A study on Solar PV and Wind energy diffusion in India and China

Barrier analysis using Interpretive Structural Modelling (ISM) method

Abhishek Dhawale

TU Delft

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I would like to dedicate this thesis to my loving parents . . .

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this thesis are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This thesis is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements.

Abhishek A. Dhawale (4729528)
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The past nine months have proven to the steepest section of my learning curve yet. This thesis has taught me a lot personally, professionally and, of course, academically. I believe it would have been bigger mountain to conquer had I not had the constant support and guidance of a few very important people.

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Thank you.

Abhishek Dhawale

Abstract

During the Paris Agreement of 2015, 195 UNFCCC members pledged to improve the global response to climate change by reducing the carbon emissions and contributing to keeping the average global temperature increase well below 2° above the preindustrial levels. The whole world is gradually shifting towards renewable resources but this transition to non-conventional energy sources looks very slow compared to what is required to prevent the extreme effects of global warming.

In this thesis, we aim to identify and analyze the barriers to diffusion of Solar PV and Wind energy in India and China, using interpretive structural analysis (ISM) method, so that we can propose solutions and policy recommendations to further accelerate the diffusion of these technologies. We chose solar PV and wind energy as our focus of study due to the fact that they are the most widespread sources of renewable energy and show the most potential. Countries that have shown tremendous promise, out of some of the largest solar and wind energy producers, are India and China. Both these countries have shown astonishing growth rates and boast of huge world shares in 2017 for the cumulative installed Solar PV. The total installed wind energy capacities for India and China till 2017 are also very large. Even though these growth rates look very large and are a promising start towards the complete shift to renewable energy, they are still not adequate to reduce the global carbon emissions levels fast enough to keep the average temperature change to 1.5°C.

Therefore, we need to find out what were the obstacles in their growth in these two countries. We found that the most commonly cited issues in the literature were lack of supporting policies, lack of consumer awareness, lack of trained, skilled personnel and, inadequate market infrastructure, among many others that have been studied during the course of this thesis. We finalized 15 barriers for each country, though a comprehensive literature study, based on the number of times they were cited by researchers. Now, we needed a methodology that would help us map the interrelations of these barriers and show us which barriers were the most important and should be tackled first. After a thorough survey of suitable methodologies, ISM was decided as the most suitable due to its ease of use, applicability across various domains, ability to handle complex system interrelations

and hierarchical presentation of results. It gives us the barriers segregated in multiple levels according to their order of importance and also maps the direction of influence among them.

After the implementation of the methodology to the 15 chosen barriers, we got a hierarchical digraph showing us the most important barriers in the bottom-most level. We found consumer awareness, lack of relevant policy and absence of trained personnel & research/educational institutes as the most vital points of failure. Lack of market infrastructure, local resources and, data & information along with bureaucratic procedures were found as some other very important problems that needed to be solved. The barriers were also ranked on the basis of their driving and dependence powers to obtain an absolute ranking even within the levels. We also conducted a sensitivity analysis where uncertain barrier relationships were changed to observe the effect on the hierarchy and the system as a whole. It was found that the barriers only jump one level up or down which shows that the system is not very sensitive to changes in barrier relationships. After this, limitations and shortcomings of this study have been discussed in detail.

Solutions are then proposed to solve these barriers as additional policy requirements, knowledge diffusion campaigns, pilot project schemes and other methods which best tackle the specific barrier. To tackle lack of supporting policy, for example, we suggest clarification of policies at the center to demarcate agency roles and project sanctioning procedures, mandatory grid connection policies to prevent power dumping and increase investor's sense of security, and giving incentives to local manufacturing to decrease reliance on imports. Lack of consumer awareness can be tackled by conducting hands-on workshops, community pilot projects to demonstrate benefits and promoting microfinance schemes for small-scale and domestic RE projects. We then go on to provide solutions for all the barriers, for both the countries, in the order importance based on the rankings. Some solutions alleviate other barriers automatically and have been explicitly tied with the problems they help counter.

We predict that if all these proposed policy solutions are implemented, the solar PV and wind industries in India and China could grow at significantly higher rates. To conclude, we answer the research questions posed in the introduction chapter and then propose a few recommendations for further research in this direction.

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Chapter 1

Introduction

This past decade has seen an extraordinary increase in the energy capacity coming from renewable resources. This is mainly due to the rising planet-wide concerns like environmental pollution, ecological degradation, species extinction, global warming and climate change effects. The whole world is gradually shifting towards renewable resources but this transition to non-conventional energy sources has been proven to be very slow compared to what is required to prevent the extreme effects of climate change. During the Paris Agreement of 2015, the member countries set individual goals for the reduction in carbon emissions from various sectors like land use, ocean and coastal zones, water use, transportation, human settlement, energy and industry. The 195 UNFCCC members that have signed the agreement aim to improve the global response to climate change by reducing the carbon emissions and contributing to keeping the average global temperature increase well below 2°C above the pre-industrial levels (UNFCCC, 2015).

Energy is necessary for almost every human activity and therefore, should be accounted as an integral part of the effort to reduce global emissions. The energy sector accounts for more than two-thirds of global greenhouse gas emissions (UNFCCC, 2018). Globally, we need more and more energy everyday as the standard of living increases, more people are connected to the grid and, industries shift towards electricity due to automation of their processes; and this electricity needs to come from cleaner, non-polluting sources. This justifies the urgency of a transition towards renewable energy. According to the Bloomberg NEF (2018)'s New Energy Outlook 2018, the global population is projected to increase from 7.3 billion in 2017 to 9.7 billion by 2050 and the electricity demand, from 25,000TWh to 38,700TWh. Renewables (excluding hydropower) currently provide 8.4% of world's electricity generation and have contributed almost 50% of the growth in global power generation in 2017 (BP, 2018). This percentage share needs to increase drastically if we even hope to stay within the 2°C temperature increase.

Among the biggest sources of renewable energy are the solar photovoltaic(PV) and wind energy. Many countries are heavily investing solar PV and wind energy to increase their renewables share in the annual energy consumption. The countries that have shown tremendous promise, out of some of the largest solar and wind energy producers, are India and China. They are the fastest growing economies in Asia and also probably around the world. They have a comparable population and human development indices (UNDP, 2017), but they are still very different in their approach towards the renewable energy and carbon emission reduction goals. In the year 2017, India and China have shown astonishing growth rates of 102% and 68%, respectively, and boast of world shares as high as 5% and 33%, respectively, for the cumulative installed Solar PV. The total installed Solar PV capacities for India and China at the end of 2017 are 19GW and 131GW, respectively. Similarly, for wind energy, India and China had 33GW and 164GW of installed capacity, with a world share of 6.4% and 32%, at the end of 2017 (BP, 2018).

1.1 Research motivation

Even though these growth rates look very large and are a promising start towards the complete shift toward renewable energy, will they be enough to reduce the global carbon emissions levels fast enough to keep the average temperature change to below 2°C?

Multiple critics to the Paris Agreement point out that even though so many countries have ratified the Agreement and are required to set a target for emissions reduction, there is no compulsory reduction amount established (Cass, 2017; Clémençon, 2016; Hansen and Wilhite, 2016; Harvey, 2015; Nuccitelli, 2018). According to Climate Action Tracker (2017) and Climate Action Tracker (2018), the current policies and goals are still insufficient to keep the temperature rise within 2°C. They also claim that the Nationally Determined Contributions (NDCs), i.e. the voluntarily decided targets by every country for itself, are underplayed and there are no standard reporting formats to track the progress made by any country (Hansen and Wilhite, 2016). The absence of fixed targets has resulted in irregularities in the RE share in the energy mix of countries. These are some of the biggest critiques to the Paris Agreement goals.

Clearly, there are obstacles that are slowing down the diffusion of solar PV and wind energy in the two countries. The next logical step, therefore, was to identify the factors acting as barriers to the growth of these two technologies at the required rates. A barrier analysis is conducted in this thesis using the Interpretive Structural Modeling (ISM) method, the significance of which is explained elaborately in the methodology literature review.

Solar PV and wind energy have been chosen as the focus of this thesis because among all the renewable sources (excluding hydropower), these two have been proven to possess the highest potential to grow. According to the IEA (2018a) market report on renewables, solar PV leads renewable capacity growth with 575 GW of new capacity by the year 2023, followed by wind energy with 324 GW. Global electricity generation using solar PV was 435TWh in the year 2017, whereas wind energy generated 1085TWh in the same year. Solar PV and wind energy generation is projected to increase substantially under the two scenarios modeled in the IEA (2018c), namely New Policies Scenario(NPS) and Sustainable Development Scenario(SDS), as shown in the table below.

	NPS		SDS	
Year	Solar(GWh)	Wind(GWh)	Solar(GWh)	Wind(GWh)
2025	1463	2304	1940	2707
2030	2191	3157	3268	4355
2040	3840	4690	6403	7730

Table 1.1 Projected global electricity generation from solar PV & wind (IEA, 2018c)

India and China have been chosen for this analysis due to their comparable population, energy demand, and sudden renewable energy growth patterns in the recent past. Both these countries are rapidly developing, extremely climate-relevant and consume huge amounts of energy annually. Their new developments and policy choices have a global impact (IEA, 2019; Urban, 2009).

	China		**India**		**World**
		% world		% world	
Population (millions)	1379	18.6	1324	17.8	7429
GDP (billion 2010 USD)	9505	12.3	2465	3.2	77362
Energy production (Mtoe)	2360	17.1	557	4.0	13764
TPES (Mtoe)	2958	21.5	862	6.3	13761
Electricity consumption (TWh)	5899	25.5	1216	5.3	23107
CO2 emissions (Mt CO2)	9057	28.0	2077	6.4	32316
Solar PV (GWh)	75256	22.9	14130	4.3	328038
Wind (GWh)	237071	24.8	44856	4.7	957694

Table 1.2 Key data for India and China (year 2016) (IEA, 2018b)

They are two of the world's largest carbon emitters but, they also currently own large shares of the world's solar PV and wind energy capacities and these numbers are only growing every year (IEA, 2019). The rapid growth of renewables, specially solar PV and wind energy, in India and China show hope towards achieving the Paris targets. These facts essentially form the motivation behind the choice of the two countries and the two forms of renewable energy that we aim to study.

1.2 Research questions

The main research question for this thesis has been articulated as follows:
How can we resolve the barriers to large-scale diffusion of Solar PV and Wind energy in India and China?

The main research question can be split into the following sub-questions:

1. What is the current status in terms of upcoming government policies & incentives, projected growth rates and 2030 targets in the two countries?

2. What are the barriers against faster diffusion of the two technologies and how are they interrelated (if at all)?

3. How should we proceed to overcome these barriers and which ones should be tackled first so as to achieve maximum impact?

Thus, in this thesis, we aim to identify and analyze the barriers to diffusion of Solar PV and Wind energy in India and China, so that we can propose solutions and policy recommendations to further accelerate the diffusion of these technologies. We plan to use the Interpretive Structural Modeling (ISM) method to study the inter-relations between barriers and finally present a hierarchy among them, so that the most important ones can be solved first.

Answers to the above questions will bring the thesis together to complete the objective. Each of these questions represent individual themes that are needed for the solutions in terms of policy recommendations using a robust ISM analysis.

1.3 Thesis structure

This section will provide a brief outline of the thesis chapters.

Chapter 2 : Current scenario, talks about the present-day conditions in both India and China. This chapter has been divided into subsections tackling various topics like the economic background, energy consumption and requirement, share of renewables in the energy mix (specially solar PV and wind), upcoming projects and commitments, supporting policies and remainder of Paris Agreement targets

Chapter 3 : Barrier identification and segregation, involves finding and identifying relevant barriers from the literature pertaining to the two countries and also other generic literature on the diffusion rates of solar PV and wind energy. Barriers are explained and then the 15 most important of them are selected for analysis.

Chapter 4 : Methodology, explains in detail the steps to be followed to carry a robust ISM analysis and follow it up with a MICMAC analysis to map the barriers on dependence vs. driving force scale. The applications of ISM & MICMAC analysis and the reason why we chose these methods will be explained in this chapter.

Chapter 5 : Barrier analysis, carries out actual analysis on the barriers chosen for each of the two countries and comes up with a hierarchical digraph as a result. Separate subsections are made for the two countries to carry out separate analyses.

Chapter 6 : Proposed solutions, enlists, in descending order of importance, possible solutions to accelerate the diffusion of solar PV and wind energy in both, India and China. Again, separate sections are made for solutions for both the countries.

Chapter 7 : Conclusion and Recommendations, brings the thesis together pointing out key results from the analysis. The research questions are explicitly answered and any shortcomings are pointed out. Recommendations are made for future research.

Chapter 2

Current scenario

We have observed tremendous increases in the global energy consumption and production in the past decade. The primary energy demand is increasing at very high rates along with it the electricity generation and the CO2 emissions (as shown in fig. 2.1). According to IEA (2018c, World Energy Outlook), these values are projected to keep on increasing until 2040 under the assumption of current policies and similar growth trends in all sectors of society.

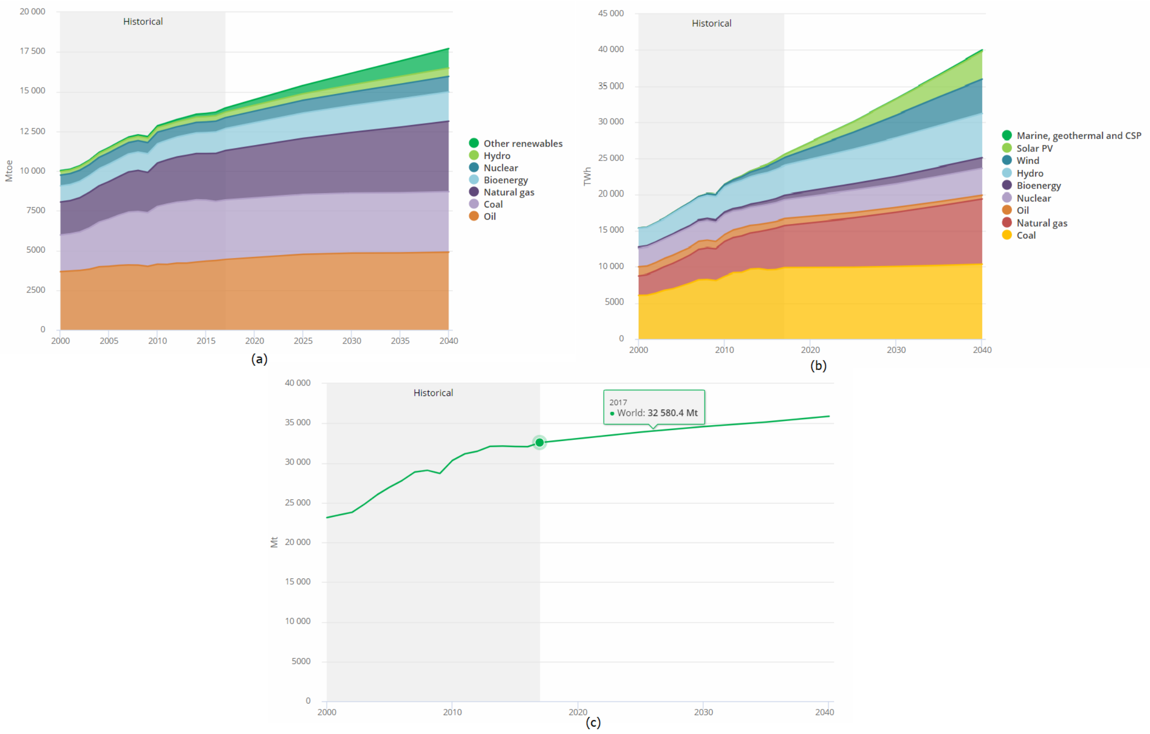

Fig. 2.1 Global trends in (a)Total Primary Energy Demand(TPED), (b)Electricity Generation and, (c) Total CO2 Emissions (IEA, 2018c)

As the world grows increasingly electrified, the shares of renewable energy in the global energy production and consumption are also increasing rapidly. Two Asian countries, namely, India and China, are responsible for the majority of this demand growth due to increasing standards of living and overall prosperity per capita. Figure 2.3 shows the primary energy consumption in the four biggest consumers in the world. Renewables account for 2/3rds of this power generation increase, with their global power share reaching almost 30%. Figure 2.2 depicts the expectations that renewables will become the most significant primary source of energy by 2040, surpassing coal, oil, and natural gas in the power sector (BP, 2019a).

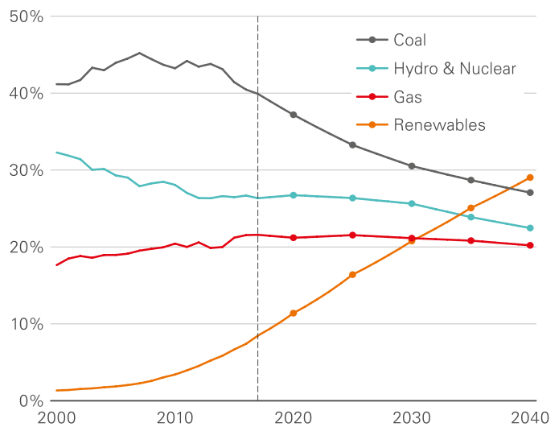

Fig. 2.2 Projected shares of Fuels in the Power Sector (BP, 2019a)

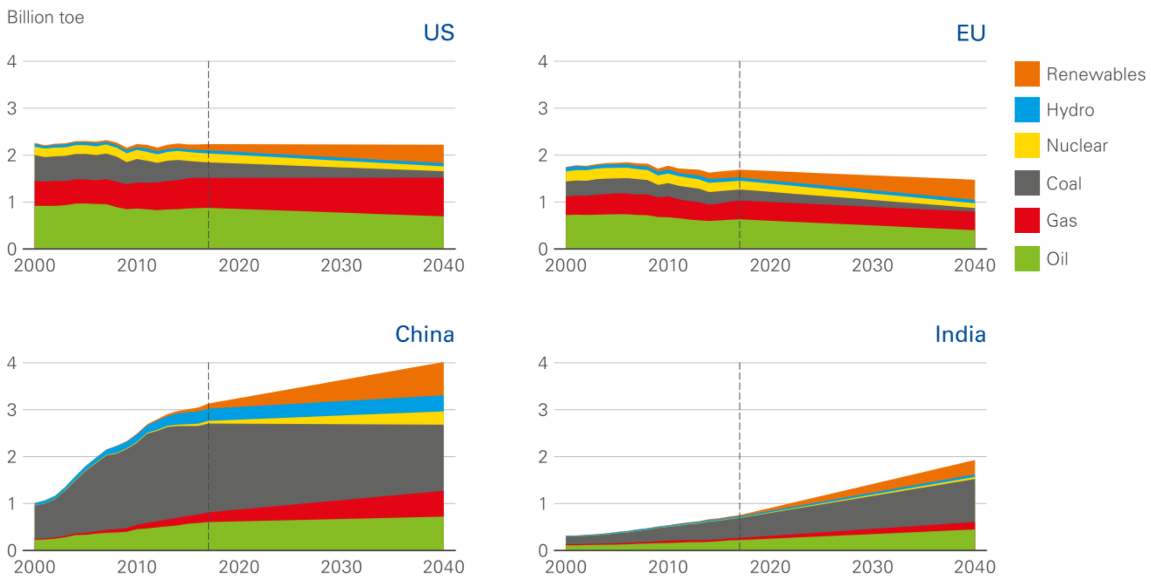

Fig. 2.3 Primary energy consumptions of the four biggest consumers in the world, namely, the US, the EU, India and China (BP, 2019a)

The present-day state of both the countries under study, namely India and China, is rapidly changing and for the better. They are both rapidly developing, globally impacting, climatically relevant and huge economies on their own. They together account for around 40% of the world's share of total installed solar capacity and 39% of the world's installed wind energy capacity in 2018 (BP, 2019b).

2.1 Renewable Energy scenario in India

In India, investment costs for RE projects is rapidly declining due to better financing options, the falling module prices, subsidies and tariff schemes like FIT (feed-in tariff) initiated by the government and private sector stakeholders. The government has also established authoritative bodies, such as the Solar Energy Corporation of India (SECI), the National Institute of Solar Energy (NISE), the National Institute for Wind Energy (NIWE) and the Indian Renewable Energy Development Agency (IREDA). They are delegated different tasks and carry out various functions within the solar and wind industry, such as, negotiating and enforcing PPAs between consumers and producers for the transaction of power and conducting capacity auctions (Aggarwal and Dutt, 2018). Government initiatives like introducing capital subsidies, net metering for domestic rooftop connections, and, waiving off the inter-state transmission costs has proved fruitful in bringing in more investors (Rathore et al., 2018). It is due to initiatives like these that the RE industry in India has seen such rapid growth rates in the recent years (as seen in fig. 2.5). Figure 2.4 shows the share of renewable energy in both, the country's primary energy mix and the electricity generation proportions. This share has also drastically increased in the past years.

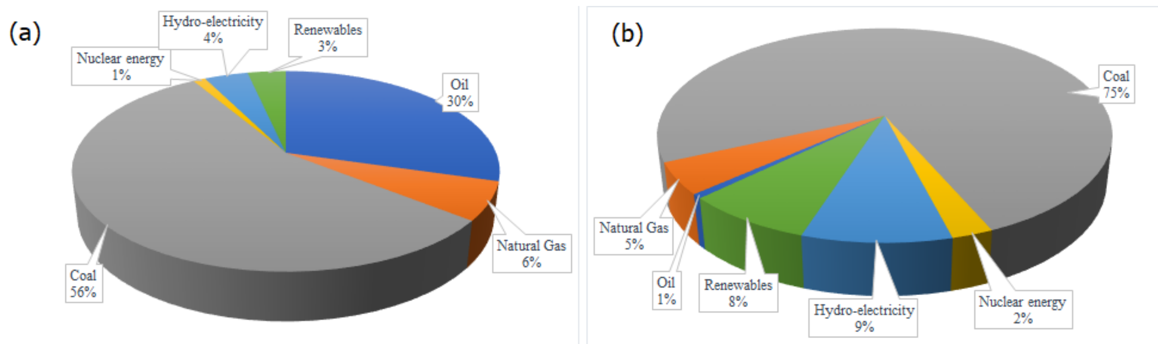

Fig. 2.4 Share of Renewables in (a) primary energy consumption and, (b) electricity generation for India (BP, 2019b)

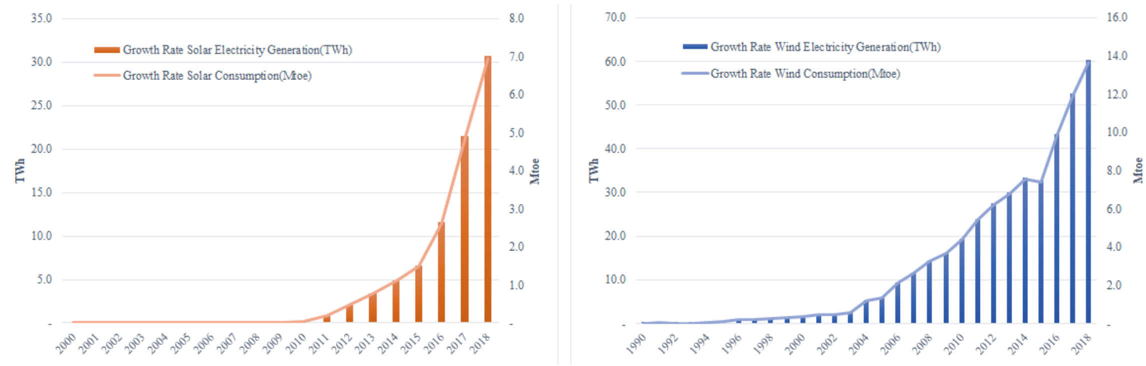

Fig. 2.5 Growth in the Solar and Wind energy industries in the past decades for India (BP, 2019b)

2.1.1 Existing and upcoming policies

The Press Information Bureau of India (PIB) reports have been instrumental in tracking the country's progress in this sector. The Ministry of New and Renewable Energy (MNRE) has been very prompt in reporting its achievements and goals for the future. The following are a few key points to evaluate the current renewable energy scenario in India (PIB; REN21, 2019):

- The private sector is responsible for the implementation of most renewable energy projects. As of 30th of November 2018, 73.95 GW of RE cumulative installed capacity exists, out of which almost 38 GW was added in the last half-decade.

- Government measures such as financial incentives, permitting upto 100% of FDI, capital subsidies, inter-state transmission charge waiver, accelerated depreciation and, viability gap funding (VGF) have proven very useful in promoting the growth of the renewable energy sector. The government has also mandated the grid operators to declare Renewable Purchase Obligations (RPOs) trajectory till the year 2022 and to facilitate the creation of a Green Energy Corridor to improve the grid integration of large-scale RE capacity additions.

- E-reverse auctions have been started to ensure a transparent bidding process and enable distributors to procure competitively priced power. To facilitate this, standard bidding guidelines have been issued to the distributors by the government. During 2018, more than 40 GW of additional large-scale solar power projects were tendered in India. But, the gap between tenders issued and auctions completed has expanded leading to many auctions being canceled retroactively, and several gigawatts of awarded capacity were annulled during the year. This has shown significant impact on the industry in terms of investment insecurity.

- The ‘Kisan Urja Suraksha evam Utthaan Mahabhiyan (KUSUM)’ scheme is being formulated by the government to encourage the farmers towards the usage of solar energy. The details of this scheme are unclear, because it is still under consideration by the government, but it is supposed to include provisions like-
  - setting up small-scale (500 KW - 2 MW) grid-connected rural solar power plants,
  - installing standalone solar water pumps to facilitate easier irrigation,
  - solarization of existing water pumps to make them grid independent and help them earn some extra income by selling off the surplus power to the grid operators.
- The government is also set to achieve 2.1 GW of rooftop solar capacity in the institutional, social, residential and governmental sector by 2020. As of 31st January 2019, almost 1.3 GW of grid-connected rooftop solar PV has already been installed according to the MNRE’s online portal. The following policy measures by the government are to be credited for the promotion of rooftop solar in the country:
  - providing residential, institutional and social sectors with central financial assistance (CFA) and achievement linked incentives for the government sector under the Rooftop Solar Scheme (RTS),
  - preparing model MoU, power purchase agreements (PPA) and CAPEX agreements for faster implementation of government sector projects,
  - mandating states to finalize and notify net/ gross metering regulations and tariffs,
  - implementing the ’Suryamitra’ program to facilitate creation of a workforce of qualified technicians,
  - creation of ’SPIN’, an online portal to hasten the project approval, monitoring and report submission processes in RTS projects and,
  - facilitation of concessional loans from big banks like the Asian Development Bank, the World Bank, the State Bank of India, etc. for faster loan disbursement in sectors where CFA is not applicable.

Despite the huge growth, the Indian rooftop market is far from achieving the initial national target of 40 GW by 2022 set by the government. Also, the growth is mainly observed in the industrial sector and, government and educational institutes looking to reduce their electricity expenditure since the upfront costs are still too high for many residential customers.

- The Government Producer Scheme has mandated the use of domestically produced solar PV cells/modules, as per the MNRE's specifications and testing requirements, for the upcoming government funded projects to create 12+ GW of grid-connected solar power capacity by 2023. This has created an huge impetus for the domestic solar PV manufacturers signaling a high demand for the next 3-4 years. This scheme is projected to create an investment of about Rs. 48,000 crores along with about 200,000 additional employment opportunities being created over the span of the scheme. This scheme also acts as a huge promotion for the 'Make-in-India' project that has been running for a long time.

- The MNRE approved a solar-wind hybrid project policy. It is done to provide guidelines for such wind-solar PV hybrid power projects by which the government aims to create better grid stability by reducing RE power variability. It would also be a more efficient use of the transmission grid and land resources involved in the project.

- The MNRE has also recently created a three member Dispute Resolution Committee to consider and mitigate the disputes between solar/wind power developers and SECI/NTPC.

According to the REN21 (2019) report, India was the second-largest solar market in Asia, with an addition of about 10.8 GW in 2018 and a cumulative total of 32.9 GW of solar power. Most of these installations have been as large-scale solar projects predominantly in Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, and Maharashtra. The installations have decreased compared to 2017, for the first time since 2014, due to factors like land acquisition, transmission constraints, flaws in the tendering system, safeguard duty on Chinese and Malaysian solar imports (about 85% of total solar imports), and, unclear categorization of goods under the new central taxation system. Despite the increased investments in the new manufacturing facilities, the investments in the solar sector are said to have fell by 27% due to decline in system costs and decrease in installations.

For wind energy installation in 2018, India was also the only other Asian country to rank among the top 10. The country secured fourth place, despite the decrease in additions by nearly 50% from the record high number in 2017. India added 2.2 GW of wind power in 2018, bringing the final year-end total to 35.1 GW. An additional 9.2 GW or more remained not constructed due to the delays in accessing transmission lines and obtaining land.

2.1.2 Commitments to Paris Agreement 2015

As per the nationally determined contributions under the Paris Agreement and other relevant commitments made by the government to increase reliance on non-fossil energy sources, India has the following targets (REN21, 2019; UNFCCC, 2015):

- 175 GW of renewable energy for electricity generation by 2022
- 20 million solar PV based lighting systems by 2022
- 100 GW of solar energy capacity by 2022
- 60 GW of wind energy capacity by 2022
- 10 GW of biomass and 5 GW of small hydro power projects by 2022
- 40% share of renewables in the country's electricity generation by 2030 and,
- 30-35% reduction in CO2 emissions (compared to 2005 levels) by 2030

There also other state-specific targets, in terms of RE share in the electricity generation and solar installed capacities, pledged to be completed by 2030.

2.2 Renewable Energy scenario in China

Until very recently, the economies of scale overshadowed the need for relevant policy in China. It was then that the government realized that public sector subsidies and FIT schemes and legislation, such as the mandatory RE certificate schemes and the RE law of 2005, are necessary for a long-term cost reduction (Gosens et al., 2017; Zou et al., 2017b). Having such policies in place and a huge push towards renewables made China the country with the largest installed capacity of renewables among all countries, a huge 1581.9 GW (25.4% of the country's energy mix) (Zhang et al., 2017). The Chinese government has setup multiple bodies, such as the National Development and Reforms Commission (NDRC), the National Energy Administration (NEA) and, the Ministry of Science and Technology (MOST), to undertake this transition to renewables. These key organizations have been assigned different roles and jurisdiction (NEA, a). The National 13th five-year plan (2016-2020), announced in December 2016 by the NEA, tackles a lot of different areas including setting targets for renewable energy shares in the energy mix, electricity generation RE shares, specific solar, wind, hydropower, geothermal and biomass targets, usage of smart systems in electricity generations etc. This comprehensive plan has therefore acted a strong reason for the tremendous growth of renewables in China (as shown in fig. 2.6). Figure 2.7 shows the huge increases in the solar PV and wind energy generation and primary consumption values.

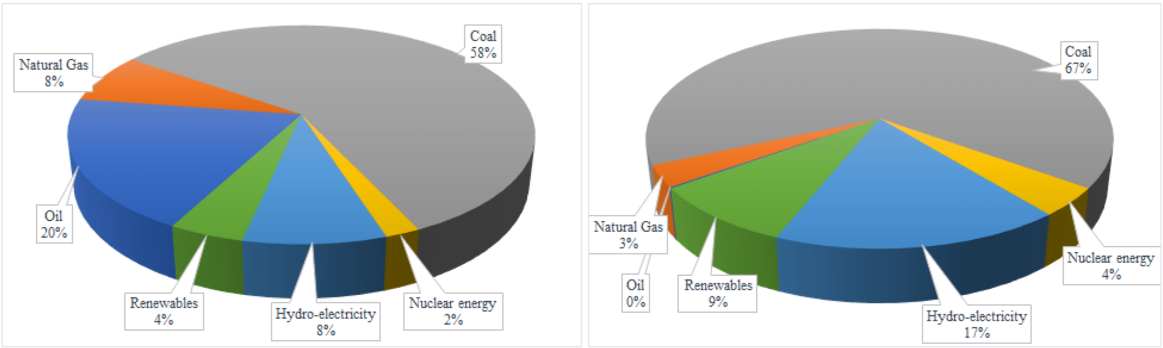

Fig. 2.6 Share of Renewables in (a) primary energy consumption and, (b) electricity generation for China (BP, 2019b)

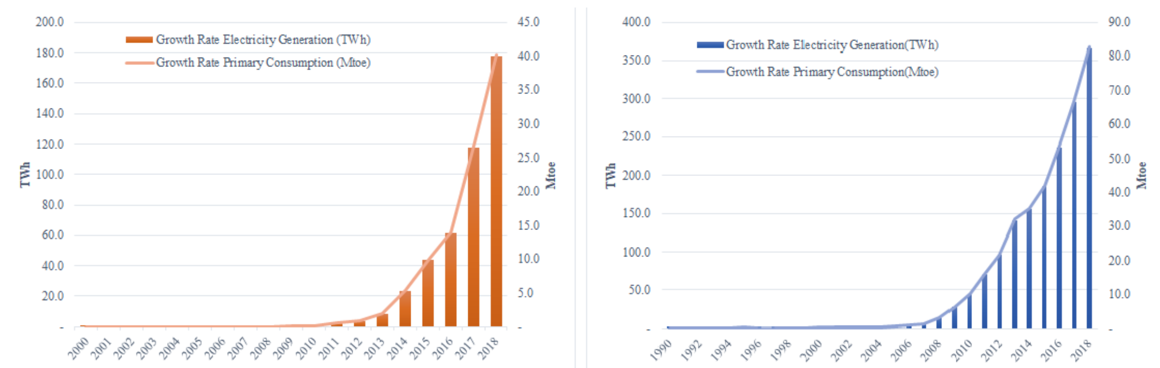

Fig. 2.7 Growth in the Solar and Wind energy industries in the past decades for China (BP, 2019b)

2.2.1 Existing and upcoming policies

The National Energy Administration reports all the policy developments on their website along with news updates about the current RE scenario (NEA, a,b, 2016). The IEA also maintains a comprehensive database of new policy measures and changes in the existing policies Ṫhese two along with the REN21 (2019) report give a decent idea about the country's RE policy scenario, as explained below:

- The Renewable Energy Law was established in 2005 to "promote the development and utilization of renewable energy, increase energy supply, improve energy structure, ensure energy security, protect the environment, and achieve sustainable economic and social development" by the Chinese government. The government wanted to makes renewable energy a priority and promote the establishment of a renewable energy market by setting fixed targets for the development of this industry.

- In 2017, the NDRC began issuing Renewable Energy Green Certificates to ease the government subsidies in the solar and wind sectors. They hoped to create a market based on voluntary trading mechanism. First, a trial program was started, where utility-scale producers were given 1 MWh worth of certificates to sell to private and government-owned businesses. The producers with certificates were ineligible for the FIT subsidies, thereby easing the load on financial government incentives and the price of the certificates was capped at the government subsidy levels. This pilot program has resulted in a possibility of mandatory green certificates being assigned from 2018 onward.

- Quotas were established for grid utilities and power purchasers, setting rules for the use of renewable power. The move was driven by growing curtailment rates for wind and solar power, which were in turn the result of China's rapid expansion of new variable renewable power generation capacity. Under the new regulations, curtailment of wind power is capped at 10% in 2019 and 5% by 2020, and solar power is capped at 5% from 2018 to 2020.

- Policy makers are promoting the ancillary grid services offered by enabling technologies and, to a lesser extent, by renewable energy. The design of appropriate power market rules is an important lever for increased participation of VRE and other enabling technologies in electricity markets and trade. In China, the 13th Five-Year Plan (2016-2020) and related initiatives aim in part to create new wholesale electricity markets that work for renewables.

- The biggest auction-related policy development in 2018, and perhaps in all recent years, occurred in China. As part of broad changes to its national solar power policy, Chinese officials halted all financial support for utility-scale and distributed solar projects in favor of project support through auctions. Wind energy projects in China also will be supported through auctions in the coming years.

- Substantial additions came despite policy changes in China that reduced the FIT payment for solar generation, capped distributed projects at 10 MW for 2018, and ended approvals for new subsidized utility-scale plants (abolishing the 13.9 GW target for 2018), mandating that they go through auctions to set power prices. The policy changes also shifted project approval to local governments. Key factors driving China's policy revisions included a backlog in FIT payments and a growing deficit in the nation's renewable energy fund, as well as concerns about uncontrolled growth and a realization that bids under the country's Top Runner programme were much lower than the national FIT. The changes reportedly signaled the central government's shift in focus from high-speed growth and dependence on subsidies, to high-quality development in order to reduce costs through technological improvements. China's market in 2018 was driven largely by the Top Runner and Poverty Alleviation programmes (and the FIT until late May).

- Centralised utility power plants (above 20 MW) accounted for nearly 53% of the year's installations (and 71% of the year-end total); the remainder was in distributed systems, which were up considerably in both their capacity added in 2018 and their share of total additions relative to previous years. Curtailment of China's solar PV generation continued to decline, from a national average of 6% in 2017 to 3% in 2018, although curtailment rates remained far higher in the remote provinces of Gansu (10%, down 10 percentage points) and Xinjiang (16%, down 6 percentage points) due to insufficient transmission capacity. Reduced curtailment and rising capacity helped increase China's solar PV output 50%, to 177.5 TWh. As a result, solar PV's share of total annual electricity generation in the country rose to 2.6% in 2018 (from 1.9% in 2017).

- The curtailment situation continued to improve as a result of policies to expand electrification (especially of heating in industry), to encourage direct trade in renewable energy among large consumers and to construct new transmission lines, as well as limitations on new wind (and solar) power capacity in problem areas. Overall, an estimated 27.7 TWh of potential wind energy was curtailed in China – a national average of 7% for the year, down from 12% (41.9 TWh) in 2017 and 17% in 2016.

Curtailment remained concentrated mainly in three provinces (Gansu, Inner Mongolia and Xinjiang), but all three saw significant reductions relative to 2017. In late 2018, China re-emphasised its aim to keep curtailment of wind generation below 10% in 2019 and 5% in 2020. Even with curtailment, China's generation from wind energy was up 20% (to 366 TWh) in 2018, and wind energy's share of total generation continued its steady rise, reaching 5.2% (up from 4.8% in 2017).

- The government issued a notice for the provisional management of distributed wind power project in April 2018. It provides the following regulations for the construction and development of onshore wind projects:
  - Technical requirements: Distributed wind power projects should be connected to the grid to 110kV and below grids and should not deliver power to the grid of higher voltage. There should be only one grid connection point for each project connected to the grid of 110kV (66kV in the northeast area), and the upper limit of total capacity for each project is 50MW. The technical solution of grid connection should be adopted centralized wind power project standard.
  - Grid connection model: Distributed wind power projects should either choose "self-consumption with surplus power connection" or "all power connection" model, but projects connecting surplus power will not receive subsidies from the Renewable Energy Development Fund.
  - Land Use: Projects can be built on land under the right of use of project developers (e.g. industrial park land), but should not occupy permanent prime farmland of China. The project planned on other types of land needs to go through application processes according to the law.
  - Market creation: Projects are allowed to directly sell electricity to users within the distribution grid.

2.2.2 Commitments to Paris Agreement 2015

China has the following targets defined under the nationally determined contributions (NDCs) under the Paris Agreement along with a few other commitments made to increase the share of renewables in the energy mix of the country under the 13th five-year plan (NEA, 2016; NRDC, 2016; UNFCCC, 2015):

- 680 GW of non-fossil electricity generation capacity by 2020 (revised in 2018)
- 105 GW of solar energy capacity by 2020, out of which 5 GW is to come from CSP

- 210 GW of wind energy capacity by 2022 (including 5 GW from grid-connected offshore wind projects)
- 35% share of renewables in the country's electricity generation by 2030 (revised in 2018) and,
- reduction to 60-65% of CO2 emission levels (compared to 2005 levels) by 2030
- reduction to 58% share of coal in the country's energy mix by 2030

Commitments were also made to promote offshore wind and ocean power development, lead renewable energy technology innovation, decrease reliance on foreign companies pertaining to the renewables domain and resolve the renewable power curtailment issue.

In conclusion, both the countries currently own huge percentages of solar PV and wind energy capacities of the world. They both have multiple agencies established specially for the purpose of improving the condition of the renewable energy industry and facilitate its smooth functioning. The investment costs in both the countries are declining due to the falling technology costs, government subsidies and tariff schemes, and better small- and large-scale financing mechanisms. It can also be attributed to the increased technological awareness of the investors. Governments of both countries have mandated grid connections to RE projects to prevent dumping of clean power and have undertaken auctioning as the mechanism to tender projects. There are also quite a few policies in place to cater to the needs of specific demographics like farmers and industries. In spite of all these policies which clearly show the steep inclination towards reliance on renewables in the two countries, there still are many barriers to the growth of solar and wind energy in both, India and China.

The following chapter deals with describing the literature study done to identify the barriers to the diffusion of solar PV and wind for both the countries, and the choice of ISM as the methodology for the consequent barrier analysis.

Chapter 3

Literature Review

In this chapter, a detailed study is conducted to outline the existing literature related to the barriers to diffusion of solar PV and wind energy in the two countries. This thesis started by first reading the UNFCCC (2015) which illuminates the need for energy transition necessary to reduce the global carbon emissions. Further, reading the BP (2016), IPCC (2018), and Climate Action Tracker (2018) pointed out the fact that even if the growth rates for both the technologies in both the countries have been extremely high, the global temperature increase will still be greater than 2°C. This proves that these technologies possess some problems which hinder their diffusion in these two countries, which we here onward refer to as *barriers*. A thorough literature search was then conducted using keywords like '*solar PV+ barriers*' and '*wind energy+ barriers*' from academic sources like Scopus, Google Scholar, ScienceDirect, ResearchGate, etc. This helped identify the barriers specific to the two countries for the two technologies. Similar barrier analyses for other countries were also studied for reference. Lastly, interpretive structural modeling(ISM) was decided upon as a fitting methodology for the thesis and, papers using this methodology were studied to understand the steps and implement it to this thesis. *Mendeley* was used to keep track of all the references and citations.

3.1 Barrier identification and segregation

A systematic barrier analysis is usually carried out to identify the problems and bottlenecks faced by any industry. The renewable energy industry follows suit and therefore has quite a few barriers of its own. Researchers like Urban (2009) started by creating energy models for the sustainable energy transition and its socio-economic, policy and environmental implications. Zhang et al. (2012) used surveys and interviews to generate a ranking of the barriers to diffusion of solar energy in Hong Kong. He used the Likert scale to quantify the responses of the survey and calculated a mean score for every barrier, which he then used to rank the barriers. These rankings were used to make recommendations to the government to smoothen the transition to renewables, specifically solar. Rai et al. (2016), Haas et al. (2018) and, Aly et al. (2019) have done similar barrier identification studies for residential solar PV in northern California, deployment of solar technologies in Chile and, large-scale solar power in Tanzania, respectively. Barriers for the diffusion of wind energy have been studied by Richards et al. (2012), Edsand (2017) and, Yermakova (2018) for Canada, Columbia and the Netherlands, respectively. These studies have also analyzed the barriers and then made recommendations towards the mitigation of those problems. Researchers like Eleftheriadis and Anagnostopoulou (2015), Yaqoot et al. (2016) and, Sen and Ganguly (2017) have also proceeded to identify and provide solutions to barriers but, they have done so for all renewable energy sources in general, unlike other researchers mentioned above who have worked specifically on solar or wind.

All these studies provided us with adequate background to go ahead with our own barrier identification and analysis for India and China. In this chapter, am more general term of ’renewable energy’ has been used a lot of times instead of ’solar PV and wind energy’ to prevent excessive repetition.

3.1.1 India

Quite some research has been done over the years to study the solar and wind energy in India for different scales of execution, different areas and markets. Abundant literature was available to understand the Indian renewable energy scenario, specially solar PV and wind, and isolate barriers from. Ansari et al. (2013)’s paper on the barriers to the implementation of solar power installations in India has formed the backbone of this whole thesis. This paper outline thirteen relevant barriers from literature and discussions with experts and establishes a contextual relationship between them. Some researchers like Khare et al. (2013); Manju and Sagar (2017); Rathore et al. (2018) present the status of solar and wind in India while also pointing out and classifying the barriers under broad headings of policy, technological, financial, institutional, and socio-economic. Kapoor et al. (2014) shows the policy evolution of solar energy in India by showing the changes in consecutive five-year plans of the Govt. of India. Chauhan and Saini (2015) looks at off-grid RE projects in the state of Uttarakhand and also gives the technology options, barriers and recommendations for them. Kar and Sharma discusses the achievements, policy, incentives, opportunities, challenges and recommendations for solar and wind power in India in two separate papers (Kar and Sharma, 2015; Kar et al., 2016). Dawn et al. (2016) analyzes the Indian solar energy scenario, policies, existing and upcoming projects, issues and, authorities responsible for its growth. A couple of other researchers like Kumar Eswarlal et al. (2011); Luthra et al. (2015); Sindhu et al. (2016) have also studied the barriers renewable energy progress in India and have proven to be very useful literature for this thesis.

Although we have identified more than 40 barriers, performing analysis on everyone of those was not possible; they have been summarized for reference in Appendix A. The barriers that we selected for analysis have been explained below in the context of India.

- *Lack of R&D work*: Research and development programs in the solar PV and wind energy sector are very slow. High costs and low efficiencies are a result of lesser R&D work. Investment in this sector goes hand-in-hand with the research done to improve the projects. Lesser R&D leads to lesser number of projects and therefore, lower investments. On the other hand, private investment and finances are required to fund this research (Ansari et al., 2013). All over the world, where companies and government funded research projects are continuously improving their scope and scale, the Indian manufacturing facilities only focus on replicating the existing technologies in much smaller processing units (Luthra et al., 2015).
- *Lack of supporting policy*: This is one of the most significant barriers. Current policies are not enough to encourage a nation-wide growth in solar PV and wind installations. Project developers have complained about the existing guidelines being unclear and absence of long-term plans for the renewable energy sector. A single comprehensive policy for REs is missing and states governments are no better at it (Sindhu et al., 2016). One of the biggest complaint that the project developers have is that the Renewable Purchase Obligation (RPO) is not legally enforceable at the center or the state level. Different State Electricity Regulatory Commissions (SERCs) reviewed the RPO and found differences in the definition of framework for RPOs, which creates even more uncertainty. Developers want a common central RPO for all the SERCs (Rathore et al., 2018). There is no uniformity of policies across all the states for renewable energy projects which results in investors backing out due to increased risk due to uncertainties (Kar and Sharma, 2015) .
- *Lack of skilled personnel and training institutes*: Degrees and vocational courses in the disciplines of renewable energy are necessary to create skilled technicians and graduates with a deep understanding of renewable energy sources and how they can be harnessed. Absence of training institutes and degree courses in the country creates a very large knowledge gap which hinders the progress in this sector. Incompetent technicians pulled

Sr. No.	Barriers	Description	Researchers
1	Lack of R&D work	Extremely slow research; mainly focused on replicating existing technology rather than innovation	3; 13; 17; 31; 32; 33; 34; 35; 37; 39; 40; 52; 62; 76
2	Lack of supporting policy	Current policies unclear; not long-term enough to attract investors	1; 3; 13; 31; 32; 34; 35; 37; 39; 40; 52; 60; 62; 76
3	Lack of skilled personnel and training institutes	Absence of field experts, degree and vocational courses	3; 13; 17; 31; 33; 34; 35; 37; 39; 40; 60; 62; 76
4	Grid issues and energy access	Grid connectivity, transmission losses and monitoring	1; 3; 13; 31; 32; 33; 34; 35; 39; 40; 52; 76
5	Legal and regulatory issues	Legislation and regulation not all-encompassing; not enforced properly	1; 13; 17; 31; 32; 33; 34; 37; 52; 62; 76
6	Lack of awareness / understanding of technology	Education and information dissemination regarding RES is absent	3; 17; 31; 33; 34; 37; 39; 40; 52; 60; 62; 76
7	Lack of financing institutions	Funds borrowed at high interest rates; investments perceived to be risky	1; 3; 31; 32; 33; 34; 35; 39; 40; 52; 62; 76
8	High initial investment cost	BOS components and storage solutions very costly	3; 13; 31; 33; 34; 35; 37; 39; 40; 60; 76
9	Lack of coordination between agencies/stakeholders	Absence of cooperation and knowledge exchange between agencies	13; 17; 31; 34; 35; 39; 40; 62; 76
10	Poor reliability and low efficiency	Technological drawbacks, resource availability and non-standardized manufacturing	3; 13; 33; 35; 37; 39; 40; 60; 62; 76
11	Poor market infrastructure	RE projects on a much smaller scale compared to the conventional energy generation companies	3; 13; 31; 32; 33; 35; 39; 40; 60; 62
12	Lack of data and information	Inaccuracy or unavailability of cloud cover, irradiance and wind speed data	3; 13; 17; 31; 35; 39; 40; 52; 60; 76
13	Lack of local infrastructure	Land acquisition is a major concern; local substations are not upgraded to handle added capacities	1; 3; 13; 31; 32; 39; 40; 60; 62
14	Lack of incentives and subsidies	Absence of incentive to invest in RE projects with long payback periods and intermittent output	13; 17; 33; 39; 40; 60; 62; 76
15	Multi-tired govt. approvals and documentation	Administrative procedures very complex; involve multiple documentation at multiple departments	1; 13; 31; 40; 52; 62; 76

Table 3.1 Brief summary of various barriers to diffusion of solar PV and wind energy in India

from other fields are bound to do a poor job resulting in bad project outputs (Kapoor et al., 2014). People with in-depth knowledge of the technology are absent at decision-making positions. The shortage of skilled professionals is evident and can include designers, service and sales representatives, policy analysts, scientists, engineers, teachers and researchers associated with the technology in direct or indirect way (Sindhu et al., 2016).

- *Grid issues and energy access*: Energy access is a major issue in India. Grid connectivity is required to transfer electricity from remote power plants to demand centers. The grid also should be able to handle the intermittency of supply and should have large-scale storage solutions as buffers. Some states like Gujarat, Tamil Nadu and Maharashtra are rich in wind energy resources and its consumption (Kar and Sharma, 2015). This energy production should be able to travel beyond the state boundaries, when in excess, to be utilized where required and it is the responsibility of the grid to provide seamless connectivity. Huge losses, of up to 30%, have been observed in the generation, transmission and distribution of electricity. These losses are not well monitored and there are major concerns about commonly occurring problems like electricity theft and meter tampering (Luthra et al., 2015).

- *Legal and regulatory issues*: There serious problems in integrated power sector reforms and absence of adequate legal guidelines for independent power producers. The developer who quotes the minimum price on power capacity (MW) or energy generation (KWh) is selected for development of the project out of all the received tenders. Bidding for power tariffs not a good idea because some developers quote low prices but end up using cheap material and low quality equipment to save on capital. Developers also say that site specific tariff should be implemented to account for variance in wind speeds and solar radiation depending on location. Otherwise, only the states with abundant resources will make progress in the solar and wind sectors (Rathore et al., 2018). Kar and Sharma (2015) calls for strong regulatory intervention in tariff revision, RPO fixation and monitoring by the government. Regulatory requirements like 70:30 debt-equity ratio for RE projects presents problems due to unavailability of debt financiers in India. Developers then need to borrow from foreign markets which becomes expensive due to the exchange rates and transaction charges. Kar and Sharma (2015). Also, laws and regulations pertaining to land acquisition, financing, foreign direct investment, electricity generation, distribution and power purchase agreements (PPAs) for renewable energy projects are unclear and not enforced stringently (Kar et al., 2016).

- *Lack of awareness / understanding of technology*: Citizens, both rural and urban, are not aware of the new technologies unless it directly affects their day-to-day life. They are also not made to understand the benefit domestic solar PV or small-scale wind could have on their community. Consumers are unaware of the technical aspects like integration with battery systems and financial benefits to the consumers. Low social and cultural acceptance causes lack of community participation. Lack of awareness about environmental and societal impact of conventional sources is also a major concern. One of the biggest problems is the lack of information and awareness on renewable energy systems and technologies among the rural people. Education and information dissemination related to renewable energy should tackle all aspects ranging from education about various renewable technologies to information about available government incentives and support schemes (Luthra et al., 2015).

- *Lack of financing institutions*: The financing mechanisms in India are not adequate. Renewable energy project developers and customers have to borrow funds at rates competitive with conventional sources of energy, in spite of having very low operation and maintenance costs. Lack of awareness of these technologies creates false ideas of renewable energy investments being risky, which leads to lending money at higher interest rates. Small-scale project financiers are not available. Banks do not accept project related agreement like PPAs and RPOs as bankable documents. RE projects face many obstacles due to high interest rates, financially unstable distribution companies, weak capital markets, lack of access to cheap, domestic, long-term debt financing (Kar et al., 2016).

- *High initial investment cost*: Even though the cost of producing solar panels is decreasing very rapidly, initial investments in a solar PV or wind project are high. These high costs come from a variety of factors ranging from India's dependence on silicon and silicon wafer imports to costly balance of system (BOS) components like inverters, cables, storage systems, etc. Need for storage solutions, like batteries, due to intermittency problems add to the cost since batteries are currently very expensive. In most cases, the immediate market benefits of RE projects are lesser than the investment cost (Ansari et al., 2013). If externalities are taken into consideration, renewables will be much cheaper than conventional power sources. This biased comparison between subsidized fossil fuels and non-subsidized renewables on the basis of technology cost leads to a higher investment costs.

- *Lack of coordination between agencies/stakeholders*: Agencies need to collaborate on projects and share developed knowledge to avoid redundant work and faster progress. Coordination and cooperation within and between agencies, institutes, ministries and other stakeholders delays the progress in RE projects. This also reduces investors willingness to invest in RE projects due to the resultant delays in processes or project mismanagement (Khare et al., 2013).

- *Poor reliability and low efficiency*: Solar panels have low energy conversion efficiencies of nearly 20% which means not all sunlight falling on the panel is converted to electricity. Even a temperature increase above operational values leads to decrease in electrical efficiency. On top of that, the day-night cycle and weather creates intermittency in the supply. Although wind turbines have much higher efficiencies than PV panels, their electricity production also depends upon wind speed and availability. These factors take a heavy toll on the reliability of these projects. Apart from these technology drawbacks, non-standardized production leads to inefficient parts and further compromises the reliability of the whole project (Manju and Sagar, 2017).

- *Poor market infrastructure*: Small size of the green electricity market discourages private investment. Most renewable energy projects are on a much smaller scale compared to the conventional energy generation companies and utilities. This directly impacts their customer reach, decision making clout compared to large companies and participation in creation of favorable electricity regulations. Weak industry network integration leads to market insecurity(Kapoor et al., 2014). Lack of manufacturers and suppliers of parts leads to lack of vertical market integration. Government-driven markets where the government gets into purchase agreements for the generated electricity work well, but only with government intervention.

- *Lack of data and information*: Meteorological institutes are responsible for providing weather data like cloud cover, solar irradiance, wind speeds, etc. This data is location dependent and is very important to estimate the yield of a solar or wind energy project at a potential site. Inaccuracy or unavailability of this data leads to bad project locations and therefore sub-par returns compared to such high investments. Data measurement centers around the country are insufficient in number and use outdated devices of measurement (Dawn et al., 2016).

- *Lack of local infrastructure*: Solar and wind projects require large land areas to be established. Land acquisition is, therefore, a major concern for the investing companies and it needs to happen within reasonable time. When a potential site is located near forest lands or is previously classified as agricultural land, the process of obtaining clearances is even tougher (Kar and Sharma, 2015). On the technological side, local substations are not upgraded to handle added capacities. In developing countries, remote village clusters consisting of two or more villages lack electricity access due to the low load and high cost of constructing long distribution lines from main grid lines. There is also limited availability of local manufacturing and specialized equipment (Sindhu et al., 2016).

- *Lack of incentives and subsidies*: Due to the high initial investment, project developers are forced to look for subsidies. Investors need incentive to put their money in a project with long payback periods and intermittent output. The capital subsidies provided by the government have many middlemen and therefore, delay the disbursement to project developers due to long processing times. Some countries have subsidized renewable energy through production-based payments or rebates. Rebates are refunds of a fixed share of the technology cost, or a share of total installation cost. Rebates can also be in the form of refunds of a certain amount of money per unit of installed capacity or tax deductions on investments in RE projects. But such measures are uncommon in India. (Luthra et al., 2015).
- *Multi-tired govt. approvals and documentation*: Land clearances, additional transmission line approvals and power purchase agreements take up a lot of time and effort of the project owner. It results in lost opportunities and deters investment due to the predicted hassles. Administrative procedures are often very complex and involve multiple documentation at various different departments. Authorization procedure is very lengthy and causes delays in project deployment due to the lack of co-ordination among central and state agencies (Aggarwal and Dutt, 2018; Rathore et al., 2018).

3.1.2 China

Many researchers have studied various aspects of solar and wind energy in China. They have looked into the changes in policy over the years, analyzed problems in it, studied the economic feasibility of such projects and also pointed out the major challenges faced by the developers of RE projects. Therefore, there was enough literature around this topic to identify barriers to the solar PV and wind energy diffusion in China. Zhao et al. (2019) and Zhao and Chen (2018) have worked on finding out what affects the development of RE power generation projects in China. These papers enlist and study the main challenges to see what causes the most impact on the development of RE projects to ensure better investment and policy decisions in the future. Multiple researchers have also studied the law and policy aspect of the renewable energy scenario in China and made recommendations to improve the underlying problems (Binz et al., 2017; Ming et al., 2013b; Schuman and Lin, 2012; Wu et al., 2017). While some researchers, like Ming et al. (2013a); Wang et al. (2012); Zhang et al. (2016); Zhao et al. (2016), studied the technological progress, policy support, current scenario and existing challenges to the diffusion of wind energy projects; others, like Song et al. (2015); Urban et al. (2018); Zhang and He (2013); Zhang et al. (2012), made similar studies in the field of solar PV.

Using the above mentioned literature and other relevant papers, we have identified more than 30 barriers but performing analysis on everyone of those was not possible; they have been summarized for reference in Appendix A. The barriers that we selected for analysis have been explained below in the context of China.

- *Lack of incentives/subsidies compared to fossil fuels*: The predominant use of fossil-fuels, specially coal, and their ongoing dominance in China's energy mix is identified as a major obstacle in the increased diffusion of solar PV. Although the prices have decreased rapidly in the last few years, it is still relatively expensive for individual consumers. This unchanging reliance on fossils diminishes efforts toward a low-carbon economy (Urban et al., 2018). On the other hand, government subsidies do not cover all the fields and subsidy management does not translate well from higher to lower level uses (Song et al., 2015). The levels of RE tariff surcharge subsidies are low and will be insufficient for the future development of RE. On top of that, the time lag between subsidy allocation and actual on-ground requirements (Ming et al., 2013b). The country's future development also seem to be focused mainly on fossils like coal and natural gas (Yang et al., 2016). High initial costs and repair costs call for government subsidies which will benefit individual consumers and serve as an incentive for investment in utility-scale projects (Zhang et al., 2012).

- *Limited policy framework or lack thereof*: Policies are not clearly defined and therefore, act as a deterrent for investors, both individuals and utility-scale, due to the increased market risks (Zhang and He, 2013). Taxation policy in favor of renewable energy development is also not a widespread approach and exists only in certain developed parts of the country. The feed-in-tariff (FIT) system failed to balance project benefits among stakeholders and grid companies. The FIT policy has given rise to issues like the cost-sharing funds problem. The funding gap has gotten worse with the increasing volume of subsidy funds, and, with the development of the RE industry, the funds used to subsidize the gap will grow (Song et al., 2015).

- *Lack of experience in technology and its management*: China majorly imports all parts with complicated designs like turbine bearings and also some other tertiary components for the RE systems. For example, China purchases wind power equipment coating materials, specially for turbine blades, mainly from foreign entities. But these coating materials are

Sr. No.	Barriers	Description	Researchers
1	Lack of incentives/subsidies compared to fossil fuels	Unfaltering reliance on fossils leads to lesser financial subsidies	6; 19; 34; 42; 57; 58; 71; 72; 75; 80; 82; 84; 85
2	Limited policy framework or lack thereof	Unclear policies, small-scale implementation and negative effects of helpful policies	6; 19; 34; 57; 58; 71; 72; 75; 80; 83; 84; 85
3	Lack of experience in technology and its management	Importing of major components	6; 19; 34; 42; 57; 58; 71; 72; 75; 83; 84
4	Financing difficulties	Longer payback periods and unfair risk evaluations deters investors	6; 19; 34; 42; 58; 71; 75; 80; 82; 84; 85
5	Grid capacity and connectivity delays	Problems with long-distance transmission and delays in connectivity	6; 19; 57; 58; 72; 82; 83; 84; 85
6	Lack of legal and regulatory framework	No standardization of legislation and central enforcement of regulations	6; 19; 57; 58; 72; 80; 82; 83; 84
7	Lack of R&D incentives	Research focused on modification of existing products rather than innovation	6; 34; 58; 72; 75; 82; 83; 84; 85
8	Lack of strategic planning and political will	Delays in subsidy money distribution and grid connectivity	19; 42; 71; 72; 75; 82; 83; 84
9	Lack of research personnel and trained manpower	Very few universities, training institutes and research organizations	19; 34; 58; 71; 72; 80; 82; 83
10	Inadequate data and information	Poor solar and wind resource data and improper distribution of weather stations	6; 19; 34; 58; 71; 72; 83; 84
11	Inadequate market infrastructure and size	Capital markets and market-based investment not fully exploited	6; 34; 58; 75; 84; 85
12	Lack of coordination among agencies	Multiple departments and ministries responsible for RE administration	6; 19; 57; 72; 82; 84
13	Resource availability	Uneven resource distribution; mostly away from load centers	58; 72; 75; 82; 83; 84
14	Lack of awareness towards technology	Very little knowledge and many misconceptions among common people	19; 34; 58; 71; 83
15	Bureaucratic hassles	Multi-step, complex and inefficient project approval system	19; 34; 72; 82; 84

Table 3.2 Brief summary of various barriers to diffusion of solar PV and wind energy in China

not designed for the high sediment concentration environment in China and therefore, wear out very easily. The bearings have a purchase cycle of one year which results in serious bottlenecks in the main blade supply. Parts with the most function in wind turbine or PV panel are still controlled by other countries with years of added R&D experience (Zhao et al., 2016).

- *Financing difficulties*: Inadequate investment in technology based research from the government has continued the dependence on importing of some crucial equipment and advanced manufacturing techniques. This situation kept China's PV and wind energy knowledge development in a reasonably passive position (Song et al., 2015). The superficial energy pricing and tax system in the country ignore the environmental cost of resources and therefore, fossils are subsidized. As a result, renewable energy has limited financial support and the payback periods are around 8-10 years due to the low FITs and electricity prices (Urban et al., 2018; Yang et al., 2016). Social acceptance of an RE project affects its risk evaluation and is a major priority for any financing institution before they lend money to a project (Zhao and Chen, 2018). All these factors play a vital role in the availability of private finance for any RE project.

- *Grid capacity and connectivity delays*: Although China has an abundance of wind and solar resources, but it is mostly the rural provinces that receive the most sunlight or wind and they are not very well connected to the grid. For example, wind energy resources are mainly concentrated in the north-western part China, whereas 3/4th of the country's electricity needs are in the central and eastern China (Zhao et al., 2016). The current grid connection subsidies do not consider long-distance transmission and increased grid penetration essential for large-scale RE growth (Ming et al., 2013b). The energy sector in China is built up around conventional fossil fuels operated and managed on a large power grid system. Due to the better control and easier dispatch offered by the conventional power plants, the current grid discriminates against renewables due to their fluctuation and intermittence in energy generation. China's Renewable Energy Law has regulations for the complete protection of RE generated electricity but a considerable quantity of this electricity is discarded annually (Yang et al., 2016). Compared to the rapid development of solar and wind farms, the construction of transmission lines is slower, leading to delays in production and supply from these projects (Zhao et al., 2016). It is a very long and bureaucratic procedure to connect RE plants to the grid. The grid companies have to make sure the the installation is in accordance with technical standards and regulations of the grid. For this, they have to specially send out engineers and are often reluctant to spend this extra time and effort (Urban et al., 2018).

- *Lack of legal and regulatory framework*: There is a inconsistency between the policies, as the renewable energy sector in China is administered by multiple agencies, impeding the rapid development of the RE industry (Song et al., 2015). Due to the absence of central standardized regulations, seemingly positive factors like the support of local governments, can lead to unforeseen problems like overcapacity posing huge governance challenges. This is mainly due to the short-term fixes developed by the local governments. For example, when to maintain revenues from the policy change of value-added tax, local governments encouraged and promoted local manufacturing. This led to a large number of new factories in the region but will inadvertently cause overcapacity problems (Zhao et al., 2016). In overcrowded cities like Hong Kong, rooftop spaces are seldom privately owned. Therefore, a lot of legal problems arise when someone wants to install a rooftop solar system but only a few tenants are willing to pay extra costs for the system. Regulations concerning the ownership of such systems are necessary to be put in place, so that they can help bring clarity to the respective responsibilities of the property owners, developers, contractors, systems suppliers, and, public-owned departments. It would be easier for individual owners to contact the responsible authority for approvals (Zhang et al., 2012). Many such localized problems can be solved by standardized legislation and proper enforcement of regulations.

- *Lack of R&D incentives*: There is a huge gap between China and other developed countries in terms of some vital components of technologies required for the RE industry. China's RE research and development usually function by importing, absorbing, digesting and modifying already refined technology. Thus, China's renewable energy technologies fall short in terms of core competitiveness of the technology and innovation capabilities, as a result of insufficient investment in fundamental and applied R&D on RE technologies (Yang et al., 2016). Although the Chinese government has established many funds for the research in solar and wind energy technologies, it is still inadequate. And, even though the technology costs have fallen rapidly, manufacturer's profit margins have declined with it which in turn has affected the R&D investments (Zhao et al., 2016). Without these investments in technological research, radical breakthroughs are highly impossible.

- *Lack of strategic planning and political will*: Problems like delays in distribution of money from the subsidies and connectivity delays resulting in idle erect wind turbines and established solar farms show a clear lack of planning (Schuman and Lin, 2012). One more evident example of poor planning is the wind turbine overcapacity example explained above. A well-intentioned measure to develop wind energy resources backfired due to the various incentive mechanisms (e.g. tax reduction/exemption, electric price compensation) and policies. This rapid development led to a mismatch between energy generation and the transmission capacity. It was difficult to connect many of these establishments to the grid because the local governments ignored the wind power development and the required grid planning and approved projects without detailed feasibility analyses. On the contrary, projects sanctioned by the central government got reliable grid connections almost immediately after approval (Zhao et al., 2016). Intermittency being a prominent characteristic of solar and wind energy generated electricity, appropriate grid planning and construction of peak regulation substations is necessary for this power to be accepted into the grid, but China has disproportionate variety of power stations and also lacks peak power regulation substations (Zhao et al., 2016).

- *Lack of research personnel and trained manpower*: There are only a few universities in China that have majors in solar or wind energy. The Chinese government has largely overlooked the improvement of education and training and the establishment of research centers within the solar and wind industry. Due to the lack of specialized education or professional training institutes, the RE industry faces issues like very few R&D personnel and sub-par O&M technicians being hired from other industries. This brings down the overall standard of the RE industry with less than optimum products and lagging research (Zhao et al., 2016). One of the major concerns of the end-users is that the system installers lack training courses in the installation of domestic solar systems. The inadequate supply of engineers, architects and other technicians in the RE industry is because the lack sufficient knowledge of the characteristics, technical skills and benefits needed to survive in the industry (Zhang et al., 2012).

- *Inadequate data and information*: Poor solar and wind resource survey always leads to low operational efficiency of the power plant. China relies on statistics to analyze the observed data of existing weather stations and anemometer towers for their resource survey. But since most measurement stations are located near the developed towns and cities whereas the project sites are usually rural areas, due to land availability, which lack weather stations. This leads to incomplete resource data sets and, therefore, inappropriate project locations for solar and wind power plants (Zhao et al., 2016).

- *Inadequate market infrastructure and size*: China's RE industry lacks efficient investment and financial channels. Options like capital markets, government funding support, strengthening RE stocks and public funding have not been fully explored yet. A market-based investment and financing system could take the burden off the governments shoulders and allow private investors and banks to help grow the solar PV and wind industry (Song et al., 2015). The renewable energy market lacks competition due to unfair electricity prices, taxation systems and inadequate support for the large-scale development. Energy prices should reflect the resource scarcity of fossil fuels and their environmental impacts (Yang et al., 2016).

- *Lack of coordination among agencies*: China has multiple government departments and ministries, like the the National Development and Reform Commission (NDRC), Ministries of Finance (MOF), Science and Technology (MOST), Agriculture (MOA), Water Resources, etc., that share the renewable energy administration. Miscommunication, conflict of interest and lack of coordination between these different ministries and departments is unavoidable due to shared responsibilities (Yang et al., 2016). This often leads to problems like delays in FIT payments to RE generators or compensations for grid connection projects (Schuman and Lin, 2012).

- *Resource unavailability*: One of the biggest resource problems is posed by the availability of land for utility-scale power plants, since there are always allocations made to agriculture or forestry or, insufficient rooftop space in case of domestic power systems. Urban areas have almost no privately owned roof space and therefore, a large number of people need to be consulted with to sanction a rooftop project (Urban et al., 2018). Policies like the FIT fail to consider the vast regional difference in resource distribution and accordingly adjust the cost variation (Zhang and He, 2013). Due to resource limitations, the payback periods for RE investments are higher in eastern China compared to the rural western China which has abundant daily solar irradiation. A similar dissonance is observed between the northern and southern parts of the country for wind speeds and consistency. This hinders the development in the parts with insufficient resources (Ming et al., 2013b).

- *Lack of consumer awareness towards technology*: There is very little knowledge about low carbon technologies, like solar PV and wind energy, among common people even in some of the biggest cities. Researchers found out about cases like the social challenges faced by low-carbon lifestyle advocate Ni Huan, who was the first person to install thin- film solar PV panels at her home in Shanghai, such as her neighbor's safety if PV systems catch fire (Urban et al., 2018). Such misconceptions can sometimes be enough to start a movement against these technologies among the uninformed public which can become a big obstacle in the domestic implementation of these technologies. Utility-scale problems like concerns that RE-generated electricity might destabilize the grid lead to poor integration of wind and solar farms with the grid and curtailment of RE-generated electricity (Schuman and Lin, 2012).

- *Bureaucratic hassles*: Renewable energy project developers have to undergo tedious procedures before the final RE tariff surcharge. First, the power grid companies collect the RE tariff surcharge from electricity consumers. It is then forwarded to the Ministry of Finance (MOF). Now, the developers need to present a series of project reports to be scrutinized and approved by multiple agencies like the National Development and Reform Commission (NDRC), the MOF and, the National Energy Administration (NEA). The MOF then allocates the RE tariff surcharge for every project to the corresponding provincial department of finance, which is then forwarded to the corresponding provincial power grid company. Finally, the power grid companies disburse this money to the concerned RE project developers. This multi-step, inefficient and cumbersome mechanism for the collection and allocation of funds deters investors which inevitably slows the industry's growth (Zhao and Chen, 2018). Complicated project approval and permit systems established by the government largely limits the diffusion of the solar PV and wind industry (Zhao et al., 2019).

Since the barriers for both the countries are now identified and contextually explained in detail, we move on to the literature dealing with the selection of ISM as the methodology for this analysis.

3.2 Methodology literature

After being first introduced by Warfield in the year 1974, as a computational solution to the interconnection problem between two related digraphs, a modified version of this structural modeling method, now known as *Interpretive Structural Modeling (ISM)*, was adapted to various problems in process design, career planning, product design, strategic planning, process re-engineering, financial decision making, engineering, competitive analysis, human resources and electronic commerce (Attri et al., 2013). It helps to accurately map out direct or indirect relationships between the elements of a system, thereby simplifying a complex system. It provides the researcher with structured model for better understanding the system dynamics.

There are a few other methods that have been used for similar multi-variable relationship decision-making studies like the *Decision Making Trial and Evaluation Laboratory (DEMATEL)*, *Analytical Hierarchy Process (AHP)* and the *Graph Theory Matrix Approach (GTMA)*. These methods are often used to solve problems relating to complex inter-relationships within a system. They are briefly described in the table below in comparison to ISM to justify the choice of ISM as the methodology for this thesis:

ISM	DEMATEL	AHP	GTMA
The relationships between factors are considered in detail in the reachability matrix. Effects of transitivity are also incorporated. These relationships helps us accurately map out the hierarchy among the factors along with individual driving and dependence powers.	Used specially to analyze the cause-effect relationships among factors under study and to mark the most critical ones by evaluating individual interdependencies.	This method works under a set of predefined evaluation criteria and assigns weights to them. It then scores the factors under consideration based on the criteria, which it then combines with the weights of the criteria to get the final score for the factor. But, it fails to consider the indirect effects between the factors.	Looks at the system as a whole and identifies the system and the subsystems all the way up to the component level. Any physical situation is represented on graphs replacing the factors with nodes and then mapping their relationships with other factors as edges. It helps choosing the most suitable solution from many alternative solutions to a single problem but is difficult to apply to qualitative factors.

Table 3.3 Comparison of different relevant methodologies with ISM (Geetha and Sekar, 2016; Movahedipour et al., 2019; Saathy; Si et al., 2018)

Out of these methods, ISM is chosen because it is easy to understand, capable of handling a large number of components and relationships, easily modifiable for different fields of research and, communicable to a larger audience. It suits the study of qualitative factors and has proven very effective in interpreting contextual inter-relationships between the factors in a complex system. It basically translates the knowledge of experts into simplifying the system into a multi-level structural model. All these qualities of ISM led to its choice as the methodology used for the barrier analysis in this thesis.

Due to its flexibility, ISM can be used in various domains of industry and governance including technical, social, and economic. Since its inception in 1974, it has been used by many reputed institutions like NASA, IEEE, etc. Wang et al. (2008) used ISM to analyze barriers for energy saving in China. Ansari et al. (2013) used it to analyze problems in implementation of solar power installations in India. Shen et al. (2016) use it for the implementation of Emission Trading System in the Chinese building sector. Kumar et al. (2017) represent the hierarchy within the 17 sustainable development goals (SDGs) set by the UN General Assembly in 2015. It has also been used to study the barriers to the transition towards off-site construction(Gan et al., 2018), energy efficiency improvements in the steel industry(Soepardi et al., 2018), bio-diesel production from waste cooking oil(Avinash et al., 2018), mass adoption of electric vehicles(Prakash et al., 2018), implementing sustainable supply chain management(Movahedipour et al., 2019) and many other studies across different industries.

The MICMAC (Matrice d'Impacts croises-multiplication appliqúe an classment) analysis is often used in succession to the ISM method. It uses the same reachability matrix from the methodology to derive driving and dependence powers of all the factors. These powers are then mapped on the axes of a graph to segregate the factors into four categories, namely, autonomous, dependent, linkage and independent.

The next chapter further explains the methodology and outlines the steps needed to be followed to successfully execute ISM followed by the MICMAC analysis for a general case.

Chapter 4

Methodology

Barriers to any technology diffusion not only affect the technology itself, but also influence one another. Therefore, it becomes vital to study the mutual relationships between the barriers to identify driving and driven barriers. Driving barriers affect the other barriers whereas, driven barriers are affected by other barriers. Sometimes, the barriers can also mutually affect each other (Wang et al., 2008). All these inter-relations needs to be understood by the policymakers before making any decision or rolling out a new scheme. It is precisely for this reason that we wish to analyze the barriers to the diffusion of solar PV and wind energy in both India and China.

The first step would be to study the literature to list out barriers existing in both the countries, which has been done in Chapter 3. These barriers are then analyzed using the Interpretive Structural Modeling (ISM) methodology which is very commonly used to map out complex relationships between multiple elements involved in a complex situation (Ansari et al., 2013). It will be further complemented by a Matrice d'Impacts croises-multipication applique´ an classment analysis(cross-impact matrix multiplication applied to classification),abbreviated as MICMAC. Barriers are classified based on dependence and driving power using the MICMAC analysis, which categorizes the barriers as autonomous barriers, linkage barriers, dependent and independent barriers (Ansari et al., 2013).

4.1 Interpretive Structural Modeling

ISM was first proposed by Warfield (1974), as an effective methodology for dealing with complex issues. It helps develop a map of the complex relationships between the multiple elements involved in a complex situation. ISM has been used multiple times in the past for similar barrier analyses to put together a plan of action to solve a problem. It is a combination words, digraphs and discrete mathematics which seamlessly brings together complex issues and provides a detailed relationship between the variables (Ansari et al., 2013). It results in a hierarchical arrangement of barriers, showing which ones have the most impact and which ones have the least. Wang et al. (2008) made an overview of the ISM methodology, saying that it perfectly depicts the structure of a system with complex interactions using graphics and words. These features have resulted into widespread use of this methodology. The table below outlines the advantages and disadvantages of using ISM:

Advantages	**Disadvantages**
It is a systematic process which can also be automated after all the inter-relationships are defined, drastically reducing human error. Therefore, it can tackle a large no. of factors at once	Increase in the no. of factors being analyzed significantly increases the difficulty to implement this methodology as all the relationships need to be defined. Manual working becomes very difficult for a larger no. of factors and computers are needed
The process is efficient and thorough as it even incorporates the transitive relationships between factors	It only takes into consideration the presence and direction of influence between factors but, fails to study the underlying causes
It is an efficient way to translate expert knowledge into a comprehensible, structured model for the system giving a much better understanding of the complex system	Although it shows us which factors are the most important, it fails to calculate the varying degrees of importance of the factors or the influence they have on the system
It can work well with qualitative factors and gives an accurate hierarchy divided as levels of importance. This helps determine which factors need to be dealt with as a priority	There is no statistical validation incorporated in the methodology, therefore all the results are hypothetical

Table 4.1 Advantages and Disadvantages of ISM (Attri et al., 2013)

The methodology as described by Warfield (1974) consists of seven steps and the flow between these steps can be outlined by the flowchart in *fig 4.1*. The flow chart and the steps have both been modified for the purpose of this study and Attri et al.'s overview of the ISM methodology has been used as reference. The various steps involved in ISM modeling are as follows:

1. **Identify the factors/variables from literature:** Literature needs to be examined and relevant variables need to be listed. Variables can be of any nature depending on the field for which this methodology is being modified. In our case, the barriers to the diffusion rates of Solar PV and Wind energy are taken as variables.

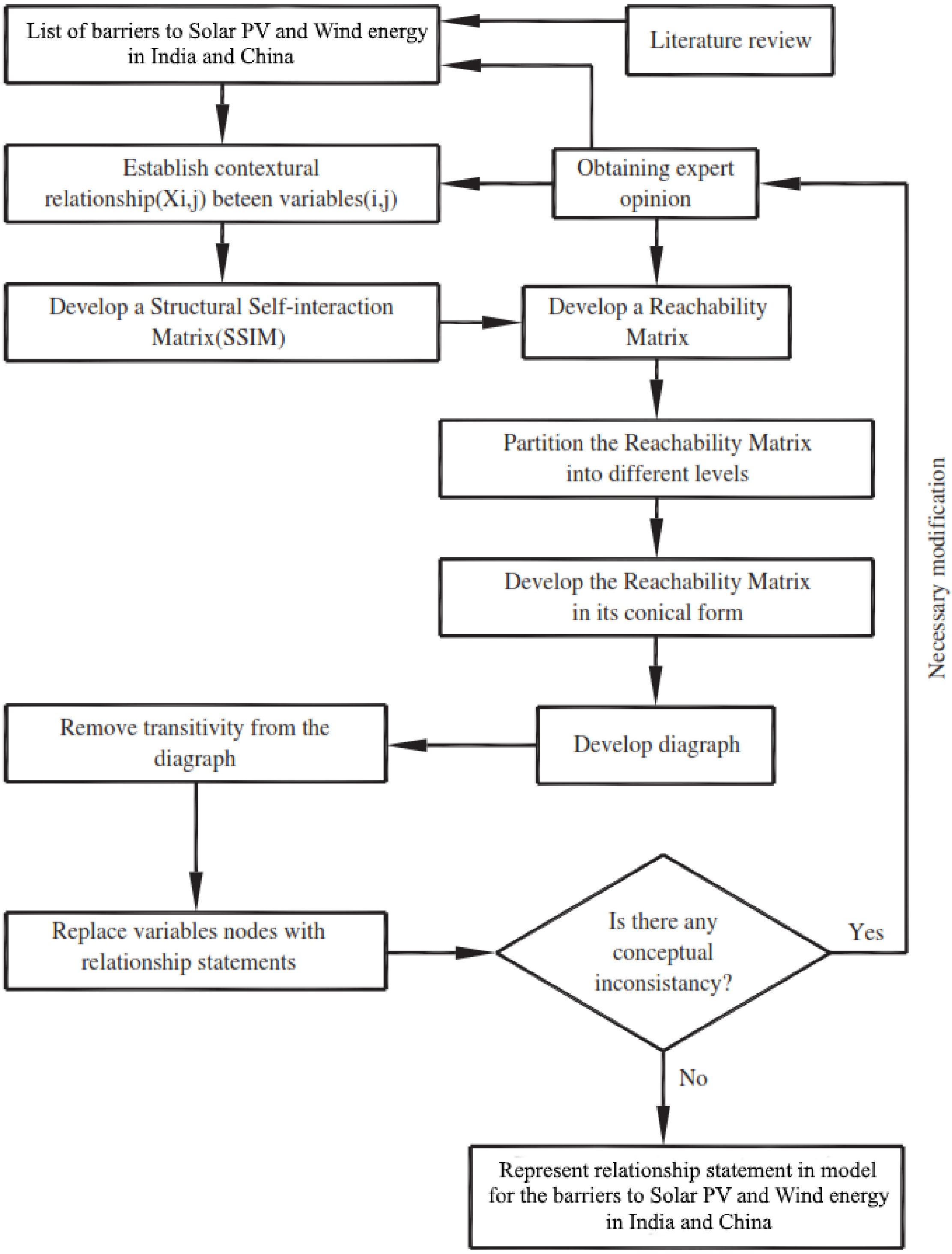

Fig. 4.1 ISM step-wise flowchart (modified from Raut et al. (2019))

2. **Develop a structural self-interaction matrix (SSIM) of elements:** A contextual relationship between the defined variables of the study has to characterized. Expert opinion, brainstorming, nominal group technique, etc. are the suggested ways in which the we can establish relationships between each variable pair. Between two factors, *i and j*, contextual relationship is defined by 'i leads to j' or 'i influences j'.

   The following four symbols are used to denote the direction of relationship between any two factors (i and j):

   - **V** for when factor i will influence factor j
   - **A** for when factor i will be influenced by factor j
   - **X** for both direction relations (i.e.,factors i and j will influence each other)
   - **O** for no relation between the factors (i.e., barriers i and j are unrelated)

   Based on this, SSIM is developed containing all factors, their relationships and the direction of their relationships.

3. **Develop a reachability matrix from the SSIM:** The next step is to create an initial reachability matrix from SSIM by substituting the four symbols (i.e., V, A, X or O) of SSIM by 1s or 0s in the initial reachability matrix. The rules for substitution are:

   - If the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0
   - If the (i, j) entry in the SSIM is A, then the (i, j) entry in the matrix becomes 0 and the (j, i) entry becomes 1
   - If the (i, j) entry in the SSIM is X, then the (i, j) entry in the matrix becomes 1 and the (j, i) entry also becomes 1
   - If the (i, j) entry in the SSIM is O, then the (i, j) entry in the matrix becomes 0 and the (j, i) entry also becomes 0

   After the initial reachability matrix is created, *1* entries* are put wherever transitivity links are pointed out during brainstorming and discussions for SSIM, for example 'i leads to j' and 'j leads to k' therefore, 'i leads to k'. The incorporation of transitive relationships gives us the final reachability matrix (Sushil, 2017).

4. **Break the reachability matrix into different levels:** From the final reachability matrix, for each factor, reachability set and antecedent sets are derived. The reachability set of any factor is composed of elements which it influences(including itself). The antecedent set of any factor is composed of elements which influence it(including itself). Then, the intersection set is derived for all these factors and levels of different factors are set. The

factors for which the reachability and the intersection sets are the same occupy the top level in the ISM hierarchy. The top-level factors do not influence the other factors above their own level in the hierarchy. Once the top-level factor is established, it is removed from consideration. The same process is then repeated to determine the factors in the next level. This process continues till the level of each factor is found. These levels help in constructing the hierarchical digraph.

5. **Convert the reachability matrix into conical form:** Factors in the same level across the rows and columns of the final reachability matrix form the conical matrix. For each factor, the driving power is the horizontal summation of ones and the dependence power is determined by the vertical summation of ones. Driving and dependence power rankings are calculated. The factors that have the maximum number of ones in the rows and columns are given the highest driving and dependence power rankings, respectively.

6. **Draw digraph based on the relationship given in reachability matrix:** The conical form of reachability matrix is converted into the preliminary digraph using nodes and lines of edges. It still includes the transitive links. After removing the indirect links, a final digraph is formed. A digraph is a visual representation of the elements and their interdependence. Naturally, the top level factor is positioned at the top of the digraph and second level factor is placed at second position and so on…

7. **Convert the resultant digraph into an ISM- based model:** Element nodes in the digraph are replaced with statements to convert it into an ISM model. The ISM model thus presents an elaborate hierarchy among its elements and helps the user anticipate the effects of changes in one element on other elements.

It is very important to review the model to check for conceptual inconsistencies and make the necessary modifications. In this thesis, a very superficial expert validation has been conducted by attending various energy transition seminars and modest discussions with field experts therefore, the ’obtaining expert opinion’ step in the flowchart has largely been omitted for lack of time.

The ISM analysis is often followed by the MICMAC analysis which is derived from the final reachability matrix in the 3rd step.

4.2 MICMAC analysis

Matrice d'Impacts croises-multiplication appliqúe an classment (cross-impact matrix multiplication applied to classification), abbreviated as MICMAC, serves to analyze the driving and dependence power of factors/elements. Its principle is based on matrix multiplication properties and is used to identify the key factors that drive the system (Attri et al., 2013).

Here, the driving and dependence power of a factor is calculated by the *summation of 1's in the factor's row and column*, respectively, from the final reachability matrix. Higher dependence values for a factor means a large number of elements need to be tackled for its removal and high driving value of means a large number of elements can be removed by tackling it (Zhao et al., 2019). This method has been used multiple times along with ISM to complement the results of ISM. It helps to better present the outcome in terms of a few key factors that drive the system under study.

Based on their drive power and dependence power, the factors, have been classified into four categories:

- **Autonomous factors:** Factors with weak drive power and weak dependence power. They are relatively disconnected from the system, with a few links that may be very strong.
- **Linkage factors:** Factors with strong drive power, as well as, strong dependence power. These factors are reactive due to the fact that any action on these factors affects the others and also causes a feedback effect on themselves.
- **Dependent factors:** Factors with weak drive power but strong dependence power.
- **Independent factors:** Factors with strong drive power but weak dependence power.

A factor with a very strong drive power is also called the 'key factor' and may fall into the category of independent or linkage factors.

Using the methodology described in this chapter we will proceed towards the analysis of the barriers, identified in the literature study chapter. The next chapter deals with the barrier analysis for both, India and China, as separate sections and the results of the analysis are elaborately presented and discussed upon in chapter following the analysis chapter.

Chapter 5

Barrier Analysis

In our research, barriers to the diffusion of solar PV and wind energy in India and China have been identified as variables in Chapter 3. Using the methodology explained in Chapter 4, we will now conduct the barrier analysis on the barriers identified previously. A MATLAB script has been written to carry out the analysis with the initial barrier relationship matrix as the input. We directly obtain the hierarchy as the output of this script and the intermediate steps are saved as separate Excel files for review later. Appendix D contains the detailed MATLAB script and all the logic behind the code has been explained as comments within the script.

5.1 Interpretive structural modeling to find the levels of barriers in India

Following the steps outlined in the previous chapter we aim to analyze the 15 barriers identified for India and get a resulting level partition for every barrier. Using the barrier levels and their inter-relations, we can make a hierarchy flowchart to demonstrate relationships between the barriers and start tackling the most influential barriers. The most influential barriers are found at the bottom-most level of the hierarchy. We will now begin the step-wise barrier analysis for barriers for India.

1. **Structural Self-Intersection Matrix**
   We proceed to examine the contextual relationship between every pair of the identified variables. This relationship is shown using the notations ’V’, ’A’, ’X’, and ’O’ which depict "i influences j", "j influences i", "i and j influence each other", and "i and j have no correlation" respectively.

For example, the relationship between the first barrier, "Lack of R&D culture", and the eighth barrier, "High initial investment cost", is shown using the letter 'V' in the first row under the column 8. This means that the lack of R&D culture in India leads to higher initial investment costs of solar PV and wind projects because if there is not enough research done to reduce the technology costs and improve upon the efficiencies, implementing the project would require larger investments. Similarly, we can infer that multi-tired govt. approvals and long bureaucratic processes causes lack of financing institutions as financiers would stay away from projects which have very long approval time since their investments produce no returns till the project is running. An 'A' in the seventh row under column 1 represents this relationship.
Table 5.1 shows the relationships between each barrier pair and Appendix B accounts for the reasoning behind all relationships. These relationships and their reasoning are determined by brainstorming wherever correlations could not be found in the literature.

	Barriers	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1	Lack of R&D culture	O	A	O	X	V	V	O	V	O	O	O	O	A	O
2	Lack of supporting policy and poor execution	V	V	O	V	V	O	V	O	V	V	V	V	X	
3	Lack of skilled personnel and training institutes	O	O	O	O	A	V	O	O	O	A	V	O		
4	Grid issues/Energy access	A	A	A	O	O	V	O	O	O	A	A			
5	Regulatory issues	V	V	V	A	V	O	V	O	V	A				
6	Lack of awareness/understanding of technology	O	O	O	O	V	O	V	O	V					
7	Lack of financing institutions and incentives	A	A	O	O	X	O	O	V						
8	High initial investment cost	O	A	A	O	A	A	O							
9	Lack of coordination between agencies/stakeholders	V	O	O	V	O	O								
10	Poor reliability and low efficiency	O	A	O	A	O									
11	Poor market infrastructure	A	A	A	A										
12	Lack of information	O	O	O											
13	Lack of local infrastructure (land and resources)	A	O												
14	Lack of subsidies/incentives inadequacy	A													
15	Multi-tired govt. approvals and documentation														

Table 5.1 SSIM for barrier relationships for India

2. **Initial Reachability Matrix**

The relationships determined in the previous SSIM need to be transformed into binary values (1s and 0s) for further analysis. The rules for substitution of the notations 'V', 'A', 'X', and 'O' are as follows:

- In the SSIM, if the (i, j) entry is V, then in the initial reachability matrix the (i, j) entry becomes 1 and the (j, i) entry becomes 0
- In the SSIM, if the (i, j) entry is A, then in the initial reachability matrix the (i, j) entry becomes 0 and the (j, i) entry becomes 1
- In the SSIM, if the (i, j) entry is X, then in the initial reachability matrix the (i, j) entry becomes 1 and the (j, i) entry becomes 1

- In the SSIM, if the (i, j) entry is O, then in the initial reachability matrix the (i, j) entry becomes 0 and the (j, i) entry becomes 0

For example, since at position (1,12) in the SSIM we see an 'X', the entries in positions (1,12) and (12,1) in the initial reachability matrix become '1' and '1' respectively. Similarly, an 'A' at (3,11) position in the SSIM leads to a '0' at (3,11) and a '1' at (11,3) positions in the reachability matrix. Table 5.2 shows the complete initial reachability matrix for the barriers for India.

	Barriers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Lack of R&D culture	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0
2	Lack of supporting policy and poor execution	0	1	1	1	1	1	1	0	1	0	1	1	0	1	1
3	Lack of skilled personnel and training institutes	1	1	1	0	1	0	0	0	0	1	0	0	0	0	0
4	Grid issues/Energy access	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
5	Regulatory issues	0	0	0	1	1	0	1	0	1	0	1	0	1	1	1
6	Lack of awareness/understanding of technology	0	0	1	1	1	1	1	0	1	0	1	0	0	0	0
7	Lack of financing institutions and incentives	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0
8	High initial investment cost	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
9	Lack of coordination between agencies/stakeholders	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1
10	Poor reliability and low efficiency	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
11	Poor market infrastructure	0	0	1	0	0	0	1	1	0	0	1	0	0	0	0
12	Lack of information	1	0	0	0	1	0	0	0	0	1	1	1	0	0	0
13	Lack of local infrastructure (land and resources)	0	0	0	1	0	0	0	1	0	0	1	0	1	0	0
14	Lack of subsidies/incentives inadequacy	1	0	0	1	0	0	1	1	0	1	1	0	0	1	0
15	Multi-tired govt. approvals and documentation	0	0	0	1	0	0	1	0	0	0	1	0	1	1	1

Table 5.2 Initial Reachability Matrix for India

3. **Final Reachability Matrix**

Although the initial reachability matrix accounts for the direct translation of the SSIM into 1s and 0s for the next steps of the barrier analysis, it does not take into account the transitivity between barriers. For example, if barrier 'i' influences barrier 'j' and barrier 'j' influences barrier 'k' then, according to the rule of transitive relationships, barrier 'i' influences barrier 'k', as shown in Fig. 5.1. Such correlations maybe lost in the translation

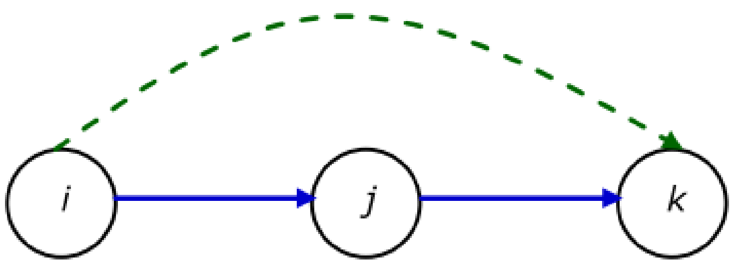

Fig. 5.1 Transitivity between barriers

from the SSIM, therefore, they need to re-checked and updated in the final reachability matrix.

	Barriers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Lack of R&D culture	1	0	1*	0	1*	0	1*	1	0	1	1	1	0	0	0
2	Lack of supporting policy and poor execution	1*	1	1	1	1	1	1	1*	1	1*	1	1	1*	1	1
3	Lack of skilled personnel and training institutes	1	1	1	1*	1	1*	1*	1*	1*	1	1*	1*	1*	1*	1*
4	Grid issues/Energy access	0	0	0	1	0	0	0	1*	0	1	0	0	0	0	0
5	Regulatory issues	1*	0	1*	1	1	0	1	1*	1	1*	1	1*	1	1	1
6	Lack of awareness/understanding of technology	1*	1*	1	1	1	1	1	1*	1	1*	1	1*	1*	1*	1*
7	Lack of financing institutions and incentives	0	0	1*	0	0	0	1	1	0	0	1	0	0	0	0
8	High initial investment cost	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
9	Lack of coordination between agencies/stakeholders	1*	0	0	1*	1*	0	1*	0	1	1*	1*	1	1*	1*	1
10	Poor reliability and low efficiency	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
11	Poor market infrastructure	1*	1*	1	1*	1*	1*	1	1	1*	1*	1	1*	1*	1*	1*
12	Lack of information	1	1*	1*	1*	1	1*	1*	1*	1*	1	1	1	1*	1*	1*
13	Lack of local infrastructure (land and resources)	1*	1*	1*	1	1*	1*	1*	1	1*	1*	1	1*	1	1*	1*
14	Lack of subsidies/incentives inadequacy	1	1*	1*	1	1*	1*	1	1	1*	1	1	1*	1*	1	1*
15	Multi-tired govt. approvals and documentation	1*	1*	1*	1	1*	1*	1	1*	1*	1*	1	1*	1	1	1

Table 5.3 Final Reachability Matrix for India

4. **Level Partitions**
   In this step, the updated reachability matrix is used to obtain the reachability set, antecedent set and intersection set segregating the barriers into different levels. The reachability set for barrier 'i' shows which barriers are influenced by barrier 'i'. Similarly, the antecedent set for barrier 'i' outlines barriers which influence barrier 'i'. The intersection set is simply the intersection of these two sets. A level is assigned to the barrier when the reachability and the intersection sets are the same for a barrier. Shown below are the first two iterations of the level partition for India's barriers. Refer to Appendix C for all the level partition tables.

Barrier Sr. No.	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1 3 5 7 8 10 11 12	1 2 3 5 6 9 11 12 13 14 15	1 3 5 11 12	
2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 5 6 7 11 12 13 14 15	1 2 3 5 6 7 11 12 13 14 15	
4	4 8 10	2 3 4 5 6 9 11 12 13 14 15	4	
5	1 3 4 5 7 8 9 10 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 3 5 9 11 12 13 14 15	
6	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
7	3 7 8 11	1 2 3 5 6 7 9 11 12 13 14 15	3 7 11	
8	8	1 2 3 4 5 6 7 8 10 11 12 13 14 15	8	1st
9	1 4 5 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	5 9 11 12 13 14 15	
10	8 10	1 2 3 4 5 6 9 10 11 12 13 14 15	10	
11	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 5 6 7 9 11 12 13 14 15	1 2 3 5 6 7 9 11 12 13 14 15	
12	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	
13	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
14	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	

Table 5.4 First iteration for level partitioning of barriers in India

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 3 5 7 10 11 12	1 2 3 5 6 9 11 12 13 14 15	1 3 5 11 12	
2	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
3	1 2 3 4 5 6 7 9 10 11 12 13 14 15	1 2 3 5 6 7 11 12 13 14 15	1 2 3 5 6 7 11 12 13 14 15	
4	4 10	2 3 4 5 6 9 11 12 13 14 15	4	
5	1 3 4 5 7 9 10 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 3 5 9 11 12 13 14 15	
6	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
7	3 7 11	1 2 3 5 6 7 9 11 12 13 14 15	3 7 11	2nd
8				1st
9	1 4 5 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	5 9 11 12 13 14 15	
10	10	1 2 3 4 5 6 9 10 11 12 13 14 15	10	2nd
11	1 2 3 4 5 6 7 9 10 11 12 13 14 15	1 2 3 5 6 7 9 11 12 13 14 15	1 2 3 5 6 7 9 11 12 13 14 15	
12	1 2 3 4 5 6 7 9 10 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	
13	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
14	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
15	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	

Table 5.5 Second iteration for level partitioning of barriers in India

5. **Final Levels**

   Table 5.6 shows the level separation of all barriers for India. This is then used to create the ISM digraph.

Level No.	Barriers to the diffusion of Solar PV and Wind in India
1st	High initial investment cost(8)
2nd	Lack of financing institutions and incentives(7)
	Poor reliability and low efficiency(10)
3rd	Lack of R&D culture(1)
	Grid issues/Energy access(4)
4th	Regulatory issues(5)
	Lack of coordination between agencies/stakeholders(9)
	Poor market infrastructure(11)
	Lack of information(12)
	Lack of local infrastructure (land and resources)(13)
	Lack of subsidies/incentives inadequacy(14)
	Multi-tired govt. approvals and documentation(15)
5th	Lack of supporting policy and poor execution(2)
	Lack of skilled personnel and training institutes(3)
	Lack of awareness/understanding of technology(6)

Table 5.6 Various levels of barriers in India.

6. **Resulting Barrier Hierarchy**

   The digraph below (fig. 5.2) depicts all the relationships between the barriers for India as a result of the analysis.

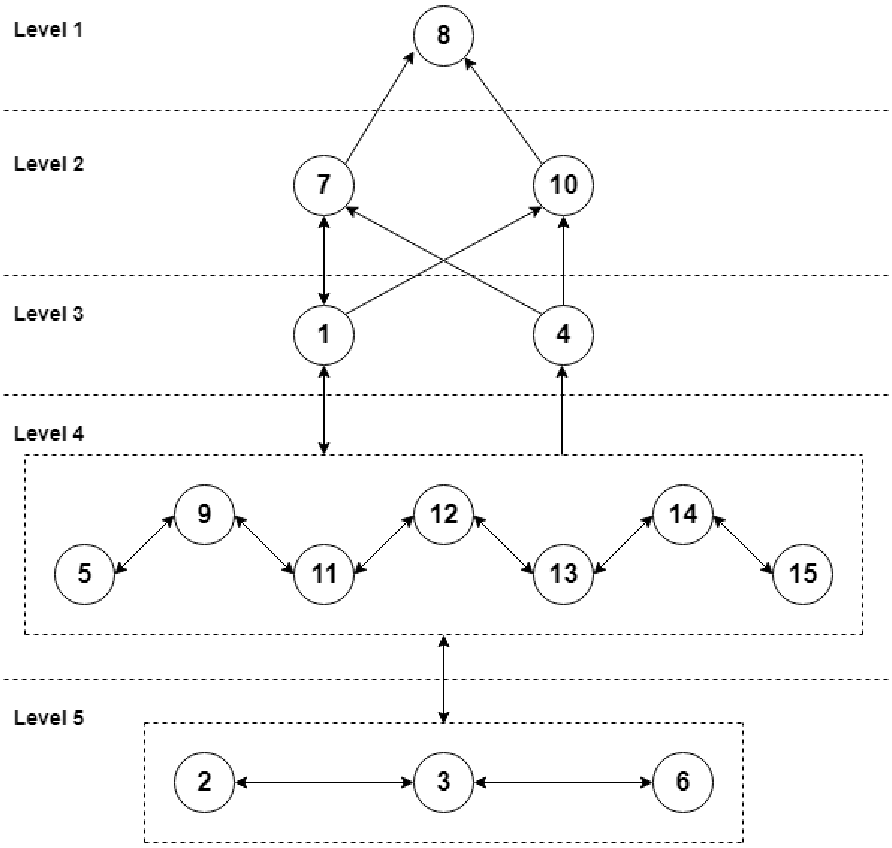

Fig. 5.2 Hierarchy and barrier inter-relationships for India (Bottom level most important)

5.1.1 MICMAC analysis

Final reachability matrix provides us the driving and dependence powers for each barrier, as a result of summation of the 1s in the rows and columns respectively. We then plot a X-Y scatter plot for all the barriers with the dependence power on the X-axis and driving power on the Y-axis. This graph is divided into four quadrants representing autonomous(I), dependent(II), linkage(III), and independent barriers(IV), respectively. This forms the basis for the MICMAC analysis. These four categories of barriers help us understand the importance of barriers based on their strong/weak driving and dependence powers. The explanation of these barrier types is provided in the Methodology chapter (chapter 4) under the Section 4.2.

From the MICMAC analysis, we have the following interpretations for the barriers for diffusion of solar PV and wind energy in India:

- Autonomous barriers operate separately from all others and are therefore relatively easy to tackle because they do not cause any feedback to the other barriers. Independent barriers, on the other hand, due their high influence help affect multiple barriers at once.

	Barriers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Driving Power**
1	Lack of R&D culture	1	0	1*	0	1*	0	1*	1	0	1	1	1	0	0	0	8
2	Lack of supporting policy and poor execution	1*	1	1	1	1	1	1	1*	1	1*	1	1	1*	1	1	15
3	Lack of skilled personnel and training institutes	1	1	1	1*	1	1*	1*	1*	1*	1	1*	1*	1*	1*	1*	15
4	Grid issues/Energy access	0	0	0	1	0	0	0	1*	0	1	0	0	0	0	0	3
5	Regulatory issues	1*	0	1*	1	1	0	1	1*	1	1*	1	1*	1	1	1	13
6	Lack of awareness/understanding of technology	1*	1*	1	1	1	1	1	1*	1	1*	1	1*	1*	1*	1*	15
7	Lack of financing institutions and incentives	0	0	1*	0	0	0	1	1	0	0	1	0	0	0	0	4
8	High initial investment cost	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
9	Lack of coordination between agencies/stakeholders	1*	0	0	1*	1*	0	1*	0	1	1*	1*	1	1*	1*	1	11
10	Poor reliability and low efficiency	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2
11	Poor market infrastructure	1*	1*	1	1*	1*	1*	1	1	1*	1*	1	1*	1*	1*	1*	15
12	Lack of information	1	1*	1*	1*	1	1*	1*	1*	1*	1	1	1	1*	1*	1*	15
13	Lack of local infrastructure (land and resources)	1*	1*	1*	1	1*	1*	1*	1	1*	1*	1	1*	1	1*	1*	15
14	Lack of subsidies/incentives inadequacy	1	1*	1*	1	1*	1*	1	1	1*	1	1	1*	1*	1	1*	15
15	Multi-tired govt. approvals and documentation	1*	1*	1*	1	1*	1*	1	1*	1*	1*	1	1*	1	1	1	15
	Dependence Power	11	8	11	11	11	8	12	14	10	13	12	11	10	10	10	

Table 5.7 Driving and Dependence powers of barriers from the Final Reachability Matrix for India

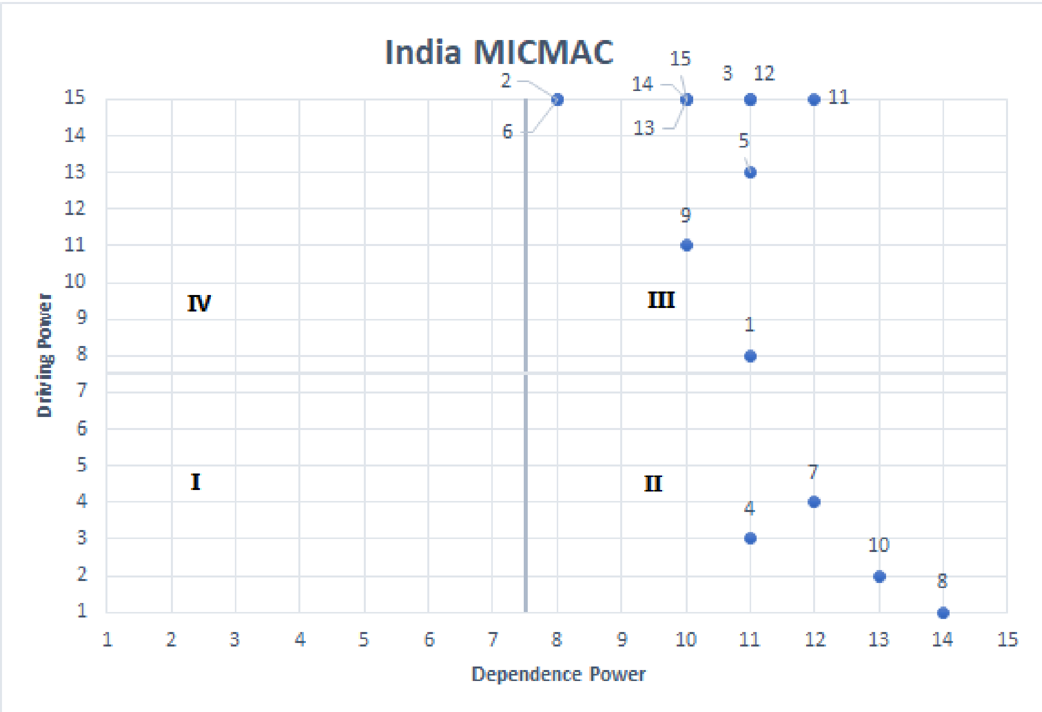

Fig. 5.3 Dependence power vs. Driving power for India's barriers

But as seen from the graph, no barriers lie in quadrants I and IV. Therefore, we can say that *there are no autonomous(I) or independent(IV) barriers* for India. This means that all the barriers have high dependence powers and are therefore very inter-related.

- Dependent barriers have weak driving power but a strong dependence power, i.e. low influence on other barriers but get influenced by a lot of other barriers. Therefore, *barriers 4, 7, 8, and 10 are dependent(II) barriers*. Grid issues, lack of finance, high initial investments and low technological efficiency are found to be highly dependent on a lot of factors ranging from awareness and policy measures to R&D.

- Linkage barriers have very high influence but they are also very dependent on other factors, i.e. high driving and dependence powers. It is very difficult to tackle these barriers since they are very closely interlinked and make the system very unstable. From the plot, *barriers 2, 3, 5, 6, 9, 11, 12, 13, 14, and 15 are linkage(III) barriers* of varying degree. Lack of policy measures, consumer awareness, R&D, lack of data, lack of regulations and all the other linkage barriers affect each other and it is difficult to tackle one of them without causing unpredictable changes in the others.

5.2 Interpretive structural modeling to find the levels of barriers in China

Following the steps outlined in the previous chapter we aim to analyze the 15 barriers identified for China and get a resulting level partition for every barrier. Using the barrier levels and their inter-relations, we can make a hierarchy flowchart to demonstrate relationships between the barriers and start tackling the most influential barriers. The most influential barriers are found at the bottom-most level of the hierarchy. We will now begin the step-wise barrier analysis for barriers for China.

1. **Structural Self-Intersection Matrix**
   We proceed to examine the contextual relationship between every pair of the identified variables. This relationship is shown using the notations 'V', 'A', 'X', and 'O' which depict "i influences j", "j influences i", "i and j influence each other", and "i and j have no correlation" respectively.

   For example, the relationship between the fourth barrier, "Lack of financing", and the twelfth barrier, "Lack of coordination among agencies", is shown using the letter 'O' in the fourth row under the column 12. This means that the lack of financiers for solar and wind projects in China has no correlation whatsoever with the coordination among responsible agencies. Similarly, we can infer that limited policy framework/lack thereof and lack of research personnel and skilled manpower, both, influence each other because, on one hand, where policy making needs people with experience in the technology at the decision making level to point out flaws and needs of policy in that field, on the other hand, absence of policy also leads to absence of knowledge generation and establishment of educational institutions in that field. An 'X' in the second row under column 9 represents this relationship.

Table 5.8 shows the relationships between each barrier pair and Appendix B accounts for the reasoning behind all relationships. These relationships and their reasoning are determined by brainstorming wherever correlations could not be found in the literature.

	Barriers	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1	Lack of incentives/subsidies compared to fossil fuels	A	O	O	O	V	O	O	A	V	A	V	V	O	A
2	Limited policy framework or lack thereof	V	V	O	V	V	V	X	A	O	V	V	V	O	
3	Lack of experience in technology and management	O	A	O	V	V	V	A	O	A	V	V	V		
4	Lack of funding/financing difficulties	A	O	O	O	X	O	O	A	O	A	O			
5	Grid capacity and connectivity delays	A	O	O	O	O	O	O	O	O	A				
6	Lack of legal and regulatory framework	V	O	V	V	V	A	A	A	O					
7	Lack of R&D	O	O	O	O	V	X	A	O						
8	Lack of strategic planning and political will	O	A	O	O	O	O	V							
9	Lack of research personnel or trained manpower	O	A	O	O	A	O								
10	Inadequate data and information	O	O	O	A	V									
11	Inadequate market size and infrastructure	A	A	A	O										
12	Lack of coordination among agencies	V	O	O											
13	Resource unavailability	A	O												
14	Lack of consumer awareness	O													
15	Bureaucratic hassles (permissions and documentation)														

Table 5.8 SSIM for barrier relationships for China

2. **Initial Reachability Matrix**

   The relationships determined in the previous SSIM need to be transformed into binary values (1s and 0s) for further analysis. The rules for substitution of the notations 'V', 'A', 'X', and 'O' are as follows:

   - In the SSIM, if the (i, j) entry is V, then in the initial reachability matrix the (i, j) entry becomes 1 and the (j, i) entry becomes 0
   - In the SSIM, if the (i, j) entry is A, then in the initial reachability matrix the (i, j) entry becomes 0 and the (j, i) entry becomes 1
   - In the SSIM, if the (i, j) entry is X, then in the initial reachability matrix the (i, j) entry becomes 1 and the (j, i) entry becomes 1
   - In the SSIM, if the (i, j) entry is O, then in the initial reachability matrix the (i, j) entry becomes 0 and the (j, i) entry becomes 0

   For example, since at position (10,2) in the SSIM we see an 'V', the entries in positions (10,2) and (2,10) in the initial reachability matrix become '1' and '0' respectively. Similarly, an ’O’ at (4,7) position in the SSIM leads to a ’0’ at both, (4,7) and (7,4), positions in the reachability matrix. Table 5.9 shows the complete initial reachability matrix for the barriers for India.

	Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Lack of incentives/subsidies compared to fossil fuels	1	0	0	1	1	0	1	0	0	0	1	0	0	0	0
2	Limited policy framework or lack thereof	1	1	0	1	1	1	0	0	1	1	1	1	0	1	1
3	Lack of experience in technology and management	0	0	1	1	1	1	0	0	0	1	1	1	0	0	0
4	Lack of funding/financing difficulties	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
5	Grid capacity and connectivity delays	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
6	Lack of legal and regulatory framework	1	0	0	1	1	1	0	0	0	0	1	1	1	0	1
7	Lack of R&D	0	0	1	0	0	0	1	0	0	1	1	0	0	0	0
8	Lack of strategic planning and political will	1	1	0	1	0	1	0	1	1	0	0	0	0	0	0
9	Lack of research personnel or trained manpower	0	1	1	0	0	1	1	0	1	0	0	0	0	0	0
10	Inadequate data and information	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0
11	Inadequate market size and infrastructure	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0
12	Lack of coordination among agencies	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1
13	Resource unavailability	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
14	Lack of consumer awareness	0	0	1	0	0	0	0	1	1	0	1	0	0	1	0
15	Bureaucratic hassles (permissions and documentation)	1	0	0	1	1	0	0	0	0	0	1	0	1	0	1

Table 5.9 Initial Reachability Matrix for China

3. **Final Reachability Matrix**

   Although the initial reachability matrix accounts for the direct translation of the SSIM into 1s and 0s for the next steps of the barrier analysis, it does not take into account the transitivity between barriers. For example, if barrier ’i’ influences barrier ’j’ and barrier ’j’ influences barrier ’k’ then, according to the rule of transitive relationships, barrier ’i’ influences barrier ’k’, as shown in Fig. 5.1.

   Correlations maybe lost in the translation from the SSIM, therefore, they need to re-checked and updated in the final reachability matrix.

	Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Lack of incentives/subsidies compared to fossil fuels	1	0	1*	1	1	1*	1	0	1*	1*	1	0	0	0	0
2	Limited policy framework or lack thereof	1	1	1*	1	1	1	1*	1*	1	1	1	1	1*	1	1
3	Lack of experience in technology and management	1*	0	1	1	1	1	1*	0	1*	1	1	1	1*	0	1*
4	Lack of funding/financing difficulties	0	0	0	1	0	0	0	0	1*	0	1	0	0	0	0
5	Grid capacity and connectivity delays	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
6	Lack of legal and regulatory framework	1	1*	1*	1	1	1	1*	0	1*	1*	1	1	1	0	1
7	Lack of R&D	1*	1*	1	1*	1*	1*	1	0	1*	1	1	1*	1*	0	1*
8	Lack of strategic planning and political will	1	1	1*	1	1*	1	1*	1	1	1*	1*	1*	1*	1*	1*
9	Lack of research personnel or trained manpower	1*	1	1	1*	1*	1	1	1*	1	1*	1*	1*	1*	1*	1*
10	Inadequate data and information	1*	1*	1*	1*	1*	1	1	1*	1*	1	1	1*	1*	1*	1*
11	Inadequate market size and infrastructure	1*	1*	1*	1	1*	1*	1*	1*	1	1*	1	1*	1*	1*	1*
12	Lack of coordination among agencies	1*	1*	1*	1*	1*	1*	1*	1*	1*	1	1*	1	1*	1*	1
13	Resource unavailability	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1	1*	1	1*	1*
14	Lack of consumer awareness	1*	1*	1	1*	1*	1*	1*	1	1	1*	1	1*	1*	1	1*
15	Bureaucratic hassles (permissions and documentation)	1	1*	1*	1	1	1*	1*	1*	1*	1*	1	1*	1	1*	1

Table 5.10 Final Reachability Matrix for China

4. **Level Partitions**
   In this step, the updated reachability matrix is used to obtain the reachability set, antecedent set and intersection set segregating the barriers into different levels. The reachability set for barrier 'i' shows which barriers are influenced by barrier 'i'. Similarly, the antecedent set for barrier 'i' outlines barriers which influence barrier 'i'. The intersection set is simply the intersection of these two sets. A level is assigned to the barrier when the reachability and the intersection sets are the same for a barrier. Shown below are the first two iterations of the level partition for China's barriers. Refer to Appendix C for all the level partition tables.

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 3 4 5 6 7 9 10 11	1 2 3 6 7 8 9 10 11 12 13 14 15	1 3 6 7 9 10 11	
2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 6 7 8 9 10 11 12 13 14 15	2 6 7 8 9 10 11 12 13 14 15	
3	1 3 4 5 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 3 6 7 9 10 11 12 13 15	
4	4 9 11	1 2 3 4 6 7 8 9 10 11 12 13 14 15	4 9 11	1st
5	5	1 2 3 5 6 7 8 9 10 11 12 13 14 15	5	1st
6	1 2 3 4 5 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 9 10 11 12 13 15	
7	1 2 3 4 5 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 9 10 11 12 13 15	
8	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	
9	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 4 6 7 8 9 10 11 12 13 14 15	1 2 3 4 6 7 8 9 10 11 12 13 14 15	
10	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	
11	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 4 6 7 8 9 10 11 12 13 14 15	1 2 3 4 6 7 8 9 10 11 12 13 14 15	
12	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	
13	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	
14	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	
15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	

Table 5.11 First iteration for level partitioning of barriers in China

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 3 6 7 9 10 11	1 2 3 6 7 8 9 10 11 12 13 14 15	1 3 6 7 9 10 11	2nd
2	1 2 3 6 7 8 9 10 11 12 13 14 15	2 6 7 8 9 10 11 12 13 14 15	2 6 7 8 9 10 11 12 13 14 15	
3	1 3 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 3 6 7 9 10 11 12 13 15	2nd
4				1st
5				1st
6	1 2 3 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 9 10 11 12 13 15	2nd
7	1 2 3 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 9 10 11 12 13 15	2nd
8	1 2 3 6 7 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	
9	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	2nd
10	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	2nd
11	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	2nd
12	1 2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	
13	1 2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	
14	1 2 3 6 7 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	
15	1 2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	

Table 5.12 Second iteration for level partitioning of barriers in China

5. **Final Levels**
Table 5.13 shows the level partition for all barriers for China. This is further used to create the ISM digraph.

Level No.	Barriers to the diffusion of Solar PV and Wind in China
1st	Lack of funding/financing difficulties(4)
	Grid capacity and connectivity delays(5)
2nd	Lack of incentives/subsidies compared to fossil fuels(1)
	Lack of experience in technology and management(3)
	Lack of legal and regulatory framework(6)
	Lack of R&D(7)
	Lack of research personnel or trained manpower(9)
	Inadequate data and information(10)
	Inadequate market size and infrastructure(11)
3rd	Limited policy framework or lack thereof(2)
	Lack of strategic planning and political will(8)
	Lack of coordination among agencies(12)
	Resource unavailability(13)
	Lack of consumer awareness(14)
	Bureaucratic hassles (permissions and documentation)(15)

Table 5.13 Various levels of barriers in China

6. **Resulting Barrier Hierarchy**
The digraph in Fig. 5.4 depicts all barrier relationships for China as a result of the analysis.

5.2.1 MICMAC analysis

Final reachability matrix provides us the driving and dependence powers for each barrier, as a result of summation of the 1s in the rows and columns respectively. We then plot a X-Y scatter plot for all the barriers with the dependence power on the X-axis and driving power on the Y-axis. This graph is divided into four quadrants representing autonomous(I), dependent(II), linkage(III), and independent barriers(IV), respectively. This forms the basis for the MICMAC analysis. These four categories of barriers help us understand the importance of barriers based on their strong/weak driving and dependence powers. The explanation of these barrier types is provided in the Methodology chapter (chapter 4) under the Section 4.2.

We can draw the following interpretations for the barriers for diffusion of solar PV and wind energy in China from the MICMAC analysis:

- Just like India, we do not observe any barriers in the left side of the plot, i.e. there are *no autonomous(I) and independent(IV) barriers for China.* The barriers in case are also found to be extremely inter-dependent with high dependence powers.

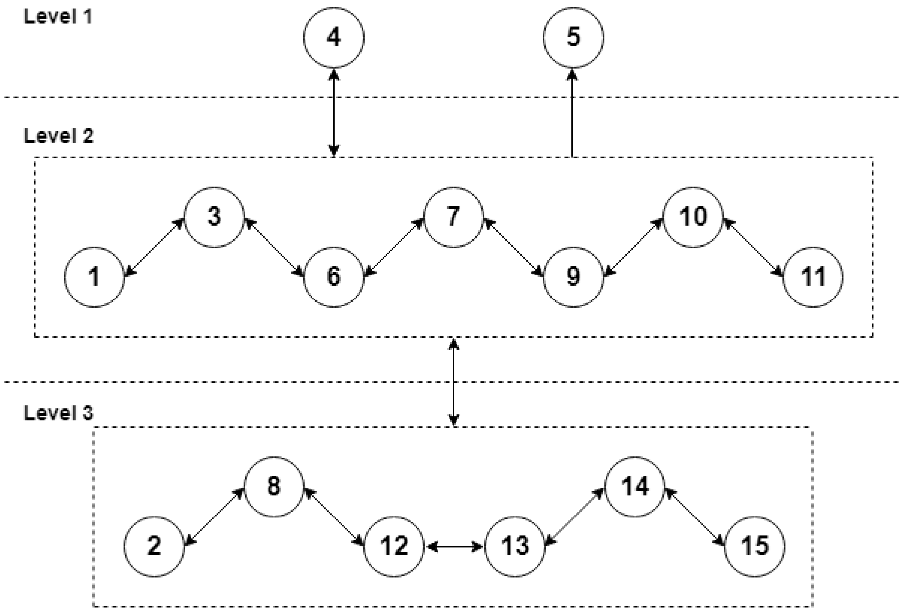

Fig. 5.4 Hierarchy and barrier inter-relationships for China (Bottom level most important)

	Barriers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Driving Power**
1	Lack of incentives/subsidies compared to fossil fuels	1	0	1*	1	1	1*	1	0	1*	1*	1	0	0	0	0	9
2	Limited policy framework or lack thereof	1	1	1*	1	1	1	1*	1*	1	1	1	1	1*	1	1	15
3	Lack of experience in technology and management	1*	0	1	1	1	1	1*	0	1*	1	1	1	1*	0	1*	12
4	Lack of funding/financing difficulties	0	0	0	1	0	0	0	0	1*	0	1	0	0	0	0	3
5	Grid capacity and connectivity delays	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
6	Lack of legal and regulatory framework	1	1*	1*	1	1	1	1*	0	1*	1*	1	1	1	0	1	13
7	Lack of R&D	1*	1*	1	1*	1*	1*	1	0	1*	1	1	1*	1*	0	1*	13
8	Lack of strategic planning and political will	1	1	1*	1	1*	1	1*	1	1	1*	1*	1*	1*	1*	1*	15
9	Lack of research personnel or trained manpower	1*	1	1	1*	1*	1	1	1*	1	1*	1*	1*	1*	1*	1*	15
10	Inadequate data and information	1*	1*	1*	1*	1*	1	1	1*	1*	1	1	1*	1*	1*	1*	15
11	Inadequate market size and infrastructure	1*	1*	1*	1	1*	1*	1*	1*	1	1*	1	1*	1*	1*	1*	15
12	Lack of coordination among agencies	1*	1*	1*	1*	1*	1*	1*	1*	1*	1	1*	1	1*	1*	1	15
13	Resource unavailability	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1	1*	1	1*	1*	15
14	Lack of consumer awareness	1*	1*	1	1*	1*	1*	1*	1	1	1*	1	1*	1*	1	1*	15
15	Bureaucratic hassles (permissions and documentation)	1	1*	1*	1	1	1*	1*	1*	1*	1*	1	1*	1	1*	1	15
	Dependence Power	13	11	13	14	14	13	13	9	14	13	14	12	12	9	12	

Table 5.14 Driving and Dependence powers of barriers from the Final Reachability Matrix for China

- We observe only two dependent(II) barriers, namely, lack of funding/financing and grid issues. Therefore, *only barriers 4 and 5 are dependent(II) barriers*. Lack of finance and grid issues are largely dependent on policy support, proper regulations, consumer awareness, project reliability and other such factors.

- Linkage barriers, which have very high driving and dependence powers, are found to be in abundance in China’s solar PV and wind energy scenario. From the graph,

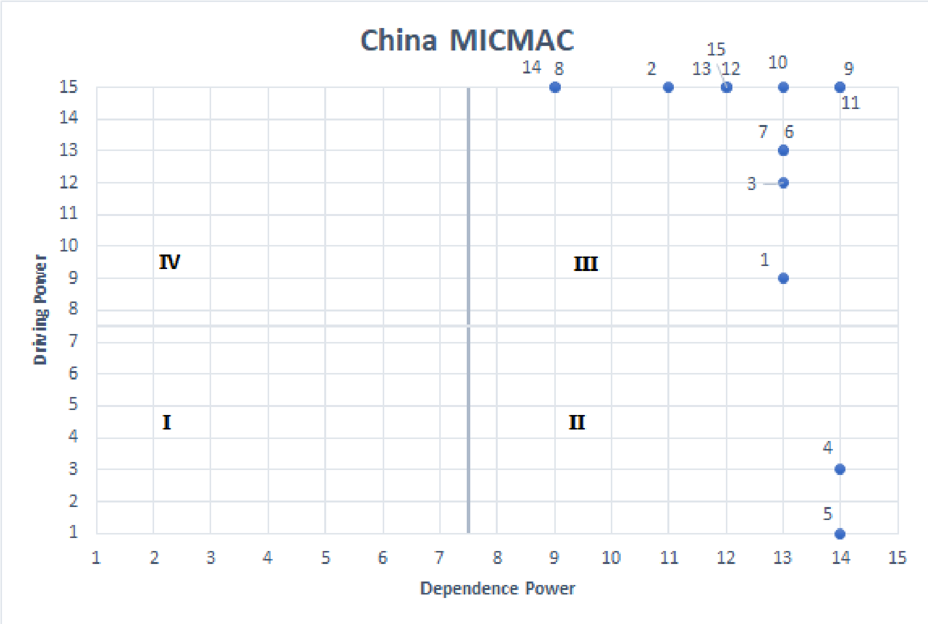

Fig. 5.5 Dependence power vs. Driving power for China's barriers

we can see that all the barriers except barriers 4 and 5 are linkage barriers of little variance in their degree of inter-dependence. *Barriers 1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15 are linkage(III) barriers* and make the system highly unstable due to their very high influence and simultaneously high inter-dependence. Lack of supporting policy, lack of planning & political will, sub-par R&D initiatives, and all the other linkage(III) barriers are very difficult to tackle individually since they always have an indeterminable feedback effect on the whole system of barriers.

The description of ISM hierarchy digraphs and barrier rankings obtained from the MICMAC analysis is carried out in the following results and discussions chapter. While briefly describing the relationships between the barriers and the ranking, this chapter will also talk about the limitations to the thesis and carry out a brief sensitivity analysis to visualize changes in the system if some relationships are changed.

Chapter 6

Results & Discussion

6.1 Results

From the ISM and MICMAC analysis, we obtain two vital pieces of information. Firstly, we can see how the barriers influence other barriers and obtain a hierarchy outlining all these inter-relations. Figures 6.1 and 6.2 show the hierarchical digraphs for India and China, respectively. Secondly, we can rank the barriers based on their driving and dependence powers, as shown in Table 6.1 and 6.2, so that we know which ones to tackle first and how much of an impact they can have on the system as a whole.

These two insights into the solar PV and wind energy industries of both, India and China, will help us improve the situations in both these countries by providing a recommendations list to both the governments, systematically tackling the barriers.

From Fig. 6.1, we see that India's barriers to the solar PV and wind energy diffusion are divided in five levels. Level 1 has only one barrier, namely high initial investment cost(8), which is affected by barrier 7 and 10 in level 2, but it in turn does not affect the level 2 barriers. The level two barriers do not influence each other but get influenced by both the level 3 barriers. Barrier 7 (lack of finance) also reverse affects barrier 1 (lack of R&D). Level 3 barriers again do not influence each other but get affected by level 4 barriers. Level 4 contains seven barriers and all of them influence each other, therefore, we can assume level 4 to be one block which affects level 3 barriers and gets affected by level 5 barriers and also by barrier 7 (lack of R&D). Similar to level 4, level 5 contains three barriers which influence each other and can be considered as a single block.

We observe an obvious cluster of barriers in the 4th and 5th levels which influence each other. This essentially means that an change in even one of them may result in a chain reaction of effects on the other barriers. These two intricate blocks of barriers, therefore, need to be tackled with utmost precision, predicting the after-effects of the tackling of one of the barriers on the remaining ones. Since the barriers in levels 1, 2 and, 3 are not related within their own levels, they can be tackled simultaneously and their solutions would not coincide. The positions of individual barriers seem very logical, in that, one would expect policy and regulatory measures to be of immense importance, along with consumer awareness and market infrastructure, showing up in the bottom levels of the hierarchy. The barrier 'lack of training institutes and skilled personnel' also fits in perfectly with the narrative that without trained individuals the industry cannot flourish beyond a certain point.

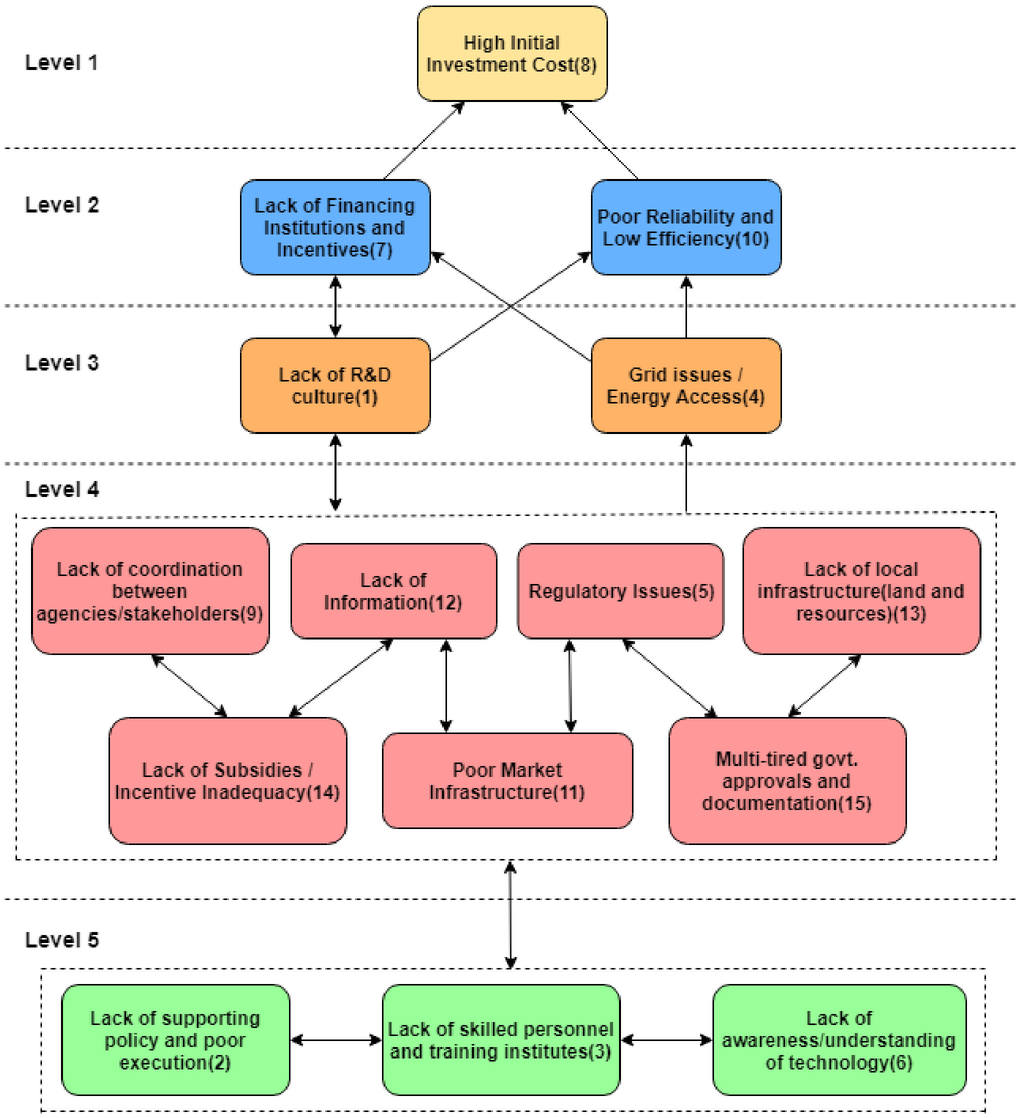

Fig. 6.1 Final ISM Hierarchy for India Barriers (Bottom level most important)

Rank	Barriers	Driving Power	Dependence Power
1	Lack of supporting policy and poor execution(2)	15	8
2	Lack of awareness/understanding of technology(6)	15	8
3	Lack of local infrastructure (land and resources)(13)	15	10
4	Lack of subsidies/incentives inadequacy(14)	15	10
5	Multi-tired govt. approvals and documentation(15)	15	10
6	Lack of skilled personnel and training institutes(3)	15	11
7	Lack of information(12)	15	11
8	Poor market infrastructure(11)	15	12
9	Regulatory issues(5)	13	11
10	Lack of coordination between agencies/stakeholders(9)	11	10
11	Lack of R&D culture(1)	8	11
12	Lack of financing institutions and incentives(7)	4	12
13	Grid issues/Energy access(4)	3	11
14	Poor reliability and low efficiency(10)	2	13
15	High initial investment cost(8)	1	14

Table 6.1 Barrier ranking according to Dependence and Driving powers for India

In case of China's barriers, as seen from Fig. 6.2, we observe only three levels. The top-most level, level 1, has only two barriers, namely, lack of finances(4) and grid issues(5), which are both affected by the level 2 barriers but they do not influence each other. We see that there are seven and six barriers, respectively, in level 2 and level 3. All the barriers within one level influence each other and can therefore be considered as one block. Level 2 barriers get affected by level 3 barriers and barrier 5 (lack of finances) and they also influence level 3 barriers in return.

The smaller level-wise distribution for China and the bigger barrier clusters make the scenario in the country even tougher to solve. The heavy interdependence of barriers will call for precise actions and accurate prediction of effects of those actions on the other barriers in the system. The bottom-most level (level 3) comprises of barriers which are of obvious value, like the need of policy framework, lack of planning, consumer unawareness and bureaucratic hassles. 'Resource unavailability' showing up in the bottom-most level was a bit of a surprise. But this can be justified by the fact that, although availability of land, grid connection and construction resources at the project site are vital everywhere, the problem is especially aggravated in China due to the huge geographical distances between the energy demand centers and project sites with the most outputs. These solar and wind projects cannot be constructed very close to the demand centers due to the high land prices and lesser irradiation or wind speed values due to the interception by the city's infrastructure. All the other barrier positions seem very logical.

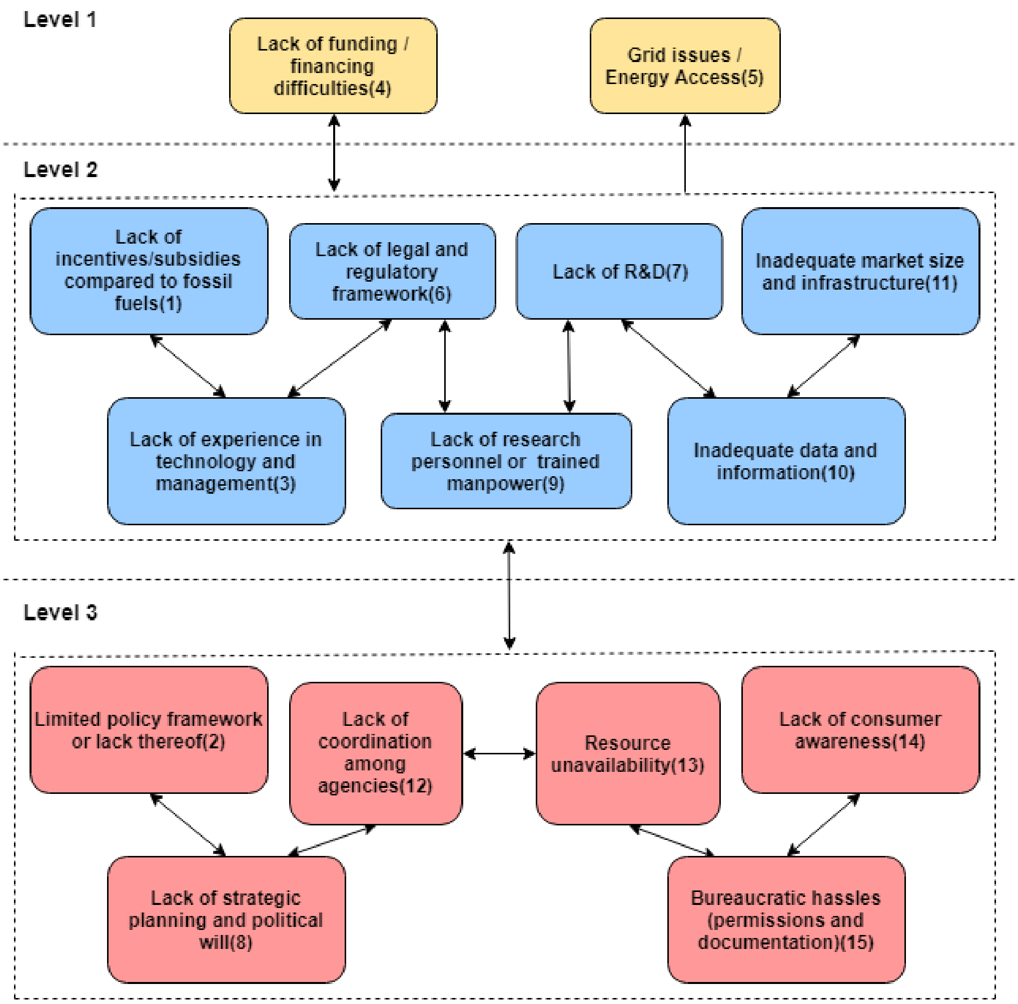

Fig. 6.2 Final ISM Hierarchy for China Barriers (Bottom level most important)

Rank	Barriers	Driving Power	Dependence Power
1	Lack of strategic planning and political will(8)	15	9
2	Lack of consumer awareness(14)	15	9
3	Limited policy framework or lack thereof(2)	15	11
4	Lack of coordination among agencies(12)	15	12
5	Resource unavailability(13)	15	12
6	Bureaucratic hassles (permissions and documentation)(15)	15	12
7	Inadequate data and information(10)	15	13
8	Lack of research personnel or trained manpower(9)	15	14
9	Inadequate market size and infrastructure(11)	15	14
10	Lack of legal and regulatory framework(6)	13	13
11	Lack of R&D(7)	13	13
12	Lack of experience in technology and management(3)	12	13
13	Lack of incentives/subsidies compared to fossil fuels(1)	9	13
14	Lack of funding/financing difficulties(4)	3	14
15	Grid capacity and connectivity delays(5)	1	14

Table 6.2 Barrier ranking according to Dependence and Driving powers for China

Both ISM digraphs tell us that we need to solve the issues in the bottom-most level to cause the most impact on the system. For India, it is level 5 consisting of barriers like lack of supporting policy(2), lack of skilled personnel(3) and, lack of awareness among consumers(6). China, on the other hand, has six barriers in its bottom-most level, level 3. These barriers are limited/no policy framework(2), lack of political will ans planning(8), lack of coordination(12), resource unavailability(13), lack of consumer awareness(14) and, bureaucratic hassles(15). Cross checking the barriers with the rankings based on driving and dependence powers, we can say that solving these will cause the biggest impact on the growth of solar PV and wind energy in India and China.

6.1.1 Comparison between the barriers in India and China

We identify quite a few barriers are common to both the countries. Their positions in the hierarchy are also very similar. *Lack of awareness among consumers* and *lack of policy measures* are the two barriers common to the bottom-most levels which means that both these barriers are very important to solve the issue. *Lack of finances, grid issues, lack of R&D, lack of subsidies/incentives, lack of legal and regulatory framework, inadequate market infrastructure, lack of trained personnel, lack of coordination among agencies, bureaucratic hassles* and *inadequate data and information* are barriers which have been found to be common for both the countries.

Although, as many as 12 similar barriers have been identified between the two countries, their interactions with each other are different, because both the countries function very differently. For example, we see a few private players in the renewable energy market in India, whereas in China, the projects are government sanctioned. Problems like the grid not being ready for the fluctuations of the power input, technological inefficiencies and complex project sanctioning procedures seem to be valid for a lot of countries globally (Aly et al., 2019; Edsand, 2017; Rai et al., 2016; Urban, 2009; Yermakova, 2018; Zhang et al., 2012). Larger number of researchers citing the same problems is also a major reason behind the commonality, since literature forms the basis of the choice of barriers for this analysis in the first place.

From the two digraphs, we can also see that the barriers for China are clustered together and more interdependent than that of India. This could be attributed to the government-controlled nature of the industries in China. In a sense, we observe a more centrally steered system in China, with a single source of origination for any changes made to the RE industry. This includes all the steps taken by the multiple agencies responsible for the functioning of the solar and wind industry, which results in a uniformity in the problems across the industry and the heavy interlinking of barriers.

This was corroborated in an informal interview with *Mr. Wim Lansink* from *Goldwind*, whose 20+ years of expertise in the wind energy industry in China proved very useful to gauge the on-ground scenario in the country (Lansink, 2019). Further, he went on to stress that there are only a handful of key players in the wind energy market and that most small-scale companies are moving towards being state-owned. He also pointed out that all big conglomerates, with any kind of clout within the industry, have members in the governmental decision making council which decides upon new policies. This proves the importance of bureaucracy in the country and validates the unidirectional, centralized flow of policy measures in the country. He also said that the extremely high FITs took away the incentive to improve technologies through R&D and the ban of publishing of research data and outcomes prevents the validation of the success of the research. All these observations from the wind energy industry by Mr. Lansink support our findings of lack of market infrastructure, R&D and, planning and the presence of bureaucratic obstacles as the barriers to the growth of the RE industry in China.

In India, on the other hand, the many agencies established for the growth of these two sectors operate at different levels and in different areas within the country and therefore have small amounts of influence over the sector as a whole. There is also a substantial difference between the state-level and central policies, due to which, some states have a much higher share of renewables than the others. This decentralized distribution of control leads to a much scattered level-wise distribution of barriers due to the presence of multiple stakeholders within the industry.

In spite of this difference in the distribution of barriers in separate levels, we still observe a similar result for both the countries in terms of the absolute hierarchical position of individual barriers.

Another comparison, in terms of the relative positions of the common barriers, can be made with the already published paper by Ansari et al. (2013). Figure 6.3 shows the hierarchy taken from the paper written by Ansari et al. which analyses the barriers to the solar power installations in India using the same methodology. Although this paper was written in 2013, we find that quite a few similar barriers relevant today. In our study, when compared to this paper, there are 10 barriers which are similar for India and 8 for China.

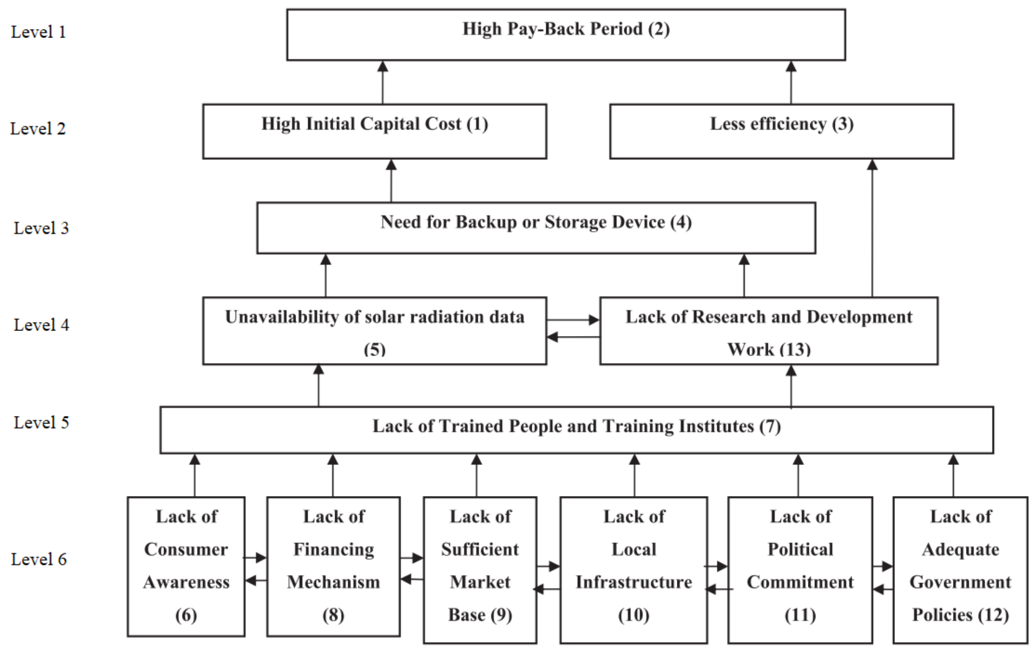

Fig. 6.3 Hierarchy for barriers from Ansari et al. (2013) (Bottom level most important)

The barriers in India show a similar positioning, as can be seen when we compare figs. 6.3 and 6.1. The lack of consumer awareness, market infrastructure, local infrastructure, relevant policy and trained people are all seen in the bottom levels for both the analyses. Lack of R&D, information insufficiency, low efficiencies and high initial investment cost also occupy similar positions in the upper levels of the hierarchy in both the analyses. Lack of financing institutions is the only barrier that shows a contrasting position when the two hierarchies are compared. Since we find that the definitions of what 'lack of financing institutions' means for both the studies are almost the same, this discrepancy can be attributed to the fact that the RE financing scenario in India is much better than what it was in 2013, due to the decreased technology costs and the reduced hesitation of investors when considering the risks of RE projects.

Even for China, we observe that 7 of the 8 common barriers occupy similar positions in the hierarchy in both the studies (comparing figs. 6.3 and 6.2). The only barrier that has declined in terms of its importance is the 'lack of financing', the reason being decreased technology costs and increased investor awareness. Although the two studies cannot be compared since they are conducted for different countries, it is interesting to see the commonality between barriers and their positions in the final hierarchy.

Now, we check for differences in the resulting hierarchies when we make changes in the initial relationship matrix, wherever we were unsure of the barrier relationships, for both the countries. This is done to check the sensitivity of of our results and to check how important the interrelations between the barriers are to the final hierarchy.

6.2 Sensitivity Analysis

As discussed before, there is a fair amount of doubt and ambiguity in establishing the relationships between barriers. The relationships have been determined mostly based on literature, whenever available, but had to come from my own understanding of the barrier interplay in the two countries. Even in cases where relationships could be defined from literature, there is an uncertainty of the present status of those relationships. They may have worsened, stayed the same or solved altogether, since being studied in the relevant papers. My own understanding of the situations in both the countries comes from academic and industrial reports and these reports do not always account for the on-ground status. To tackle these barrier relationship uncertainties, a brief sensitivity analysis has been conducted.

We wanted to check the changes in the final ISM hierarchy by varying some relationships in the initial relationship matrix (SSIM). We have made a few changes in the SSIMs of both the countries and the resulting hierarchy will be compared to the one we obtained from our main analysis. Some relationships that have been changed are shown in bold and the values that we have used for the main analysis are shown in brackets right next to them in the following tables (Tables 6.3 and 6.4). These were relationships we were unsure about. These relationships can be perceived in different ways by different stakeholders. The uncertainty also arises from the fact that sometimes the relationships can be extrapolated from factors not under the study scope.

	Barrier	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1	Lack of R&D culture	O	A	O	X	**O**(V)	V	O	V	O	O	O	**V**(O)	A	**A**(O)
2	Lack of supporting policy and poor execution	V	V	**V**(O)	V	V	O	V	**V**(O)	V	V	V	V	X	
3	Lack of skilled personnel and training institutes	O	O	O	O	A	V	O	O	**A**(O)	A	V	O		
4	Grid issues/Energy access	A	**O**(A)	A	**V**(O)	O	V	O	O	**A**(O)	A	A			
5	Regulatory issues	V	V	V	A	V	O	V	O	V	A				
6	Lack of awareness/understanding of technology	O	O	O	O	V	O	V	O	V					
7	Lack of financing institutions and incentives	A	A	**V**(O)	O	X	O	O	**O**(V)						
8	High initial investment cost	O	A	A	O	A	A	O							
9	Lack of coordination between agencies/stakeholders	V	O	**V**(O)	V	**V**(O)	O								
10	Poor reliability and low efficiency	O	**V**(A)	O	A	O									
11	Poor market infrastructure	A	**X**(A)	**X**(A)	**O**(A)										
12	Lack of information	O	O	O											
13	Lack of local infrastructure (land and resources)	A	O												
14	Lack of subsidies/incentives inadequacy	A													
15	Multi-tired govt. approvals and documentation														

Table 6.3 Changed SSIM for barrier relationships for India

	Barrier	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1	Lack of incentives/subsidies compared to fossil fuels	A	O	O	O	**X**(V)	O	O	A	V	A	**O**(V)	V	O	A
2	Limited policy framework or lack thereof	V	V	**V**(O)	V	V	V	X	A	**V**(O)	V	V	V	A(O)	
3	Lack of experience in technology and management	O	A	O	V	V	**O**(V)	A	O	A	V	**O**(V)	V		
4	Lack of funding/financing difficulties	A	**A**(O)	O	O	X	O	**V**(O)	A	O	A	**V**(O)			
5	Grid capacity and connectivity delays	A	O	O	O	O	V	O	**A**(O)	**A**(O)	A				
6	Lack of legal and regulatory framework	V	**A**(O)	V	V	V	A	A	A	O					
7	Lack of R&D	O	O	**A**(O)	O	**O**(V)	X	A	O						
8	Lack of strategic planning and political will	O	A	O	**V**(O)	**V**(O)	O	V							
9	Lack of research personnel or trained manpower	O	A	O	O	A	O								
10	Inadequate data and information	O	O	O	A	**O**(V)									
11	Inadequate market size and infrastructure	A	A	**X**(A)	**A**(O)										
12	Lack of coordination among agencies	V	O	**V**(O)											
13	Resource availability	A	O												
14	Lack of awareness	O													
15	Bureaucratic hassles(permissions and documentation)														

Table 6.4 Changed SSIM for barrier relationships for China

The resulting hierarchies have been placed side by side in two separate figures (Fig. 6.4 and 6.5), on for each country. On the left is the figure that we obtained on after our analysis and on the right is the figure obtained after changes in the SSIM.

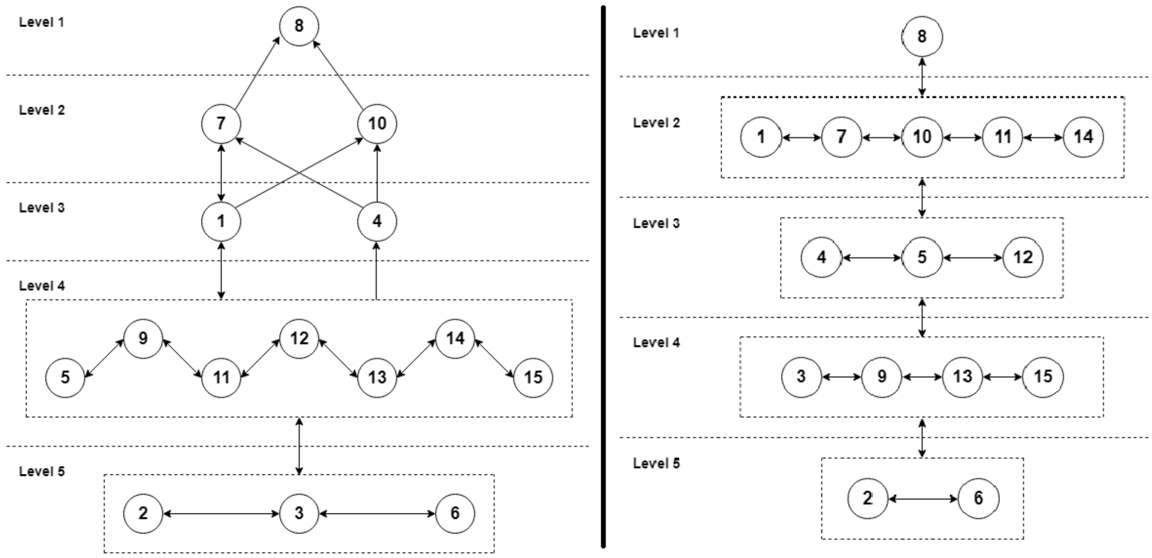

Fig. 6.4 Changes in hierarchy and barrier inter-relationships for India (Left -> Original || Right -> Changes in SSIM)

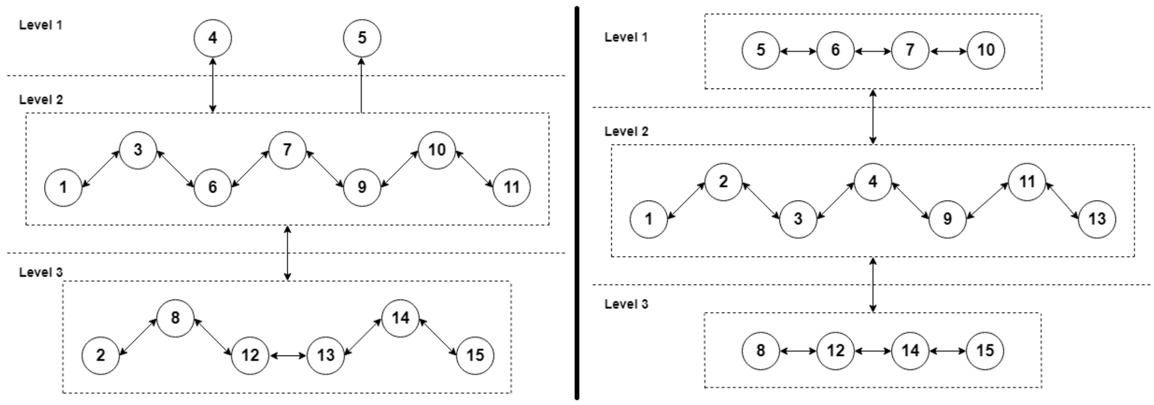

Fig. 6.5 Changes in hierarchy and barrier inter-relationships for China (Left -> Original || Right -> Changes in SSIM)

We observe a minimal change in the ISM hierarchies for both the countries. The overall structure and the number of levels stays the same but, a few barriers are seen jumping one or two levels up or down. In case of India, barriers 11 and 14, namely poor market infrastructure and lack of subsidies/incentives, *jumped two levels up*, i.e. their importance decreased. All the other barriers have only jumped one level and most other barriers stayed in their place.

For China, barrier 4 (lack of financing) came a *level down* whereas, the other barriers jumped one level up. Barriers 1, 3, 5, 8, 9, 11, 12, 14 and, 15 remained in their positions.

From this, we can say that the solar PV and wind energy sectors in both, India and China, are moderately sensitive to changes in barrier relationships. Although the overall skeleton of the ISM digraph stays almost the same, changes in barrier relationships do affect the system as a whole. Playing with the relationships of just one barrier we can analyze its effects on the whole system. For now, we have only made changes in the relationships we were unsure about to see how much of an effect our uncertainties have on the system.

6.3 Discussion

After successfully implementing the chosen methodology on the barriers selected for both the countries and after the numerous brainstorming sessions with my thesis supervisor, I have realized that there have been quite a few limitations to this study in terms of my approach towards the methodology and the barriers themselves. These issues that are lacking in the study have been briefly discussed below.

- Firstly, the barriers could not be successfully quantified because we relied on literature to identify the barriers. Although, the MICMAC analysis gives a pretty fair ranking of the barriers, a better methodology could have been used to make quantification on an absolute scale. Methods like the *Weighted-ISM (W-ISM)* and *Fuzzy MICMAC* analysis could have been used had we surveyed relevant stakeholders asking them to rate the barriers on the Likert scale (from 0 to 5) and then obtain a mean rating for every identified barrier. This would greatly help the barrier ranking on an absolute scale.

- Secondly, we could not apply the methodology to the complete set of identified barriers for each country. This was mainly because of the fact that it was very difficult to identify relationships between each barrier pair purely on the basis of brainstorming by myself. The SSIM matrix encapsulating all the barrier relationships was validated in a group discussion with my thesis supervisor and another student working on a similar topic under the same supervisor, but, even after that the complete matrix could not be validated. In this thesis, a very superficial expert validation has been conducted by attending various energy transition seminars and modest discussions with field experts and other researchers working in the same domain, therefore, there maybe some gaps in establishing relationships between barriers in the first step of ISM.

- Then, apart from the qualitative validation, a statistical validation is also needed to prove that the barriers are actually relevant on ground. It means that the set of barriers identified from the literature need to be validated against the actual barriers which exist in the industry. This is again dependent on the survey results from the industry stakeholders. This is one of the major limitations to the ISM method. Without the statistical validation the resulting hierarchy is very hypothetical and the on-ground importance of the barriers could be starkly in contrast to what has been observed in the study.

- In this thesis, we have carried out the selection of barriers from the number of identified barriers purely on the basis of how many researchers cited it. This method may factor in the personal biases of the researchers and the situation on ground could be different than what the academia assumes. This way of selection also brings with it the issue that the chosen barriers might not completely reflect the system. Also, the transitivity that we have incorporated in the final reachability matrix could arise from barriers outside the scope of research. In cases like these, the ISM hierarchy would not paint the most accurate picture of the whole scene. Therefore, a more comprehensive study including all relevant barriers needs to be done to understand the whole complex system of solar PV and wind energy growth in the two countries.

- It could also be pointed out that the results of this thesis are skewed, in that only past literature has been used to identify the barriers. Although, we have restricted our literature for barrier identification to 2011 and later, today, when the solar and wind industries are changing at such a rapid pace and with them the policies and regulations around them, arguments can be made against the relevance of some barriers in the present scenario.

- Lastly, it needs to be noted that the barriers identified and analyzed for India are very similar to the ones presented in Ansari et al. (2013). A brief comparison the commonality of the barriers is made in section 6.1.1. This can be attributed partly to the method used to pick out the barriers from literature. The technology related problems like grid stability, low efficiencies, etc. are global issues and it needs better research in terms of technology to solve them.

Although all these points lacking in this thesis have been explicitly pointed out, they do not invalidate the results of my analysis; only that, if implemented, they would have improved the accuracy of the results of this analysis even further. A few things that make this study novel and prove the strengths of my work are:

- Firstly, an extensive literature study has been conducted for identification of barriers and to make a choice for the methodology. The literature study has helped us identify more that 40 barriers for India and more than 35 barriers for China. This long list of barriers, as outlined in Appendix A, shows all the problems that the solar and wind energy industry is facing in the two countries. This list could be directly used in the future for a similar analysis and would result in a clearer picture of the RE scenario in the two countries. The methodology literature helped us make a choice taking into consideration the advantages and potential applications of quite a few research methods. ISM was chosen because it was best suited for such a complex system barrier analysis. Variations of the ISM method could be used in the future in presence of survey data to get a more accurate result.

- A thorough sensitivity analysis conducted in the previous section, to observe the effects of changes in barrier relationships on the final hierarchy, is another feature that strengthens and validates the analysis. It shows us that the hierarchy is not very sensitive to changes in relationships and that the barriers only move a level up or down which means that their importance is absolute and independent of their influence on other barriers.

- This thesis is novel in that there are 4 new barriers for India that have been studied along with their interactions with the other barriers. The simultaneous analysis of China's barriers also demonstrates the scenario in the world's fastest growing RE energy-producing economy and is a good metric to compare barriers with. This thesis also tries to make a better co-relation between the results of the ISM analysis and the proposed solutions, rather than presenting very generic solutions as done in most other ISM papers.

- We have also written a MATLAB script which eases further use of methodology. The program only requires the initial relationship matrix, i.e. the SSIM, as the input and gives the level-wise hierarchy as the output, while simultaneously saving all the steps in between, as separate sheets in one Excel file, for verification and publication.

Finally, it is also necessary to mention the usefulness of the methodology itself. ISM definitely makes it easy to tackle multiple barriers since the process can be automated and is very straightforward, but it is very tough to map all the interrelations between the barriers. For example, 15 barriers require articulating 105 interrelationships. Each of these relationship needs to be thought about thoroughly and more the no. of barriers, more the no. of relationships to be mapped. This can very quickly become too complicated and beyond a single person's effort and was one of the main reasons why we restricted ourselves to only 15 barriers.

After the relationships are mapped, the process is fairly simple. The resulting hierarchy gives a decent idea about the system under study and shows all the directions of influence for every barrier. The fact that the barriers themselves do not affect the methodology mean that it can be applied to any field of study and we do not have to restrict ourselves only to barrier analyses. The MICMAC analysis, which is often used in conjugation with ISM, helps plot the factors under study on the basis of their driving and dependence power on the X- and Y- axes. This divides the factors into four separate categories which are very useful to determine the solutions to the system.

Since, failure to study the causes behind the direction of influence between barriers and their individual degree of importance are the biggest disadvantages of this methodology, I would not recommend it to be used by itself, especially without survey data which could definitely help quantify the degree of importance and present a more accurate resultant scenario. Instead, I would recommend using modified versions of the ISM, like the weighted ISM or the fuzzy MICMAC analysis. These possess the benefits of ISM and also simultaneously overcome its limitations using survey data.

The next chapter deals with the policy recommendations to the governments of India and China to tackle all the barriers studied in this thesis. The recommendations are made barrier-wise, in a descending order of importance, to increase the ease of understanding.

Chapter 7

Proposed Solutions

In this chapter, we aim to propose some form of solutions to the barriers identified in the study, so as to accelerate the diffusion of solar PV and wind energy in the two countries. Solutions are in the form of policy recommendations to the governments of the two countries assuming the order or importance of the barriers found from the analysis to be true.

We tackle the situations in both countries starting from the bottom-most level, which is the most important level, and then moving upwards. The barriers in the bottom-most level of the hierarchical digraph appear at the top of the rankings. For ease of study, we have made a level-wise segregation of the policy recommendations while also briefly explaining the effects it will have in alleviating the other connected barriers. One thing needs to be made clear that solving the barriers in the bottom-most level will not automatically solve all the barriers above them, even though they are inter-related. But, it definitely serves to alleviate the effects of the barriers above that level on the system as a whole.

7.1 India

The resulting digraph obtained from the analysis, as shown in fig. 6.1, points out the barriers that are most influential to the growth of solar PV and wind energy in India. The following policy recommendations for the Indian government are proposed taking into consideration the hierarchy digraph and the driving-dependence power rankings (in table 6.1), both of which show the same output.

- **Lack of supporting policy and poor execution (2)**
  - Specific policy for all renewables is required because all renewables work differently and have different issues and efficiencies based on the country's resources. A roadmap

for gradual progress towards the set targets is as important as the target itself. Clear policy terminology with distinctly set guidelines to achieve nationally set targets should be created. This basic skeleton of policies needs to be applied at the central level, which the other states can build upon as required. This would help to clearly demarcate the role of stakeholders at every level and reduces inter-agency conflict and drastic policy variations from state-to-state.

  - Centralized policies mandating grid connection and sale of power of RE projects is required. Heavy penalties should be imposed to ensure compliance of policy. The existing renewable purchase obligations (RPOs) should be clearly defined as percentages of electricity generation and should be steadily increased over time. This creates a sense of income security among project developers and investors and promotes investment by creating a long-term market demand.
  - Policies like net-metering and FITs are important to increase the number decentralized projects, especially on a smaller scale, like rooftop solar, small-scale solar-wind hybrid projects and building integrated PV systems (BIPV). Provisions like exemptions or rebates on locally sourced products and their mandatory use will help promote local manufacturing of PV modules or wind turbines. This reduces grid dependency, incentivizes small scale businesses and creates additional jobs within the country while also reducing dependence on imports and expenditure in import duties.

- **Lack of awareness/understanding of technology (6)**
  - Consumer awareness campaigns need to be conducted to eradicate the misinformation and doubt among the public. Factors like community/personal benefits, technological/financial feasibility, and environmental effects need to be conveyed to the general public. Many a times government schemes go unnoticed or underutilized because of some social stigma around the technology.
  - Community pilot projects need to be sanctioned and enforced to demonstrate the functionality and added value that RE projects would bring to their lives. It helps eradicate the unnecessary stigma associated with the technology and leaves the consumers better off and less reliant on the central grid due to domestic power productions alternatives.
  - Awareness could also be created by conducting hand-on workshops to demonstrate technology and show its use, and making RE technologies a part of the primary and secondary school curriculum in the form of projects and assignments. Politicians could be educated about the benefits of the technology, in case they are not aware, so that they include it in their campaign agendas.

  - Introduction and promotion of microfinance schemes and project implementation workshops for the public to boost domestic solar and wind power projects. This incentivizes small-scale businesses and creates energy independence among consumers. If implemented on a national scale, it would take substantial pressure off the central electricity grid.

- **Lack of local infrastructure (13)**
  - Local resources need to be made available as fast as possible to facilitate easier and faster construction. Dedicated construction resource suppliers should be assigned to projects to prevent shortages and delays. Trained manpower suppliers should also be assigned to such projects.
  - There is need for speedy land acquisition procedures to reduce the project establishment time. For this, proper land demarcation needs to be conducted by the state and central governments. An approach could be by analyzing the barren and infertile lands and designating them to RE projects.
  - Immediate grid connections and reliable power management stations must be made available in remote locations where usually such solar and wind projects are constructed. It facilitates faster income generation for the project developer thus making it a reliable investment due to shorter pipeline times. It also makes it lucrative for future investors since they have demonstrable projects to have the financial security to make the investment.

- **Lack of subsidies/incentives inadequacy (14)**
  - The subsidies given to fossil fuels need to be reduced or abolished altogether and, mechanisms need to be put in place to incorporate the price externalities. Carbon emissions tax or systems like the Emissions Trading System (ETS) need to be put in place to remove such price externalities. This would make it a leveled comparison between fossils and renewables. Comparable prices would make renewables the obvious investment choice thereby decreasing the country's reliance on fossil fuels.
  - Mechanisms like capital subsidy, variability gap funding (VGF) etc. need to be incorporated aggressively to deal with the high initial costs of RE projects. Some niche technologies like floating PV, hydrogen and compressed air storage, etc. should be given subsidies to remove the initial financial market-entry barrier. This helps create incentive of investments on RE projects as the investment size significantly decreases. New technologies are encouraged creating an impetus towards more research in the field.

- **Multi-tired govt. approvals and documentation (15)**
  Although, clearer policies, resource allocation, power purchase mandates and better jurisdiction for the multiple agencies present in the country will significantly contribute towards alleviating this barrier, focused efforts need to be taken, to assign duties to all the agencies which are mutually exclusive and to standardize the RE project development based on technology and size, to allow for faster sanctioning and project deployment.

- **Lack of skilled personnel and training institutes (3)**
  - Training workshops need to be conducted for people from other industries with a similar knowledge background to supply the demand of large number of professionals for all levels of work, right from installation technicians to policy analysts, in the solar and wind energy industry.
  - Establishment of training institutes with frequent, short-term, low-cost training workshops could help tackle this problem better. Better project outcomes are obtained as the people working on it have a better knowledge about the technology itself. This could also help create a lot of jobs in the renewables sector and filling them with qualified professionals.
  - More educational and research institutes dedicated to the solar PV and wind energy need to be established to increase research activities and data collection for renewable energy technologies. The existing institutes could also be allowed to add new programs to their list, dealing with the study of these technologies. Increases the awareness about the industry among people while creating better job opportunities for the youth.
  - Inculcating the practice of focused research within the field of solar PV and wind energy along with the formal education initiatives. Long-term advantages could be people with the exact technological knowledge at the decision-making and policy-making level. The research institutes would also contribute towards better resource data for wind speeds and solar irradiance.

- **Lack of data and information (12)**
  - Funding for the meteorological institutes within the country needs to be increased. Large number of remote weather data monitoring systems need to be installed and the collected data needs to be stored and analyzed to improve prediction efficiencies of wind speeds and solar irradiation. This data also needs to be shared with all relevant agencies and project developers to ensure demarcation and allotment of high-yield project locations.
  - Apart form these data gathering initiatives, there is also an immediate need for better reporting standards for the project developers and knowledge sharing between agencies.

Consortia including at least a few key players from all segments of the market, from government and financiers to project developers and public representatives, can be established for knowledge sharing within specific industries. This would keep all the stakeholders aware of the latest advancements in the industry and the probable dos-and-donts for RE projects. Better information and data will lead to better project yields which will in turn make it profitable for the investors to put their money in the projects.

- **Poor market infrastructure (11)**
  - Currently the RE market, in general, is very government-driven. A free market with numerous private players could prove instrumental in increasing the solar and wind energy capacities. To make this happen, private investment needs to be incentivized and local manufacturing needs to be promoted to make it easier for companies to expand over all verticals of the market from manufacturing components to actual project development. Greater mandatory RPO percentages and prompt grid connection already lessens the burden of solving this issue and facilitates better market integration.
  - Private companies are also looking for bigger project sizes to be tendered so that they control a big enough energy supply share to actually have a say at the table. This could help RE favorable decision making. Also with RE specific policies and standardized project development procedure, an increase in the number of market entrants could be expected because the uncertainty around the RE projects is done away with.
- **Legal and regulatory issues (5)**
  - Regulations dealing with site specific tariffs need to be implemented based on the resource availability in a region. This also applies to revision of FITs and RPO targets on a state-level going by the local conditions. Decentralized, local enforcement and monitoring of policies made by the center and state governments is necessary.
  - Strict penalties need to be imposed on failure to comply with RPOs. If ETS or emission cap is implemented, excess emission penalties also need to be enforced on the fossil-based industries which go beyond the permissible emission levels.
  - Regulations like the 70:30 debt/equity ratio for financing of RE projects needs to be done away with since domestic financiers do not prefer debt financing. Borrowing foreign capital then proves very expensive. Although to tackle this, the allowable percentage share of foreign direct investment (FDI) in a RE project has already been increased to 100%.
- **Lack of coordination between agencies/stakeholders (9)**
  This barrier is mostly mitigated if measures are taken to improve knowledge sharing

between agencies, agency roles are clearly demarcated, policies are clear & unambiguous and, standardization of project development procedure. The formation of consortia, as suggested before, is one of the most promising ways to bring stakeholders from all segments of the industry/market together.

- **Lack of R&D culture (1)**
  Increased investments in solar and wind energy related R&D activities along with bigger research grants to universities could significantly improve the state of research in this field. Formal education in the various RE technologies available will also help bring the focus of research to these topics. Focused national R&D programs to improve the grid stability, energy efficiency, low-cost RE technologies, etc. could guide the researchers, field experts and manufacturing industries to put their efforts towards achieving the national targets. International co-operation to gain knowledge on better manufacturing technologies and RE applications could save time and effort and research efforts could be built on the existing work rather than re-inventing the wheel.

- **Lack of financing institutions (7)**
  Encouraging small-scale project finance, low interest rates on loans for RE related projects and availability of domestic financing options will prove stimulative in growing these industries. Banks should be educated towards accepting RPOs and PPAs as relevant bankable documents against the intermittency risk of these solar and wind energy projects and should be encouraged to invest on RE projects. Re projects could be made lucrative for financiers if the external costs of fossil fuels are added to the project cost and fossil subsidies are phased out. Mitigation of other barriers like consumer awareness, lack of RE specific policies and regulations and project delays due to multiple reasons will definitely make it profitable for more financiers to invest in RE projects.

- **Grid issues and energy access (4)**
  - Decentralized projects and implementation of micro- and mini-grid concepts effectively takes the burden off the central grid infrastructure thereby providing consistent energy access in the remote areas.
  - Better grid component technology, monitoring measures and reliable grid connectivity even in remote areas, where RE projects are established, will help tackle with the grid stability issues that come along with the intermittency of renewables. Large scale storage solutions are also needed to act as buffers for grid stability.
  - Large-scale smart grid infrastructure and remote data gathering and monitoring stations will help implement concepts like demand side management and help make the grid

more bilateral in nature and deal better with intermittency. Cross-border transmission costs and long distance transmission infrastructure could further reduce the intermittency shocks to the grid.

- **Poor reliability and low efficiency (10)**
  Increased research in the field of solar PV and wind energy technologies will help solve the low efficiency issues. Poor reliability, on the other hand, is solved when there is better data available for optimal project locations and clarity around the policies in terms of grid connectivity and land acquisition. This barrier is seen to be solved as a by-product of mitigating other barriers.

- **High initial investment cost (8)**
  As in the case of the previous barrier, this barrier is solved by solving other barriers by bringing in policies to make RE cost-comparable to fossil fuel based projects and by research focused specifically on decreasing the cost of components of a solar PV or a wind energy system.

7.2 China

Our barrier analysis has produced the hierarchical digraph (fig.6.2) and the rankings based on driving-dependence powers (shown in table 6.2) which helps us clearly identify the barriers which need to be tackled first. The following policy recommendations are based on the combined outcome of the hierarchy and the ranking, but for ease of understanding, have been presented barrier-wise ranked from the most to the least important.

- **Lack of strategic planning and political will (8)**
  - China needs better planning to integrate the technology manufacturers, grid operators, projects developers and other stakeholders to prevent problems like the recent wind over-capacity problem. Apart from policy planning, the planning also needs to happen in the infrastructure development, grid design, market development, project investment and energy consumption sectors. The government needs to promote market-driven mechanisms and establish energy management systems to strengthen the grid. Helps prevent problems like over-capacity, grid connection unavailability and grid instability.
  - A long-term plan, to make renewables competitive, is necessary. Energy pricing which incorporates the resource scarcity and environmental effects caused due to fossil fuels should be implemented. To make the renewables competitive, carbon taxes and emission

certificates need to be put into action. A portion of the money collected through taxes could then be used to increase research activities in the field of renewables. This will help reliance on fossil fuels and promote the use of RE.

- **Lack of consumer awareness (14)**
  Social, environmental and financial concerns of the consumers need to be addressed through awareness camps and workshops. Pilot projects can be established that operate within the community's control to make them used to the new technology and realize the benefits to society. Project developers also need to be made aware of the grid stability after addition of renewables. This will lead to a larger no. of domestic and private, utility scale projects in the presence of adequate micro-financing options.

- **Limited policy framework or lack thereof (2)**
  - The government of China should look into making a clearer policy framework for renewables. There is need for technology specific policy within the renewables sector. The country's main vision should be designed keeping in mind the targets they have set. This main vision should be very well formulated and a step-by-step guideline must be provided to ensure that the targets are met. Clearer policies is a positive signal towards the growth of that industry as more stakeholders will be interested in that market. It will also lead to a controlled growth in the field rather than an unpredictable spike in one direction.
  - The policy difference between economic centers and rural China should be phased out. Many important policies like the RE taxation exemption, FIT etc. are non-uniform over the geography of the country and therefore fail to positively impact all stakeholders. Uniform policy throughout the country makes it easier for project developers to choose sites for their projects and the choice can be made purely based on the highest resource availability. Cost-sharing funds problem created by the FIT can be mitigated and the subsidy funds can be put to proper use.
  - Policy measures to ensure grid connectivity, sale of renewable power and investments in RE projects, like the Renewable Portfolio Standards (RPS), are of utmost importance. Mandatory grid connectivity and power purchase agreements need to be enforced by the government and non-compliance should be tackled with heavy penalties. This would prevent idle projects and losses to project developers and investors.
  - Policy measures supporting RE power integration with the grid, ease of inter-province power transmission to demand centers and, concessional loans for RE projects should be created along with taking steps to reduce the establishment time of the project due

to long approval times. Leads to faster sanctioning and construction of RE projects, resulting in quicker added generation capacity. Power curtailment issue can be reduced substantially by inter-province power exchange.

- **Lack of coordination among agencies (12)**
  A special governing body to manage central policy formulation and execution for renewable energy could be a good way to reduce discrepancies in policy making. The roles of multiple agencies responsible for the RE administration need to be clarified and, their powers and jurisdiction needs to be defined. If the roles of national and state-level agencies is clarified and processes are standardized, there is lesser conflict and easier implementation of policy due to better coordination between agencies. This, in turn, would lead to faster disbursement of subsidies and funds, like the FIT, to the project developers and better knowledge sharing among agencies.

- **Resource unavailability (13)**
  The central policies should be able to tackle the vast geographic expanse of China along with which comes a huge resource variability. Schemes like the FIT should be comprehensive enough to consider the difference in solar and wind resources from region-to-region. Therefore, provinces should be encouraged to build on the policies established at the center. Resource-based policy in terms of forest/agricultural land allocation and use of residential/commercial rooftops should also be clearer. Strengthening the transmission grid and improving cross-border flow helps prevent problems of power transmission to urban demand centers from rural resource-rich project sites, like the wind speed discrepancy between north and south of the country. It also promotes local power generation and leads to better project incomes due to location-based tariffs.

- **Bureaucratic hassles (15)**
  This barrier is expected to be solved by clearer policies, better role definition among agencies, standardization of project development procedures and prompt grid connection and power sale mandates. With lesser documentation and project approval times, investors are expected to be less inhibited towards investing in RE projects.

- **Inadequate data and information (10)**
  - Most weather data measurement stations are located near the cities and demand centers but there is a need for stations even at remote locations and rural areas to get accurate measurement from the exact project locations instead of depending on estimations. Large data sets from all over the country will give a better picture of the best project

locations according to irradiance and wind speed values. This data needs to be analyzed and made available for the project developers.

  - There is also imminent need for standardized reporting in the industry and knowledge sharing among the relevant actors. Information sharing is extremely important and can be achieved by establishing consortia including stakeholders from various market segments.

- **Lack of research personnel and trained manpower (9)**
  - Technicians hired from other industries need to be given at least the basic training about the implementation of the technology. For this, training institutes need to be established where short-term, low-cost workshops are conducted to regularly update their knowledge. This also applies to the policy and decision makers who have no clue about the technology. They need to be educated about the basic functioning, advantages and hurdles of solar PV and wind technologies. This will definitely improve the project outcomes and provide skilled professionals in every segment of the RE industry.
  - Increase the number of educational and research institutes with a dedicated focus towards the solar PV, wind energy and other RE technologies. The existing universities could expand their course prospectus by adding courses related to the various RE technologies. This will improve the research activities and data collection for renewable energy technologies and create awareness about the jobs in these industries.

- **Inadequate market size and infrastructure (11)**
  The investment and the growth in these sectors needs to be market-driven and not driven by the government. This can be achieved when the policies around solar and wind energy projects are clear and investors do no face the added risk of project sanctioning delays and unavailability of grid connectivity. This will also take the burden off the governments shoulders, since they can then move purely towards market regulation instead of being a key player and driving the market, and the solar and wind energy sectors will grow even more rapidly. All this can be done when the government revises the energy pricing to make renewables cost competitive and phases out the fossil subsidies.

- **Lack of legal and regulatory framework (6)**
  - Regulations dealing with location specific tariffs need to be implemented taking into consideration the resource availability in a region. The regulations about all the matter concerning RE sources are unclear and need to be consolidated by the government at the center.

- The legal and regulatory working areas of the multiple agencies related to renewables need to be tackled first and decided upon. This issue, when resolved, could efficiently reduce the lack of co-ordination between agencies and provide a sense of stability for the investors of RE projects. Also, project developers will have lesser problems with establishing the project in terms of sanctioning and subsidy distribution.
- Problems of common rooftop ownership in congested urban areas need to be resolved by proper legislation around the issue. Along with the policies decided in the center, supporting regulatory and legislative guidelines are of utmost importance to ensure proper enforcement of policies.

• **Lack of R&D (7)**
The research in solar and wind energy sectors in China requires huge private investments to move away from mere replication of technologies to innovation. The government should award more and bigger research grants to the researchers working in this sector. Promotion of local manufacturing will automatically call for R&D being conducted by private companies to gain market dominance instead of the current replication activities. Research needs to be directed to solving grid stability issues, innovating storage solutions and, decreasing cost and increasing efficiencies of RE technologies. This is further mitigated if there are formal educational institutions that push the research in the right direction.

• **Lack of experience in technology and management (3)**
The growth in China is restricted by the dependence on imports of the high-tech components of the solar PV and wind energy technologies. Impetus to local manufacturing and R&D activities will help alleviate this barrier which is also helped by the huge scale of projects in China. The more the local stakeholders are involved in large projects, the faster they obtain experience with technology.

• **Lack of incentives/subsidies compared to fossil fuels (1)**
The government needs to work towards phasing out fossil fuel subsidies and promote reliance on renewables to make RE technologies cost competitive. Depending on the project size, capital subsidies need to be provided to reduce the financial burden on the investors. Timely subsidy allocation and distribution is equally necessary for RE projects to be viable investment options for investors and project developers.

• **Lack of funding/financing difficulties (4)**
The financing institutions should provide small- and large-scale project finance at low interest rates and should be educated about the technology so that they account for income

security through PPAs and RPOs when assessing the risk for a project. Bank and other financiers should also be educated about the perceived risk that comes with social nonacceptance and factors like intermittency, grid stability and the need for storage that comes with these RE technologies. Government funded R&D activities could also help provide financial security and increase the trust of investors in these technologies. Along with these measures, fair energy pricing, competitive investment sizes of RE and fossils and national targets for RE shares in the energy mix will also help pulling in serious financiers to this sector.

- **Grid capacity and connectivity delays (5)**
  - Implementation of micro- and mini-grid concepts and decentralized generation could effectively provide consistent energy access in the remote areas thereby reducing load on the central grid infrastructure.
  - Better grid component technology, monitoring measures and reliable grid connectivity even in remote areas, where RE projects are established, will help tackle with the grid stability issues that come along with the intermittency of renewables. Large scale storage solutions are also needed to act as buffers for grid stability.
  - Large-scale smart grid infrastructure, remote data gathering and monitoring stations and, better long distance transmission will help implement concepts like demand side management and help make the grid more bilateral in nature and deal better with intermittency. Abolishing cross-border transmission costs could further ease this process and reduce dumping of excess power.
  - Along with all this, steps need to be taken to reduce the grid construction and connection time and subsidies need to incorporate long distance transmission grid infrastructure costs. Grid extension procedure needs to be standardized and regulations around it should be made clear to avoid sanctioning delays.

Now that we have proposed solutions to all the barriers for both the countries in a descending order of the barrier's importance (ranking), I would like to weigh in on how to begin the process of removing barriers in these two countries based on my knowledge about them. Since it is not feasible for the any government to implement all the recommendations, the following advice mainly addresses the question of *'What are few most important things that India/China needs to do in order to improve the diffusion of solar and wind energy?'* keeping aside the barrier hierarchy obtained before.

One thing that both countries need to focus on is strengthening their grid infrastructure. This can be done by introducing grid-connected microgrid concepts for rural and isolated communities, large-scale storage facilities to act as buffers for the intermittency and, bettering the monitoring and control infrastructure of the central grid to handle the bilateral power flow. Long-distance cross-border flow capabilities also need to be significantly enhanced to better deal with the changes in demand and supply. Concepts like demand side management need to be implemented at the consumer level to predict rise and fall in demand in certain areas. Secondly, decreasing fossil fuel subsidies for middle- and upper-class population is very important along with the implementation of either carbon taxation or emission trading certificate schemes for large-scale users of energy in both the countries.

Apart from this common advice to both countries, India needs to focus on clarification and implementation of long-term policies regarding renewables. RPO percentages should be defined and increased annually to provide security of sale of power to RE producers. Micro-financing initiatives and tax rebates are vital for the widespread use of domestic solar PV or wind energy projects. Incentives could also be provided to increase local manufacturing by mandating some percentages of locally sourced PV panels or wind turbines within the projects or by providing discounts on local products.

China, on the other hand, needs to consolidate and unify its RE policy over the whole geography taking into account the regional variability in resources. This ensures project location choices being made considering only the energy yield. Accurate data sets for rural areas and feasible project locations need to be readily available along with prompt grid connections. To effectively tackle the bureaucracy issues, the RE sector should be headed by multiple agencies with separate roles which function independently and are autonomous in their decision making.

There are two points that need to be mentioned explicitly about the policy recommendations made to both the countries.

Firstly, the barriers might seem generic to those who know the on-ground status of these two renewable energy sources in both, India and China. This is mainly because the progress in both these countries is driven primarily by a few areas within the country (eg. few states in India like Andhra Pradesh, Tamil Nadu, Maharashtra, etc. and the industrialized areas in and around Beijing in China) and the policies implemented in those regions have advanced much further than the country as a whole, whereas, the recommendations have been made considering the entire country as one region.

Secondly, all other researchers, that used ISM as the methodology, have either stopped at the analysis without proposing any solutions or provided very general recommendations which could have been arrived at even without the analysis. This thesis, not only provides recommendations to all the barriers in their order of importance, but also establishes an overarching story of how each country can begin tackling the issue of lower diffusion of these two technologies. This has been done to provide a point of origin to the solutions, considering that it is not feasible for the countries to implement everything we recommend all at once.

These two points needed to be addressed separately because the discussions for the rest of the thesis are written in the previous chapter.

The next chapter is the concluding chapter that ties together the whole thesis. It links the research questions established in the first chapter to the findings of our barrier analysis and the proposed solutions. It also presents a few recommendations for future research in the same direction.

Chapter 8

Conclusion

In this chapter we aim to specifically answer the main and sub- research questions posed in the introduction chapter which will bring the thesis to its conclusion along with a few recommendations for future research in a similar direction. Sub-research questions are answered first to provide a good overview of the research and then, the answer to the main research question brings together problem and the solutions and concludes the thesis.

What is the current status in terms of upcoming government policies & incentives, projected growth rates and 2030 targets in the two countries?
India and China are rapidly developing, economies. Their decisions and moves towards renewables have huge global impacts. Together they account for more than 1/3rd the share of both, solar and wind energy capacities, of the world.

The investment costs for RE projects in India are rapidly falling due to falling technology prices, better subsidies and tariff schemes, and financing options. The government has introduced many measures, like capital subsidies, net metering schemes and increased foreign investment shares, to facilitate this transition to an RE dominated energy industry. The government has also begun enforcing mandatory RE electricity purchases on grid operators, started e-reverse auctioning for transparent bidding, introduced a decentralization of solar energy-based devices for farmers and, are increasing investments in creation of data measurement centers and a strong, technically-trained workforce for RE technologies. They still have to deal with their reliance on imports, tendering system flaws and problems of long-distance transmission and land acquisition. The country has set goals of 100GW of solar energy capacity and 60GW of wind energy capacity by 2022 and is still way behind its targets even at the current growth rates.

Until very recently, China has succeeded in growing their RE industry not because of concrete policy supporting RE technologies but due to the economies of scale. Overall fall in technology costs coupled with the introduction of subsidies, FIT schemes and RE certificates along with supporting policies, the country has succeeded in growing at even higher rates. The government also introduced a cap on renewable power dumping, started national auctions, promoted local manufacturing and invested in long-distance transmission infrastructure. Although due to the lack of planning they had to deal with problems like wind over-capacity and pending FIT payments due to high tariffs, they are still the country with the largest installed RE capacities in almost all RE technologies. The current policy takes into consideration the growth of RE in the energy mix in an effective long-term five-year plan with concrete targets. China has committed to 105GW of solar energy capacity by 2020 which they have already surpassed and 210GW of wind energy capacity by 2022 which they are well on the track to achieve.

What are the barriers against faster diffusion of the two technologies and how are they interrelated (if at all)?
We have identified 15 barriers for each country from the literature, as shown in tables 3.1 and 3.2. For India, the few most important issues that need to be solved for faster diffusion of Solar PV and wind energy are *lack of RE-specific policy*, *lack of skilled technicians & education institutes within this sector* and, *consumer unawareness about the technology and its effects*. For China, along with the *lack of awareness and RE-specific policy*, factors like *resource unavailability*, *lack of coordination among agencies*, *bureaucratic hassles* and *lack of planning* form the bottom-most level of the hierarchy consisting of the most important barriers. Although both the countries have many coinciding barriers their distribution within the hierarchy is very different. We find that the barriers are more scattered between levels for India, whereas, for China, they are very clustered. This can be attributed to the distributed power structure in India's governance and a more centrally controlled governmental structure in China. The individual barrier inter-relations have been mapped in the first step of the methodology for each country under the SSIM matrix (tables 5.1 and 5.8).

How should we proceed to overcome these barriers and which ones should be tackled first so as to achieve maximum impact?
According to the results of the ISM methodology, we should proceed level-wise, starting with the bottom most level, to overcome these barriers and cause the most impact on the system since these bottom-level barriers affect the most other barriers. Since the driving-dependence power ranking also gives us a coherent result, we could work towards solving these barriers one-by-one ranking-wise. In most cases, the impacts of solving one barrier on the system could be predicted looking at all the barriers that it affects, but there could also be some

unforeseen effects on the system since the barrier relationship only provides the direction of influence and not the type of aftereffects on the system. Therefore, policymakers should definitely consult the figures showing the hierarchy between barriers (figs. 6.1 and 6.2) for both the countries before making any changes to predict the policy outcome, at least to some degree.

How can we resolve the barriers to large-scale diffusion of Solar PV and Wind energy in India and China?
The barriers analyzed in the thesis can be resolved by making fundamental changes to the policy, regulations and legislation specific to renewables. There are some common solutions for both the countries like, long-term RE targets, mandatory grid connections and sale of renewable electricity, promotion of decentralized projects, increased consumer awareness and introduction of formal education and training courses in this sector. Both the countries are lacking in the electricity access in remote areas and reliability of grid, and therefore, measures need to be taken to strengthen the grid infrastructure and allow inter-state/inter-province transmission to improve grid stability. Bureaucratic procedures causing delays in subsidy distribution and project commencement have also been pointed out as problems in both the countries which can be solved by clearer establishment of roles of various agencies functioning within this sector.

If all the barriers are solved, we predict that the solar and wind energy growth could be rapid enough to meet the Paris agreement targets for both the countries. The scope of this analysis could be expanded to include all identified barriers to map the interactions within this complex system even more efficiently. A similar analysis, if done for other countries, could help expose the most crucial factors that prevent these RE sources from growing fast enough.

8.1 Recommendations for future research

Below are some recommendations for any future research with a similar scope of research or the same methodology approach:

- Even if barriers are identified from the literature, stakeholder survey is vital for any kind of quantification of the barriers. A survey asking the respondents to mark the importance of barriers could really help better gauge the complete solar and wind energy scene and obtain a more definitive ranking for the barriers.

- Verification of the barrier relationship matrix from external agents functioning within the solar and wind industries is very important for the results to be extremely accurate. Relevant experts from industry and academia should be consulted when defining barrier inter-relations. It could also reveal the difference between the opinions of academic and the industry professionals, if any.

- The more the number of barriers studied together, the better perspective of the RE scenario we obtain. Unlike this study, analysis of all identified barriers could really paint a much clearer picture of the solar and wind energy industries in the two countries.

- Time-dependent changes in importance and variability of barriers themselves needs to be accounted for if the study is done over a longer period of time. There are barriers that may gain or lose importance over time due to various factors and these changes in positions on the hierarchy diagram could be interesting to observe.

- Transitivity only accounts for comparison within the analyzed barriers but in practice can arise from a third variable not under study, as mentioned in the limitations of this study. Expert opinion is needed to accurately point out the existence of such an extrinsic transitivity.

- For any further analysis for these countries or even for other countries, variations of the methodology are suggested which will assign weights to the importance of barriers.

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Appendix A

All Identified Barriers from Literature

This appendix includes all the barriers identified from literature for both the countries.

India

	Barrier	Barrier analysis literature	No. of references
1	Lack of R&D culture	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Eswarlal 2011, Khare 2013, Kapoor 2014, Chauhan 2015, Luthra 2015, Kar 2016, Kar 2015, Manju 2017, Dawn 2016, Rathore 2018,	13
2	Lack of supporting policy and poor execution	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Eswarlal 2011, Khare 2013, Kapoor 2014, Chauhan 2015, Luthra 2015, Kar 2015, Manju 2017, Shukla 2018, Aggarwal 2018, Rathore 2018,	13
3	Lack of skilled personnel and training institutes	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Eswarlal 2011, Khare 2013, Kapoor 2014, Chauhan 2015, Luthra 2015, Kar 2016, Manju 2017, Shukla 2018, Dawn 2016,	12
4	Grid issues	Yaqoot 2016, Karakaya 2015, Khare 2013, Kapoor 2014, Chauhan 2015, Luthra 2015, Kar 2016, Kar 2015, Manju 2017, Aggarwal 2018, Rathore 2018,	11

5	Regulatory issues	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Eswarlal 2011, Kapoor 2014, Chauhan 2015, Kar 2016, Kar 2015, Aggarwal 2018, Dawn 2016, Rathore 2018,	11
6	Lack of awareness/understanding of technology	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Eswarlal 2011, Kapoor 2014, Luthra 2015, Kar 2016, Manju 2017, Shukla 2018, Dawn 2016, Rathore 2018,	11
7	Lack of financing institutions and incentives	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Khare 2013, Kapoor 2014, Luthra 2015, Kar 2016, Kar 2015, Manju 2017, Aggarwal 2018, Rathore 2018,	11
8	High initial investment cost	Yaqoot 2016, Karakaya 2015, Eswarlal 2011, Khare 2013, Kapoor 2014, Chauhan 2015, Luthra 2015, Kar 2016, Manju 2017, Shukla 2018,	10
9	Lack of coordination between agencies/stakeholders	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Khare 2013, Kapoor 2014, Chauhan 2015, Luthra 2015, Manju 2017, Dawn 2016,	9
10	Poor reliability and low efficiency	Yaqoot 2016, Sindhu 2016, Eswarlal 2011, Khare 2013, Chauhan 2015, Luthra 2015, Kar 2016, Manju 2017, Shukla 2018,	9
11	Poor market infrastructure	Sindhu 2016, Khare 2013, Kapoor 2014, Chauhan 2015, Luthra 2015, Kar 2016, Kar 2015, Manju 2017, Shukla 2018,	9
12	Lack of information	Yaqoot 2016, Khare 2013, Kapoor 2014, Chauhan 2015, Luthra 2015, Manju 2017, Shukla 2018, Dawn 2016, Rathore 2018,	9
13	Lack of access to credit/capital	Sindhu 2016, Yaqoot 2016, Kapoor 2014, Luthra 2015, Kar 2016, Kar 2015, Manju 2017, Aggarwal 2018, Rathore 2018,	9
14	Lack of subsidies/incentives inadequacy	Sindhu 2016, Yaqoot 2016, Chauhan 2015, Luthra 2015, Kar 2016, Manju 2017, Shukla 2018, Dawn 2016,	8

15	Lack of local infrastructure (land and resources)	Sindhu 2016, Kapoor 2014, Chauhan 2015, Luthra 2015, Kar 2015, Manju 2017, Shukla 2018, Aggarwal 2018,	8
16	Lack of proper standards	Sindhu 2016, Yaqoot 2016, Kapoor 2014, Chauhan 2015, Manju 2017, Shukla 2018, Dawn 2016, Rathore 2018,	8
17	Lack of experts at decision and policy making levels	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Khare 2013, Kapoor 2014, Luthra 2015, Kar 2016, Manju 2017,	8
18	Small market size	Sindhu 2016, Yaqoot 2016, Khare 2013, Kapoor 2014, Luthra 2015, Kar 2016, Kar 2015, Manju 2017,	8
19	Multi-tired govt. approvals and documentation	Sindhu 2016, Yaqoot 2016, Kapoor 2014, Chauhan 2015, Manju 2017, Aggarwal 2018, Rathore 2018,	7
20	Design and ease of operation/Technology complexity	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Eswarlal 2011, Chauhan 2015, Luthra 2015, Manju 2017,	7
21	Lack of solar radiation and wind data measuring centers	Sindhu 2016, Yaqoot 2016, Eswarlal 2011, Kapoor 2014, Chauhan 2015, Luthra 2015, Rathore 2018,	7
22	Solar and wind manufacturing challenges	Sindhu 2016, Yaqoot 2016, Khare 2013, Kar 2016, Manju 2017, Shukla 2018, Rathore 2018,	7
23	Resource availability	Yaqoot 2016, Karakaya 2015, Eswarlal 2011, Chauhan 2015, Luthra 2015, Kar 2015, Manju 2017,	7
24	Legislative failures/Lack of legal framework	Sindhu 2016, Kapoor 2014, Chauhan 2015, Luthra 2015, Kar 2016, Aggarwal 2018,	6
25	Lack of specialized courses on RET engineering	Sindhu 2016, Karakaya 2015, Kapoor 2014, Luthra 2015, Kar 2016, Shukla 2018,	6
26	Storage issues	Sindhu 2016, Yaqoot 2016, Kapoor 2014, Chauhan 2015, Luthra 2015, Manju 2017,	6
27	Installation and maintenance issues	Yaqoot 2016, Karakaya 2015, Khare 2013, Chauhan 2015, Manju 2017, Shukla 2018,	6

28	Low affordability of weaker sections of the society	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Kapoor 2014, Luthra 2015, Shukla 2018,	6
29	Lack of strong political will	Sindhu 2016, Kapoor 2014, Luthra 2015, Manju 2017, Aggarwal 2018,	5
30	Perceptional problem	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Kapoor 2014, Luthra 2015,	5
31	Lack of financial literacy/policy awareness	Sindhu 2016, Kapoor 2014, Shukla 2018, Dawn 2016, Rathore 2018,	5
32	High payback period	Sindhu 2016, Yaqoot 2016, Karakaya 2015, Eswarlal 2011, Shukla 2018,	5
33	Political instability	Sindhu 2016, Kapoor 2014, Aggarwal 2018, Dawn 2016,	4
34	Non-functioning of agencies at local levels	Sindhu 2016, Yaqoot 2016, Kapoor 2014, Rathore 2018,	4
35	Lack of competition	Sindhu 2016, Yaqoot 2016, Khare 2013, Kapoor 2014,	4
36	Operation and maintenance costs	Sindhu 2016, Yaqoot 2016, Khare 2013, Chauhan 2015,	4
37	Partnership issues	Sindhu 2016, Kapoor 2014, Shukla 2018,	3
38	Resistance to new technology	Sindhu 2016, Yaqoot 2016, Karakaya 2015,	3
39	Budgetary constraints	Sindhu 2016, Khare 2013, Kar 2016,	3
40	Cost of BoS components	Sindhu 2016, Karakaya 2015, Kapoor 2014,	3
41	Environmental and ecological barriers	Yaqoot 2016, Luthra 2015,	2
42	Lack of entrepreneurial action and innovation	Sindhu 2016,	1
43	Unfair energy bidding and tendering	Rathore 2018,	1
44	Transparency and accountability	Rathore 2018,	1

Table A.1 All barriers identified from literature for India

China

	Barrier	Barrier analysis literature	No. of references
1	Lack of incentives/subsidies compared to fossil fuels	Wang 2008, Zhang 2012, Schuman 2012, Karakaya 2015, Ming 2013, Wang 2012, Yang 2016, Zou 2017, Zhao 2019, Binz 2017, Sen 2017, Eleftheriadis 2015, Zhao 2018,	13
2	Limited policy framework or lack thereof	Wang 2008, Zhang 2012, Schuman 2012, Karakaya 2015, Zhao 2016, Wang 2012, Yang 2016, Zou 2017, Zhao 2019, Binz 2017, Sen 2017, Eleftheriadis 2015,	12
3	Lack of experience on technology and management	Wang 2008, Schuman 2012, Karakaya 2015, Zhao 2016, Ming 2013, Wang 2012, Yang 2016, Zhao 2019, Binz 2017, Sen 2017, Eleftheriadis 2015,	11
4	Lack of funding/financing difficulties	Wang 2008, Zhang 2012, Karakaya 2015, Ming 2013, Yang 2016, Zou 2017, Zhao 2019, Binz 2017, Sen 2017, Eleftheriadis 2015, Zhao 2018,	11
5	Grid capacity and connectivity delays	Schuman 2012, Zhao 2016, Wang 2012, Zou 2017, Zhao 2019, Binz 2017, Sen 2017, Eleftheriadis 2015, Zhao 2018,	9
6	Lack of legal and regulatory framework	Zhang 2012, Schuman 2012, Zhao 2016, Wang 2012, Zhao 2019, Binz 2017, Sen 2017, Eleftheriadis 2015, Zhao 2018,	9
7	Lack of R&D incentives	Karakaya 2015, Zhao 2016, Wang 2012, Yang 2016, Zou 2017, Zhao 2019, Binz 2017, Sen 2017, Zhao 2018,	9
8	Lack of strategic planning and political will	Wang 2008, Zhao 2016, Ming 2013, Wang 2012, Yang 2016, Zhao 2019, Eleftheriadis 2015, Zhao 2018,	8
9	Lack of research personnel or trained manpower	Wang 2008, Zhang 2012, Karakaya 2015, Zhao 2016, Wang 2012, Sen 2017, Eleftheriadis 2015, Zhao 2018,	8

10	Inadequate data and information	Wang 2008, Karakaya 2015, Zhao 2016, Wang 2012, Zhao 2019, Binz 2017, Sen 2017, Eleftheriadis 2015,	8
11	Less investments due to high risk	Wang 2008, Schuman 2012, Zhao 2016, Ming 2013, Zhao 2019, Binz 2017, Sen 2017, Eleftheriadis 2015,	8
12	Inadequate market size and infrastructure	Karakaya 2015, Yang 2016, Zou 2017, Zhao 2019, Binz 2017, Sen 2017,	6
13	Lack of coordination among agencies	Schuman 2012, Wang 2012, Zhao 2019, Binz 2017, Eleftheriadis 2015, Zhao 2018,	6
14	Resource availability	Zhao 2016, Wang 2012, Yang 2016, Zhao 2019, Sen 2017, Zhao 2018,	6
15	Lack of awareness	Wang 2008, Karakaya 2015, Zhao 2016, Sen 2017, Eleftheriadis 2015,	5
16	Bureaucratic hassles	Karakaya 2015, Wang 2012, Zhao 2019, Eleftheriadis 2015, Zhao 2018,	5
17	Low conversion efficiency/reliability issues	Schuman 2012, Karakaya 2015, Zhao 2016, Binz 2017, Sen 2017,	5
18	Inadequate installation space and local infrastructure	Zhang 2012, Zhao 2016, Yang 2016, Binz 2017, Eleftheriadis 2015,	5
19	Lack of stakeholder participation	Zhang 2012, Zhao 2016, Binz 2017, Sen 2017, Eleftheriadis 2015,	5
20	Long payback period	Zhang 2012, Schuman 2012, Karakaya 2015, Zhao 2019, Eleftheriadis 2015,	5
21	Lack of appropriate and advanced manufacturing technologies	Wang 2008, Yang 2016, Zou 2017, Sen 2017,	4
22	High initial costs	Zhang 2012, Karakaya 2015, Sen 2017, Eleftheriadis 2015,	4
23	Environmental issues	Zhao 2016, Zhao 2019, Sen 2017, Zhao 2018,	4
24	Objections from vested interest groups (oil, gas, coal, etc.)	Wang 2008, Karakaya 2015, Eleftheriadis 2015,	3
25	Social acceptance	Sen 2017, Eleftheriadis 2015, Zhao 2018,	3

26	High installation and maintenance/repair costs	Zhang 2012, Karakaya 2015, Eleftheriadis 2015,	3
27	Structural issues in retrofitting to existing infrastructure	Zhang 2012, Karakaya 2015,	2
28	Storage issues	Karakaya 2015, Zhao 2018,	2
29	Lack of industrial framework	Wang 2008, Zhao 2019,	2
30	Lack of public participation	Wang 2008, Sen 2017,	2
31	Safety and and stability concerns	Karakaya 2015, Zhao 2016,	2
32	Complexity of system design	Karakaya 2015,	1
33	Aesthetic considerations	Zhang 2012,	1

Table A.2 All barriers identified from literature for China

Appendix B

Explaining Barrier Relationships

This appendix explains all the barrier relationships for both the countries. Basically justifying the choices made in the first step of the analysis chapter, i.e. the SSIM matrix.

	Barriers	15 Multi-tired govt. approvals and documentation	14 Lack of subsidies/incentives inadequacy	13 Lack of local infrastructure	12 Lack of information	11 Poor market infrastructure	10 Poor reliability and low efficiency	9 Lack of coordination between agencies/stakeholders	8 High initial investment cost	7 Lack of financing institutions and incentives	6 Lack of awareness/understanding of technology	5 Regulatory issues	4 Grid issues/Energy access	3 Lack of skilled personnel and training institutes	2 Lack of supporting policy and poor execution
1	**Lack of R&D culture**	**(O)**	**(A)** Lower the subsidies in any sector, lower is the incentive to improve technology by R&D; sometimes R&D itself is subsidized	**(O)**	**(X)** Bad data sets will lead to faulty research outcomes; Lack of R&D in information gathering will result in inadequate data	**(V)** R&D is the precursor to every new market. Without sufficient R&D, the market would not emerge/grow	**(V)** Research is the only way to improve technological efficiencies and thereby improving reliability	**(O)**	**(V)** Through research,as technology becomes more efficient and cheap to produce, investment costs will decrease	**(O)**	**(O)**	**(O)**	**(O)**	**(A)** Inadequacy of education institutes dealing with these technologies leads to lesser no of researchers in the field	**(O)**
2	**Lack of supporting policy and poor execution**	**(V)** Unclear policies lead to more documentation and longer approvals	**(V)** Subsidies are a major part of supporting policy. Lack of policy will definitely reduce the incentives for that technology	**(O)**	**(V)** Better policy will lead to better data collection centers and good quality information. Could also mean ambiguity of information due to unclear policies	**(V)** Policy support encourages market growth due to perceived stability/lower risks	**(O)**	**(V)** Clearer policy leads to better interactions between responsible agencies as each has its work outlined without overlap/ambiguity	**(O)**	**(V)** Financiers are reluctant to invest in projects with unclear policy support due to higher risks of loss	**(V)** Absence of policy related to technology will hinder awareness among consumers as it would not concern them directly	**(V)** If there is no policy made in the first place, regulations and legislation built around that issue is usually absent	**(V)** Grid companies are reluctant to improve grid capacities and energy access to remote project locations without the safety of existing policy support	**(X)** Absence of policy will prevent knowledge development in educational and research institutions. The converse is also true because absence of field experts at the decision making level will lead to ignorance of those industries	
3	**Lack of skilled personnel and training institutes**	**(O)**	**(O)**	**(O)**	**(O)**	**(A)** Without the market demand for jobs in the field, there is no incentive to create educational and technical institutes to train individuals	**(V)** Absence of researchers to improve efficiency. Untrained technicians may cause mistakes during installation which reduces project reliability	**(O)**	**(O)**	**(O)**	**(A)** People unaware of the technology, its related-courses and prospective opportunities will not get trained or educated in the field	**(V)** Lack of technology experts at decision making positions leads to regulatory and legislative failure	**(O)**		
4	**Grid issues/Energy access**	**(A)** Delays in grid connection approvals and lengthy procedures	**(A)** Grid companies often lack financial incentives to expand the reach of the grid to remote places where the project is established	**(A)** Inadequate local grid infrastructure leads to problems like need for upgrades and low handling capacities	**(O)**	**(O)**	**(V)** Poor grid capacities cause unreliability in projects because it leads to dumping of overproduced electricity	**(O)**	**(O)**	**(O)**	**(A)** Lack of tech. experience will result in ignorance of grid expectations in terms of capacity, reachability, distributed generation and bilateral flow	**(A)** There should be stringent regulations for grid expansion and enforcement of power purchase agreements to avoid power dumping. Thus, lack of regulations lead to grid issues			
5	**Regulatory issues**	**(V)** Lengthy procedures are a result of improper regulations	**(V)** Absence of regulations and legislation causes delays in disbursement of subsidies	**(V)** Enforcement of regulations help deal with problems of land acquisition, etc.	**(A)** Information asymmetry may cause improper regulations. The market may be in the need of different regulations by the time the sanctions are imposed	**(V)** Lack of regulations or bad enforcement leads to slower market growth as no one would invest in a unstable market	**(O)**	**(V)** Clearer regulations lead to better interactions between responsible agencies as each has its work outlined without overlap/ ambiguity	**(O)**	**(V)** Financiers are reluctant to invest without proper regulation and legislation due to increased risk of losses	**(A)** Lack of understanding of technology among decision making consumers lead to regulatory issues				
6	**Lack of awareness/understanding of technology**	**(O)**	**(O)**	**(O)**	**(O)**	**(V)** Awareness of stakeholders is important to promote market growth of a certain technology	**(O)**	**(V)** Lack of understanding of technology will cause confusion of roles among decision making agencies	**(O)**	**(V)** Perceived risk among the public is a major factor for financiers to make investment decisions in a technology. Thus, unawareness may lead to financiers backing out					

Table B.1 Barrier relationships explained for India(1/2)

	Barriers	15 Multi-tired govt. approvals and documentation	14 Lack of subsi-dies/incentives inadequacy	13 Lack of local infrastructure	12 Lack of information	11 Poor market infrastructure	10 Poor reliability and low efficiency	9 Lack of coordination between agencies/stake-holders	8 High initial investment cost	7 Lack of financing institutions and incentives	6 Lack of awareness/un-derstanding of technology	5 Regulatory issues	4 Grid issues/Energy access	3 Lack of skilled personnel and training institutes	2 Lack of support-ing policy and poor execution
7	**Lack of financing institutions and incentives**	**(A)** Long processing times and lengthy approval times deter investors due to late returns on investment	**(A)** Lack of subsi-dies/incentives deters financiers from investing in a project due to much higher than required investment amounts	**(O)**	**(O)**	**(X)** Lack of finance prohibits market growth. Poor market deter financiers	**(O)**	**(O)**	**(V)** Lack of finance forces the developer to invest more of his own money which basically increased investment						
8	**High initial investment cost**	**(O)**	**(A)** Lesser the subsidies more is the investment required	**(A)** Absence of grid connectivity, delayed land acquisitions and local manufacturing causes non-productive investments	**(O)**	**(A)** Poor local markets force the developer to import components thus increasing the investment cost	**(A)** Lower efficiency leads to larger number of panels or turbines required for the same level of output power, therefore larger investment	**(O)**							
9	**Lack of coordination between agencies/stakeholders**	**(V)** Lack of coordination usually leads to lengthy process times and multiple documentation	**(O)**	**(O)**	**(V)** Information asymmetry caused by lack of co-ordination between different responsible agencies. Knowledge sharing is absent	**(O)**	**(O)**								
10	**Poor reliability and low efficiency**	**(O)**	**(A)** Technologies with low efficiencies need to be subsidized to be market vi-able/competitive. Thus, without subsidies, efficiency remains low	**(O)**	**(A)** Bad project reliability due to bad resource information which leads to sub-optimal outputs	**(O)**									
11	**Poor market infrastructure**	**(A)** Bureaucracy forces stakeholders to exit the market very soon if the processes are too long and cumbersome	**(A)** The more the subsidies, bigger the market.	**(A)** Market depends on local resource availability	**(A)** Market growth hindered due to lack of information exchange and knowledge diffusion within stakeholder community										
12	**Lack of information**	**(O)**	**(O)**	**(O)**											
13	**Lack of local infrastructure (land and resources)**	**(A)** Land acquisition etc. takes time due to bureaucratic hassles	**(O)**												
14	**Lack of subsidies/incentives inadequacy**	**(A)** Delays in disbursement of subsidies due to long approval procedures													
15	**Multi-tired govt. approvals and documentation**														

Table B.2 Barrier relationships explained for India (2/2)

	Barriers	15 Bureaucratic hassles	14 Lack of consumer awareness	13 Resource unavailability	12 Lack of coordination among agencies	11 Inadequate market size and infrastructure	10 Inadequate data and information	9 Lack of research personnel or trained manpower	8 Lack of strategic planning and political will	7 Lack of R&D	6 Lack of legal and regulatory framework	5 Grid capacity and connectivity delays	4 Lack of fund-ing/financing difficulties	3 Lack of experience on technology and management	2 Limited policy framework or lack thereof
1	**Lack of incentives/subsidies compared to fossil fuels**	**(A)** Delays in disbursement of subsidies due to long approval procedures	**(O)**	**(O)**	**(O)**	**(V)** The more the subsidies, bigger the market	**(O)**	**(O)**	**(A)** When there are no plans for the development of solar or wind in the future and no willingness from the politicians, there will be lesser subsidies by the government in this sector	**(V)** Lower the subsidies in any sector, lower is the incentive to improve technology by R&D; sometimes R&D itself is subsidized	**(A)** Inefficient implementation of regulation and legislation causes delays in subsidy disbursement or improper distribution	**(V)** Grid companies often lack financial incentives to expand the reach of the grid to remote places where the project is established	**(V)** Lack of subsi-dies/incentives deters financiers from investing in a project due to much higher than required investment amounts	**(O)**	**(A)** Subsidies are a major part of supporting policy. Lack of policy will definitely re-duce the incen-tives for that tech-nology
2	**Limited policy framework or lack thereof**	**(V)** Unclear policies lead to more documentation and longer approvals	**(V)** Absence of policy related to technology will hinder awareness among consumers as it would not concern them directly	**(O)**	**(V)** Clearer policy leads to better interactions between responsible agencies as each has its work outlined without overlap/ ambiguity	**(V)** Policy support encourages market growth due to perceived stability/lower risk	**(V)** Better policy will lead to better data collection centers and good quality information. Could also mean ambiguity of information due to unclear policies	**(X)** Absence of policy will prevent knowledge development in educational and research institutions. The converse is also true because absence of field experts at the decision making level will lead to ignorance of those industries	**(A)** If there is enough political will for the development of a sector/technol-ogy, policy framework will be created surrounding that sector/ technology	**(O)**	**(V)** If there is no policy made in the first place, regulations and legislation built around that issue is usually absent	**(V)** Grid companies are reluctant to improve grid capacities and energy access to remote project locations without the safety of existing policy support	**(V)** Financiers are reluctant to invest in projects with unclear policy support due to higher risks of loss	**(O)**	
3	**Lack of experience on technology and management**	**(O)**	**(A)** Lack of awareness will prevent technological experience	**(O)**	**(V)** Lack of understanding of technology management will cause confusion of roles among decision making agencies	**(V)** Market growth is slower if lesser stakeholders are experienced with the technology and its management	**(V)** Experience with technology will increase the importance of data and information	**(A)** Lack of research personnel and technical experts will result in a lack of experience with technology	**(O)**	**(A)** Lack of research will result in a lack of experience with technology	**(V)** Lack of understanding of technology among decision making consumers lead to regulatory issues	**(V)** Lack of tech. experience will result in ignorance of grid expectations in terms of capacity, reachability, distributed generation and bilateral flow	**(V)** Lack of experience in management of technology increases risk of the project which is a major deterrent for financiers		
4	**Lack of funding/financing difficulties**	**(A)** Long approvals deter investors due to long ROIs and thus cause financing difficulties for projects	**(O)**	**(O)**	**(O)**	**(X)** Lack of finance prohibits market growth. Poor market deter financiers	**(O)**	**(O)**	**(A)** Lack of political will may act as a deterrent for financiers to invest in a technology	**(O)**	**(A)** Financiers are reluctant to invest without proper regulation and legislation due to increased risk of losses	**(O)**			
5	**Grid capacity and connectivity delays**	**(A)** Delays in grid connection approvals and lengthy connection times	**(O)**	**(O)**	**(O)**	**(O)**	**(O)**	**(O)**	**(O)**	**(O)**	**(A)** There should be stringent regulations for grid expansion and enforcement of power purchase agreements to avoid power dumping. Thus, lack of regulations lead to grid issues				

Table B.3 Barrier relationships explained for China (1/2)

	Barriers	15 Bureaucratic hassles	14 Lack of consumer awareness	13 Resource unavailability	12 Lack of coordination among agencies	11 Inadequate market size and infrastructure	10 Inadequate data and information	9 Lack of research personnel or trained manpower	8 Lack of strategic planning and political will	7 Lack of R&D	6 Lack of legal and regulatory framework	5 Grid capacity and connectivity delays	4 Lack of funding/financing difficulties	3 Lack of experience on technology and management	2 Limited policy framework or lack thereof
6	**Lack of legal and regulatory framework**	**(V)** Lengthy procedures are a result of improper regulations and unenforced legislation	**(O)**	**(V)** Problems of land and other resource acquisition solved faster by better legislation	**(V)** Clearer regulations lead to better interactions between responsible agencies as each has its work outlined without overlap/ambiguity	**(V)** Lack of regulations or bad enforcement leads to slower market growth as no one would invest in a unstable market	**(A)** Information asymmetry may cause improper regulations. The market may be in the need of different regulations by the time the sanctions are imposed	**(A)** Lack of technology experts at decision making positions leads to regulatory and legislative failure	**(A)** Lack of planning and political will decrease the focus on improving regulations and legislation around the technology	**(O)**					
7	**Lack of R&D**	**(O)**	**(O)**	**(O)**	**(O)**	**(V)** R&D is the precursor to every new market. Without sufficient R&D, the market would not emerge/grow	**(X)** Bad data sets will lead to faulty research outcomes; Lack of R&D in information gathering will result in inadequate data	**(A)** Inadequacy of education institutes dealing with these technologies leads to lesser no of researchers in the field	**(O)**						
8	**Lack of strategic planning and political will**	**(O)**	**(A)** If the politicians are not aware of the benefits of new technology, there will be no planning and political will	**(O)**	**(O)**	**(O)**	**(O)**	**(V)** Lack of political will and planning will in terms of establishing research and training institutes is very important							
9	**Lack of research personnel or trained manpower**	**(O)**	**(A)** People unaware of the technology, its related-courses and prospective opportunities will not get trained or educated in the field	**(O)**	**(O)**	**(A)** Without market demand for jobs, there is no incentive to invest in training and education in a certain field	**(O)**								
10	**Inadequate data and information**	**(O)**	**(O)**	**(O)**	**(A)** Lack of coordination causes information asymmetry and absence of knowledge sharing	**(V)** Market growth hindered due to lack of information exchange and knowledge diffusion within stakeholder community									
11	**Inadequate market size and infrastructure**	**(A)** Bureaucracy forces market players to exit due to cumbersome procedure	**(A)** Consumer stakeholder awareness necessary for them to invest in markets which promotes growth	**(A)** Market develops with difficulty in places with lack of resources	**(O)**										
12	**Lack of coordination among agencies**	**(V)** Lack of co-ordination leads to lengthy process times and multiple documentation	**(O)**	**(O)**											
13	**Resource unavailability**	**(A)** Resource acquisition delayed due to lengthy procedures	**(O)**												
14	**Lack of consumer awareness**	**(O)**													
15	**Bureaucratic hassles (permissions and documentation)**														

Table B.4 Barrier relationships explained for China (2/2)

Appendix C

All Level Partitions

This appendix shows all the level partitions for both the countries since the analysis chapter has been kept concise, showing only the the first two levels.

India

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 3 5 7 8 10 11 12	1 2 3 5 6 9 11 12 13 14 15	1 3 5 11 12	
2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 5 6 7 11 12 13 14 15	1 2 3 5 6 7 11 12 13 14 15	
4	4 8 10	2 3 4 5 6 9 11 12 13 14 15	4	
5	1 3 4 5 7 8 9 10 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 3 5 9 11 12 13 14 15	
6	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
7	3 7 8 11	1 2 3 5 6 7 9 11 12 13 14 15	3 7 11	
8	8	1 2 3 4 5 6 7 8 10 11 12 13 14 15	8	**1st**
9	1 4 5 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	5 9 11 12 13 14 15	
10	8 10	1 2 3 4 5 6 9 10 11 12 13 14 15	10	
11	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 5 6 7 9 11 12 13 14 15	1 2 3 5 6 7 9 11 12 13 14 15	
12	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	
13	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
14	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	

Table C.1 First iteration for level partitioning of barriers in India

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 3 5 7 10 11 12	1 2 3 5 6 9 11 12 13 14 15	1 3 5 11 12	
2	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
3	1 2 3 4 5 6 7 9 10 11 12 13 14 15	1 2 3 5 6 7 11 12 13 14 15	1 2 3 5 6 7 11 12 13 14 15	
4	4 10	2 3 4 5 6 9 11 12 13 14 15	4	
5	1 3 4 5 7 9 10 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 3 5 9 11 12 13 14 15	
6	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
7	3 7 11	1 2 3 5 6 7 9 11 12 13 14 15	3 7 11	**2nd**
9	1 4 5 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	5 9 11 12 13 14 15	
10	10	1 2 3 4 5 6 9 10 11 12 13 14 15	10	**2nd**
11	1 2 3 4 5 6 7 9 10 11 12 13 14 15	1 2 3 5 6 7 9 11 12 13 14 15	1 2 3 5 6 7 9 11 12 13 14 15	
12	1 2 3 4 5 6 7 9 10 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	
13	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
14	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
15	1 2 3 4 5 6 7 9 10 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	

Table C.2 Second iteration for level partitioning of barriers in India

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 3 5 11 12	1 2 3 5 6 9 11 12 13 14 15	1 3 5 11 12	**3rd**
2	1 2 3 4 5 6 9 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
3	1 2 3 4 5 6 9 11 12 13 14 15	1 2 3 5 6 11 12 13 14 15	1 2 3 5 6 11 12 13 14 15	
4	4	2 3 4 5 6 9 11 12 13 14 15	4	**3rd**
5	1 3 4 5 9 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 3 5 9 11 12 13 14 15	
6	1 2 3 4 5 6 9 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
9	1 4 5 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	5 9 11 12 13 14 15	
11	1 2 3 4 5 6 9 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	
12	1 2 3 4 5 6 9 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	1 2 3 5 6 9 11 12 13 14 15	
13	1 2 3 4 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
14	1 2 3 4 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	
15	1 2 3 4 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	

Table C.3 Third iteration for level partitioning of barriers in India

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
2	2 3 5 6 9 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
3	2 3 5 6 9 11 12 13 14 15	2 3 5 6 11 12 13 14 15	2 3 5 6 11 12 13 14 15	
5	3 5 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	3 5 9 11 12 13 14 15	**4th**
6	2 3 5 6 9 11 12 13 14 15	2 3 6 11 12 13 14 15	2 3 6 11 12 13 14 15	
9	5 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	5 9 11 12 13 14 15	**4th**
11	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	**4th**
12	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	**4th**
13	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	**4th**
14	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	**4th**
15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	2 3 5 6 9 11 12 13 14 15	**4th**

Table C.4 Fourth iteration for level partitioning of barriers in India

China

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
2	2 3 6	2 3 6	2 3 6	**5th**
3	2 3 6	2 3 6	2 3 6	**5th**
6	2 3 6	2 3 6	2 3 6	**5th**

Table C.5 Fifth iteration for level partitioning of barriers in India

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 3 4 5 6 7 9 10 11	1 2 3 6 7 8 9 10 11 12 13 14 15	1 3 6 7 9 10 11	
2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 6 7 8 9 10 11 12 13 14 15	2 6 7 8 9 10 11 12 13 14 15	
3	1 3 4 5 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 3 6 7 9 10 11 12 13 15	
4	4 9 11	1 2 3 4 6 7 8 9 10 11 12 13 14 15	4 9 11	**1st**
5	5	1 2 3 5 6 7 8 9 10 11 12 13 14 15	5	**1st**
6	1 2 3 4 5 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 9 10 11 12 13 15	
7	1 2 3 4 5 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 9 10 11 12 13 15	
8	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	
9	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 4 6 7 8 9 10 11 12 13 14 15	1 2 3 4 6 7 8 9 10 11 12 13 14 15	
10	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	
11	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 4 6 7 8 9 10 11 12 13 14 15	1 2 3 4 6 7 8 9 10 11 12 13 14 15	
12	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	
13	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	
14	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	
15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	

Table C.6 First iteration for level partitioning of barriers in China

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1 3 6 7 9 10 11	1 2 3 6 7 8 9 10 11 12 13 14 15	1 3 6 7 9 10 11	**2nd**
2	1 2 3 6 7 8 9 10 11 12 13 14 15	2 6 7 8 9 10 11 12 13 14 15	2 6 7 8 9 10 11 12 13 14 15	
3	1 3 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 3 6 7 9 10 11 12 13 15	**2nd**
6	1 2 3 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 9 10 11 12 13 15	**2nd**
7	1 2 3 6 7 9 10 11 12 13 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 9 10 11 12 13 15	**2nd**
8	1 2 3 6 7 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	
9	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	**2nd**
10	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	**2nd**
11	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	1 2 3 6 7 8 9 10 11 12 13 14 15	**2nd**
12	1 2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	
13	1 2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	
14	1 2 3 6 7 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	2 8 9 10 11 12 13 14 15	
15	1 2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	2 3 6 7 8 9 10 11 12 13 14 15	

Table C.7 Second iteration for level partitioning of barriers in China

Barrier Sr. No.	Reachability Set	Antecedent Set	Intersection Set	Level
2	2 8 12 13 14 15	2 8 12 13 14 15	2 8 12 13 14 15	**3rd**
8	2 8 12 13 14 15	2 8 12 13 14 15	2 8 12 13 14 15	**3rd**
12	2 8 12 13 14 15	2 8 12 13 14 15	2 8 12 13 14 15	**3rd**
13	2 8 12 13 14 15	2 8 12 13 14 15	2 8 12 13 14 15	**3rd**
14	2 8 12 13 14 15	2 8 12 13 14 15	2 8 12 13 14 15	**3rd**
15	2 8 12 13 14 15	2 8 12 13 14 15	2 8 12 13 14 15	**3rd**

Table C.8 Third iteration for level partitioning of barriers in China

Appendix D

MATLAB Script for ISM Analysis

This appendix shows the MATLAB script written to carry out the ISM analysis string from the SSIm as the input to the hierarchy as the output.

```
clc;
clear all;

%—————————————Import SSIM Excel file——————————————————————

[num,ssim] = xlsread('India SSIM.xlsx');      % Full SSIM matrix
%[num,ssim] = xlsread('China SSIM.xlsx');      % Full SSIM matrix
barr = size(ssim,1)+1;                        % No. of barriers
k = barr:-1:2;

%—————————————Convert SSIM into Initial Reachbility Matrix——————
% Initializing the intial reachbility matrix
init_reach_mat = ones(barr);

for i = 1:barr
for j = 1:(barr-i)
if ssim{i,j}=='V'                  % 'V' --> barrier 1 influences 2
init_reach_mat(i,k(j))= 1;
init_reach_mat(k(j),i)= 0;
elseif ssim{i,j}=='A'              % 'A' --> barrier 2 influences 1
init_reach_mat(i,k(j))= 0;
init_reach_mat(k(j),i)= 1;
elseif ssim{i,j}=='X'% 'X' --> barrier 1 and 2 influence each other
```

```
init_reach_mat(i,k(j))= 1;
init_reach_mat(k(j),i)= 1;
elseif ssim{i,j}=='O'% 'O' --> no relation between barriers 1 and 2
init_reach_mat(i,k(j))= 0;
init_reach_mat(k(j),i)= 0;
else
fprintf('Error');
end
end
end

init_reach_mat
%writematrix(init_reach_mat,
%'Initial reachability matrix.xlsx','Sheet',1);

%----------Validation using initial reachability matrix----------
%----------Comment everything above this----------
% [init_reach_mat] = xlsread('Validation_Zhao Init Reach Matrix.xlsx')
% barr = size(init_reach_mat,1);                    % No. of barriers

%------Account for transitivity in Initial Reachbility Matrix------
% Initializing the final transitivity matrix
fin_rea_mat = init_reach_mat;
% To keep track of changes in initial matrix
check_mat = init_reach_mat;
c=2;          % counter to see transitivity

while true
prev = fin_rea_mat;
for i = 1:barr
for j = 1:barr
for k = 1:barr
if(fin_rea_mat(i,j)==1&&fin_rea_mat(j,k)
    ==1&&fin_rea_mat(i,k)==0&&c<=2)
    fin_rea_mat(i,k) = 1;        % gives final reachability matrix
    check_mat(i,k) = c; % to show where transitivity affects matrix
```

```
end
end
end
end
c = c + 1;
if fin_rea_mat == prev  % previous iteration and new iteration
    break;              % will give same result when
end                     % transitivity is accounted for
end

check_mat
%writematrix(check_mat,'Final reachability matrix.xlsx','Sheet',1);

%————Level Partitioning of the final reachability matrix————
reach_set = zeros(barr);           %\   Initializing matrices for
ant_set = zeros(barr);             % >  rechability, antecedent
inter_set = zeros(barr);           %/   and, intersection set


for i = 1:barr
for j = 1:barr
    % column no. of 1's in a row form reachability set
if fin_rea_mat(i,j)==1
    reach_set(i,j) = j;                    % Reachability set
end
    % row no. of 1's in a column form antecedent set
if fin_rea_mat(j,i)==1
    ant_set(i,j) = j;                      % Antecedent set
end
% finds common elements between the reachability and antecedent sets
if (fin_rea_mat(i,j)==1 && fin_rea_mat(j,i)==1)
    inter_set(i,j) = j;                    % Intersection set
end
end
end
```

```
% initilized to note the heirarchy among barriers
hierarchy = zeros(1,barr);
% initialized to note levels in level partitioning
x = 1;

while true
y = 1;               % counter to maintain the serial column-wise
              % entry per level of the heirarchy matrix
for i=1:barr
   % to obtain a scalar
h = (reach_set(i,:)==inter_set(i,:))*ones(barr,1);
                          % value for the if condition statement

if (h==barr && nnz(reach_set(i,:))~=0)  % first condition checks
                          % if the intersection and reachability
                          % sets are the same

hierarchy(x,y) = i;     % second condition helps skip the already
y = y + 1;              % partitioned barriers by omission
end
end

%writematrix(reach_set,'Level Partitioning.xlsx',
%'Sheet',x,'Range','A1:O15');
%writematrix(ant_set,'Level Partitioning.xlsx',
%'Sheet',x,'Range','Q1:AE15');
%writematrix(inter_set,'Level Partitioning.xlsx',
%'Sheet',x,'Range','AG1:AU15');

for j=1:barr                     % this loop is used to nullify
if hierarchy(x,j)~=0             % the already partitioned barriers
a = hierarchy(x,j);              % to move on to the next level
reach_set(a,:) = zeros(1,barr);
inter_set(a,:) = zeros(1,barr);
ant_set(a,:) = zeros(1,barr);
```

```
reach_set(:,a) = zeros(barr,1);
inter_set(:,a) = zeros(barr,1);
ant_set(:,a) = zeros(barr,1);
else
break;
end
end

x = x + 1;

if (nnz(reach_set)==0)      % stops the while loop when all barriers
break;                          % successfully level partitioned
end
end

hierarchy     % prints the hierarchical levels
%writematrix(hierarchy,'China_Heirarchy.xlsx','Sheet',1);
```