Federal	3000	ACME solar	600	2.44
						Azure Power	300	2.64
						Rutherford Soalr Farms	200	2.70
						Renew Power	500	2.71
						SB Energy Solar	1100	2.71
						Adani	300	2.71
46	2018	August	Odisha	State	200	Aditya Birla Renewables	75	2.79
						Eden Renewable	50	3.19
						Sukhbir Agro	25	3.19
						Gupta Power	20	3.19
						ACME solar	30	3.20
47	2018	August	Andhra Pradesh	Federal	2000	ACME solar	600	2.59
48	2018	September	Gujarat	State	500	Avaada Power	300	2.44
						Aditya Birla Renewables	100	2.44
						Azure Power	100	2.45
49	2018	November	Uttar Pradesh	Federal	150	Shapoorji Pallnji Group	50	3.29
50	2018 (Wind and solar hybrid)	December	All India	Federal	1200	SB ENergy	450	2.67
						Adani Green Enenrgy	390	2.69
51	2019	January	Gujarat	State	500	UPC Energy Group	50	2.55
						Adani Green Enenrgy	150	2.67
						ReNew Power	105	2.68
						Orange Renewables	120	2.67

						Gujarat State Electricity corp	75	2.67
51	2019	February	Rajasthan	Federal	750	Fortum	250	2.48
						AcME solar	250	2.44
						UPC Renewables	250	2.48
						ReNew Power	110	2.49
						Indian conglomerate	40	2.48
52	2019	February	All India	Federal	1200	ReNew Power	300	2.55
						Azure Power	300	2.58
						Eden Renewable	300	2.60
						SB ENergy	300	2.61
53	2019	May	Maharastra	Federal	250	NTPC	100	2.91
						Tata Power REL	100	2.88
						Solar Arise	50	2.87
54	2019	May	Gujarat	State	700	Engie	200	2.65
						Tata Power REL	100	2.70
						Gujarat Industries power	100	2.68
						Gujarat State Electricity corp	100	2.68
55	2019	June	All India	Federal	1200	Ayana Renewable Power	300	2.54
						ReNew Power	300	2.54
						Azure Power	300	2.54
						Avaada Power	50	2.65
						Mahindra Susten	250	2.54
56	2019	September	All India	Federal	1200	ReNew Power	300	2.71
						Avaada Power	300	2.71
						UPC Renewables	300	2.71
						Tata Power REL	60	2.72
57	2020	February	All India	Federal	1200	SB ENergy	600	2.50
						eden Renewable	300	2.50
						AMP Energy	100	2.50
						Renew Power	200	2.51

Appendix 3: Results and analysis (extended)

Table 1 Profitability under (a) different policy combinations but with 0.03 EUR/kwh electricity tariff and (b) at best case scenario but lower electricity tariff

	(a) Current tariff (0.03 €/kWh)												(b) Lower tariff (0.02 €/kWh)		
	30% CS			**60% AD**			**60% AD and 5-year avg CS for each state**			**30% CS and 60% AD**			**30% CS and 60% AD**		
	IRR	**DPBP**	**PI**	**IRR**	**DPBP**	**PI**	**IRR**	**DPBP**	**PI**	**IRR**	**DPBP**	**PI**	**IRR**	**DPBP**	**PI**
KN	12%	< 25 years	1.01	5%	-	0.36	6%	-	0.49	17%	< 14 years	1.42	2%	-	0.22
TN	10%	< 24 years	1.04	5%	-	0.41	7%	-	0.65	15%	< 14 years	1.57	1%	-	0.19
MH	13%	< 17 years	1.27	5%	-	0.50	7%	-	0.71	20%	< 10 years	1.69	-3%	-	0.12
CH	1%	-	-0.09	-5%	-	-0.45	-5%	-	-0.38	2%	-	0.32	*	-	-0.64
BI	-2%	-	-0.28	-8%	-	-0.62	-8%	-	-0.56	-2%	-	0.15	*	-	-0.82

*too many annual negative returns