



ENERGY TRANSITION IN THE ANDAMAN AND NICOBAR ISLANDS

Backcasting Analysis to Aid a Transition to
Sustainable Energy in Andaman and Nicobar
Islands by 2040

Aditya Vardhan Vallabhaneni

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Aditya Vardhan Vallabhaneni

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Supervisor:

Dr. ir. J. N. Quist

Thesis Committee:

Dr. ir. J. N. Quist TU DELFT

Prof. dr. K. Blok TU DELFT

Dr.ir. K. F. Mulder TU DELFT

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Delft University of Technology

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Executive Summary

Most nations across the world have understood the dangers and threats of global warming. The threat is even more extreme in the case of islands such as Andaman and Nicobar Islands due to the chances of submergence as a result of increasing sea levels. Despite these dangers, there have not been any concrete actions to shift towards sustainable energy. These islands are unique from other small island developing states (SIDS) that face a similar set of problems. The uniqueness is that the archipelago is a federal territory of India and has better access to resources to make a successful transition. This makes it interesting to examine the existing situation in the islands and to plan a transition towards sustainable energy supply.

In order to plan a transition on the archipelago, the five step backcasting methodology proposed by Quist will be used. Certain elements of energy backcasting from the Robinson approach will be borrowed as well. Based on these approaches and the existing scenario in the islands, the main research question has been formulated as follows.

‘What are the possible pathways that can be followed by various actors in order to attain a 100% sustainable energy transition in Andaman and Nicobar Islands?’

The five-step methodology of the Quist framework has been condensed into four steps in this thesis study and the required activities have been rearranged to fit this case. The first step of the backcasting analysis deals with establishing the current energy situation in the archipelago. The second step is to develop the future visions for the archipelago. The third step of the analysis identifies the required changes and interventions to make a successful transition. The necessary transitional pathways are also partially defined while laying out the required interventions. The final fourth step, establishes the implementation scheme for the defined transitional pathways.

The current energy situation in the islands depends almost entirely on the diesel and other fossil fuel imports from the Indian mainland which in turn is heavily dependent on international trade. As of now, the locally produced renewable energy is only 10% of the installed capacity for electricity. The current state of infrastructure is in no state to support a successful transition and is characterized by high losses. In addition to this, the underdeveloped economy enables the usage of inefficient fuels such as firewood for cooking.

Based on the current energy scenario, an endpoint of the year 2040 has been chosen for a full-scale transition to sustainable energy supply to occur. It is assumed that the wide range of fuels used for services like cooking and transport will eventually be electrified. Five main objectives have been developed that outline the main desired vision. Using these visions as a basis, general morphological analysis has been used to develop scenarios for the islands. An optimizing model has been used to develop cost optimal energy configurations that describe how the future could look like.

It was observed that some sort of baseload technologies are necessary. In the case of these islands, the feasible baseloads are biomass and OTEC which are key to the technical and economic feasibility of the transition. The energy configurations developed were optimized on

the basis of costs of electricity generation. Therefore, these configurations are to great extent dependent on the learning curves of technologies (especially OTEC).

In order to analyse the changes needed to reach these targets, ‘What-How-Who’ analysis has been used. The changes necessary to achieve these futures span over a wide range of actors. Disruptive changes are necessary in the energy system of the archipelago. Policy makers are the most important actors throughout the transition. Strong policy framework, financial incentives and infrastructure upgradation is necessary to assist the transition. These changes are necessary to attain a good flow of investments from the private sector. Additionally, such interventions are necessary for the population of the archipelago to adopt to the necessary changes and invest in electric vehicles, energy efficient appliances and practices. The restructuring of the energy market is necessary in the archipelago to promote competition and increase the economic efficiency in the archipelago.

After the identification of the required interventions, transitional pathways and implementational timelines have been developed. While, planning a transition for the individual islands, it has been observed that four of the eight islands considered needed immediate actions as the current generation capacity is quite old and obsolete. It has been envisioned that 75% renewable energy coverage can be achieved for these islands in the initial phases itself. In the rest of the islands, due to size of their demands, this increase in coverage will occur at a much later stage. The transition in these islands needs large sized OTEC plants which will be implemented towards the end of the timeline due to the anticipated effects of learning.

Overall, technically a transition to a 100% sustainable energy supply is technically feasible. However, the economic feasibility of this transition depends on the global development of OTEC. The materialization of these visions, to a major extent is in the hands of the public administration who has to show it’s commitment towards the transition and has to implement the necessary changes.

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Chapter 1: Introduction

1.1. Problem Introduction

In the twentieth century, the global mean temperature rose by 0.6 °C and this has led to the rise in sea level by about 2 mm per year. This increase in global temperature will have unpredictable consequences on the weather patterns and ecology across the globe. By the end of the twenty first century, the global mean sea level rise is expected to be higher. As a result of increased temperatures, there has been a decline in the sea-ice thickness especially in the northern hemisphere (IPCC, 2007). This is a huge concern for the low lying coastal regions and smaller island nations. As far as islands are concerned, they could potentially become inhabitable, even though they are the least responsible for the climatic change. Island nations such as Marshall Islands and Maldives have voiced out their concerns to the international community and have been keen on moving away from a fossil fuel economy in order to keep the global temperature rise at 1.5 °C from the preindustrial levels (UNFCC, 2005; Wong, 2010).

However, the current energy scenario in most of the islands is different. Most of the islands are highly dependent on imported fossil fuels for their energy requirements and the renewable energy potential in these islands is being heavily under-utilized. In most of the cases, expensive and highly emitting stand-alone diesel generators are being used to power the islands. In addition to the fuel costs, the transportation costs of the fuel and several other overhead costs lead to a very high electricity generation cost in these regions (Weisser, 2003). Many islands do not even have adequate energy supply and in certain Pacific Islands such as Papua New Guinea and Solomon Islands, 70% of the households do not have adequate access to electricity (Dornan, 2014).

The widespread integration of renewable energy systems can reduce the effect of external elements on the local energy system, address issues such as energy poverty and offer a cost-effective and reliable energy supply. According to Weisser (2003), many small island developing states (SIDS) still continue to use fossil fuels and are far from a full-scale integration of renewable energy sources. This could be due to various reasons like lack of awareness and knowledge about their renewable energy potentials, insufficient financing frameworks, insufficient institutional frameworks and inadequate human resource capacities.

Andaman and Nicobar Islands in the Indian Ocean, although does not belong to the SIDS, possesses a similar set of energy problems as the SIDS. However, it must be mentioned that the socio-political sphere of these islands is not the same. These islands are classified as an Union Territory (Federal Territory) of India. Despite having the access to decent financing, human resources, technical universities and knowledge centers, the archipelago is still underdeveloped in terms of energy infrastructure and has failed in initiating a successful transition to a sustainable energy future. Issues such as lack of reliable supply of energy and large-scale consumption of very traditional fuels plague the islands. These features make this archipelago an interesting choice for this study.

1.2. Comparison between SIDS and Andaman and Nicobar Islands

The main common characteristics of SIDS, based on Romano et.al (2016) and Wolf et.al (2016) that apply for this archipelago as well are given as follows:

- Ecological fragility
- Remoteness and limited resources
- Volatility and susceptibility to external global economic factors and shocks
- Lack of economics of scale
- Relatively high costs for transportation and energy
- Heavy dependence on imported fossil fuels

Nevertheless, there is a difference in the aspect of access to human resources, institutional and financial capacities that can drive them towards sustainability. They are usually absent in the SIDS, but this archipelago has access to them as it is an Indian territory, thereby theoretically making the transition easier. However, this is not the case in reality due to a wide range of reasons.

1.3. Research Objective and Scientific Knowledge Gap

In order to develop a feasible roadmap and initiate an energy transition in the Andaman and Nicobar Islands, a backcasting analysis will be performed. As a part of this research, an initial analysis will be performed on the energy landscape of the island group. This analysis will serve as the basis for developing ideal visions for the future. The development of the visions will include an optimization step whose main purpose is to develop cost optimal renewable energy configurations for the islands. Based on these future visions, backcasting will be performed to reach the developed visions. This backcasting analysis will be done in two steps. In the first step, the required changes and interventions are identified. In the second step, practical transitional pathways are drawn which aid in reaching the targets.

As far as the existing literature is concerned, there are multiple sources that provide good insights into various frameworks and details about the backcasting analysis framework and transitional pathways. The five step backcasting framework proposed by Quist (2007) will be used for this research. Several authors argue that transition pathways still consider the political and policy influence as an exogeneous factor and fail in integrating it as a part in the pathways. The absence of these factors makes the analysis of the sociotechnical system incomplete, especially for mid-term and long-term future studies (Marletto, 2014). Therefore, in this research, policy and political interactions will also be considered as an endogenous factor in order to provide more realistic pathways. The choice of backcasting methodology provides suitable support for this assumption.

The existing studies do not use a very comprehensive modelling methodology when it comes to designing scenarios for the backcasting analysis. Combining a vigorous modelling exercise

and the backcasting could lead to very interesting outcomes in this space. The effect of learning rates and the costs of technologies in the future will be incorporated into the optimization process and its effect on the energy mix will be studied. Overall, the usage of these varied elements together is a novel idea and has not been tried before to the author's knowledge. This could result in very interesting and possibly better transitional pathways.

The usage of backcasting analysis on islands in the Indian ocean for energy studies has been quite low with most of the studies being concentrated either in the Pacific region or the Mediterranean. This is primarily due to the absence of large number of data sources. An attempt has been made in this research study to make estimations and bridge the data void to an extent. Performing these kinds of studies on the developing world could give more insights to facilitate a leapfrog to sustainability.

1.4. Research Approach

In spirit, the backcasting analysis qualifies as a qualitative analysis as it considers a particular set of goals and works backwards on attaining these targets with the exemption of Robinson approach. This falls in line with the “causes of effects” nature of the qualitative analysis (Mahoney et.al, 2006). In addition to this, methodologies such as morphological analysis for scenario development in this research study are essentially qualitative. Extensive qualitative meta-analysis has to be performed based on secondary data sources in order to gain insights on the energy scenario in the region of study, establish a proper methodological framework of analysis and also to investigate the influence of various actors in the energy landscape. The backcasting framework in this case also allows numerous quantitative elements to be incorporated into this study. Therefore, quantitative elements from energy backcasting by Robinson and an optimization model have been incorporated into the study.

The primary crux of this thesis will be based on the basic backcasting framework suggested by Quist (2007). The thesis of Agarwala (2017) uses the framework on Grenada and Curacao Islands and serves as an inspiration for this research study. The thesis of Illoldi (2017) on optimal configuration of hybrid renewable energy systems will be used as a base for the optimization of scenarios. These three research studies serve as an important source for the framework and research approach of this thesis. Additionally, thesis by Nodar (2016) and Langer (2018) have also been instrumental for this study.

1.5. Research Questions

Considering the main research objective and the framework chosen, the main research question has been articulated as follows.

‘What are the possible pathways that can be followed by various actors in order to attain a 100% sustainable energy transition in Andaman and Nicobar Islands?’

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

- How does the present energy landscape of the Andaman and Nicobar Islands look like?
- Who are the most prominent actors in the energy landscape of the archipelago?

- What does the desired future of the energy system of the archipelago look like and to what extent do learning rates of technologies influence the desired energy configurations?
- What are the drivers and barriers of the energy transition in Andaman and Nicobar Islands?
- What are the imperative changes needed to materialize the visions?

All of these aforementioned sub-questions converge into answering the main research question. Each of these questions, represent individual themes that are needed for the fulfillment of a robust backcasting analysis.

1.6. Thesis Outline

Chapter 2 deals with presenting a comprehensive literature survey on all the core concepts such as the various backcasting methodologies and transitional pathways.

Chapter 3 proposes a methodological framework for the entire research study based on the literature survey in chapter 2. The chapter concludes by establishing a list of islands that are chosen within this archipelago to perform this study and the list of tasks needed to be performed throughout the entire study.

Chapter 4 deals with the first step of the backcasting process known as the strategic problem orientation step. As a part of this step, the energy system in the location of the study is analyzed and the renewable energy potentials in the region are mapped. A stakeholder analysis and a PESTEL analysis are performed to analyze the role of relevant actors and analyze the external environment respectively.

Chapter 5 represents the second step of the backcasting. It presents with the establishment of visions and development of scenarios for the future. This includes the modelling exercise performed based on the thesis of Illoldi (2017).

Chapter 6 presents the actual backcasting step. This chapter is an amalgamation of steps 3,4,5 of the backcasting. This includes identifying the required changes, interventions using the What-How-Who analysis and the development of transitional pathways.

Chapter 7 presents a discussion and reflection on the entire thesis study. The major aspects discussed in this chapter are the novelty of this thesis, the short comings of this thesis, the validation of the modelling results and recommendations for further research.

Chapter 8 presents the final conclusions of this research. In this chapter, the sub-research questions and the main research questions are answered and recommendations are given.

Chapter 2: Literature Survey

In this chapter, a comprehensive literature study will be performed on the existing literature which helps in establishing a suitable methodological framework for this research. This literature study provides insights into core concepts like future studies, backcasting analysis, different backcasting approaches and transitional pathways. The methodology for finding relevant literature and scoping down necessary literature will be provided.

2.1. Methodology Applied for Finding Literature

In order to perform this literature study similar backcasting studies such as Agarwala (2017), Broich (2015) and the thesis of Quist (2007) are taken as references in identifying the core concepts. Apart from these studies, online databases such as SCOPUS, ScienceDirect and Google Scholar have been used. Keyword combinations such as ‘*Backcasting*’, ‘*Backcasting + Energy*’ and ‘*Transitional Pathways*’ have been used. Meta-Analysis has been performed on the literary sources found. In addition to this, Snowballing is also used to find relevant sources based on the preliminary literature found. These literary sources have been used to find information regarding the core concepts. Table (2.1) shows the list of sources that were used for the core concepts.

Table (2.1): Core-concept wise sources used for literature review

Core Concepts	Future Studies	Scenarios and Typologies	Backcasting	Backcasting Approaches	Transitional Pathways
Literature Sources	• Jan Oliver Schwarz (2007) • Mattias Hojer (2000) • Dreborg (1996) • Phdungsilp (2011)	• Amer et.al (2013) • Amara (1981) • Borjeson (2006) • Quist (2007) • Quist and Vergragt (2011) • Ducot (1980) • Milestad (2014) • Ritchey (1998) • Ritchey (2002) • Ritchey (2011)	• Robinson (2003) • Kishita et.al (2017) • Ericson (2003) • Dreborg (1996) • Quist (2007) • Anderson (2001) • Quist et.al (2006) • Phdungsilp (2011) • Robinson (1982) • Hojer (2000) • Quist et.al (2011) • Kanyama (2007)	• Robinson (2003) • Phdungsilp (2011) • Robinson (1982) • Quist (2007) • Anderson (2001) • Robinson (1990) • Holmberg (1998) • Ran Chen et.al (2012) • Quist et.al (2004) • Weaver et.al (2000) • Quist et.al (2006) • Vergragt (2005) • Vergragt et.al (2002) • Quist et.al (2011) • Agarwala (2017)	• Moradi et.al (2017) • Marletto (2014) • Rip et.al (1997) • Foxon et.al (2013) • Nelson et.al (1982) • Kemp et.al (1998) • Geels (2002) • Geels et.al (2007) • Smith et.al (2010)

2.2. Future Studies

Numerous studies have been performed on the topic of future studies and as a direct result lot of approaches and definitions were formed. The use of future studies has become prominent in the 1950's for governmental and military purposes. Later future oriented think-tanks have gained prominence in the private sector (Schwarz, 2007).

The primary functions of future studies can be classified into two roles. Firstly, in order to find out what the future looks like and to help in either adapting to the change or to be prepared for the change. This is usually employed by businesses or planning authorities. The second role is to plan a development path for the future and steer the change in that direction rather than letting it take its natural course. Big corporations and planning authorities usually have the power to change the course of action (Höjer et.al, 2000). Overall, it can be stated that future studies can be helpful in getting a better understanding of future opportunities and uncertainties.

Dreborg (1996) classifies the future studies into four types when used in the topic of sustainability. They are directional studies, short-term studies, forecasting studies and alternative solutions and visions. Directional studies focus on policies or measures that can help in the transition towards sustainability in the short-term. Short term studies usually have immediate targets that can help the transition in the short term. Forecasts are usually used for extrapolating the existing trend into the future and to develop an understanding of how the future might look like (Phdungsilp, 2011). The visions and alternative solutions allow the development of ideal futures and help in working towards those futures. The two widely used methods are scenarios and visions. However, each of these typologies have their own time frames of study and levels of fulfilment of targets which is shown in figure (2.1).

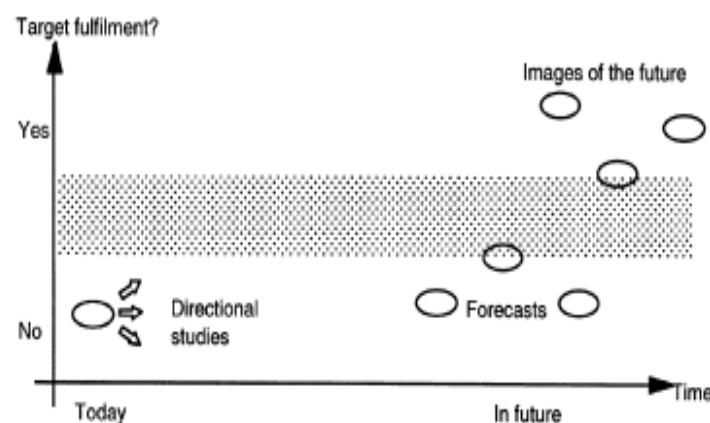


Figure (2.1): Applicability of different types of future studies (Phdungsilp, 2011)

2.3. Scenarios

According to Amer et.al (2013), scenarios can be defined as a depiction of the future and the course of events that can lead to that future. The future developed will be as a result of these course of events and can also be heavily influenced by various combinations of trends and policies. Amara developed three main categories for scenario-future studies (as cited in Börjeson et.al, 2006). The three types are predictive, exploratory and normative scenarios. They essentially represent the themes of what will happen in the future?, what can happen in the future? and how can a specific target be reached? Each type of scenario can be further classified into two categories. This classification is shown in figure (2.2).

What will happen in the future? : Predictive scenarios are used to answer this question. The main aim of predictive scenarios is to create an image of what the future is going to look like

and make a plan to adopt to the most likely future. It is usually self-fulfilling and is used widely by planners and investors. The predictive scenarios can be further classified into Forecasts and What-if scenarios. Forecasts are usually carried out with the theme of what will happen in case the most likely development unfolds. This is done with the help of trend extrapolation and quantitative data (Quist, 2007). The what-if scenarios are employed to investigate what will happen on the condition of some specific events (Börjeson et.al, 2006).

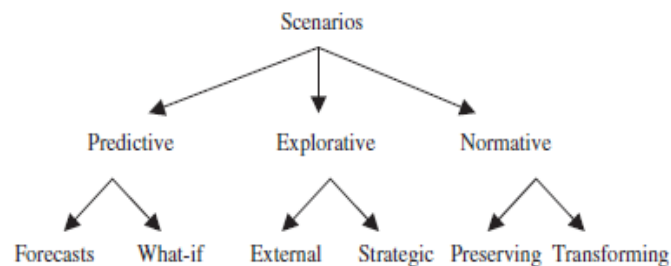


Figure (2.2): Scenario typology (Börjeson et.al, 2006)

What can happen in the future? : Exploratory scenarios are used to answer this question. Exploratory scenarios are used to investigate the different situations or developments that can occur in the future. They usually involve multiple developed scenarios that can occur, taking into different perspectives into consideration. Explorative scenarios differ with what-if scenarios in their starting points. The explorative scenarios consider a starting point in the future whereas what-if scenarios consider the starting point in the present. They are further subdivided into external scenarios and strategic scenarios (Börjeson et.al, 2006). These methodologies are widely used for strategic purposes and has been employed by Shell and Intergovernmental panel on climatic change (IPCC) in the past (Quist et.al, 2011).

How can a specific target be reached? : Normative futures deal with answering this question. This methodology is primarily used in order to attain desirable futures. It is used by planners or decision makers to drive towards visions and move away from undesirable or unnecessary possibilities and occurrences (Ducot et.al, 1980). Börjeson et.al (2006) further categorizes normative futures into preserving scenarios and transforming scenarios. The transforming scenarios methodology has been widely used in field of ‘sustainability’ and are mostly employed in for longer time frames (Milestad et.al, 2014).

2.4. Backcasting Analysis and Methodological Framework:

In this section, literature relating to backcasting analysis is studied and the use of backcasting for sustainability is studied and it is compared with other types of future studies in this regard. Then, different backcasting approaches are investigated and they are compared with each other. This section ends with a detailed overview of each of the approaches

2.4.1. Introduction to Backcasting

According to Robinson (2003), backcasting is an approach to analyse futures by taking various concerns into consideration. The basic idea of backcasting is to delineate the desirable futures,

to extrapolate backwards from the future to the present and analyse various technology and policy options that turn these envisioned futures into reality (Kishita et.al, 2017). Backcasting is essentially normative in nature and belongs to the transformative scenario methodologies and is widely used in planning a transition to sustainability (Ericson, 2003). The envisioned futures in backcasting are based on desirability (social or environmental) but not on likelihood of occurrence. The desirable futures are defined based on criteria that is external to the analysis (Robinson, 2003). Generally backcasting is used in solving long term complex problems involving a wide range of actors in the society and also takes into consideration the aspects of technological innovation and change. The problem-solving nature and idea of attaining desirable futures form its normative nature (Dreborg, 1996).

Backcasting was first proposed by Lovins in the 1970's as an alternative planning technique for electricity supply and estimating the demands. The energy studies during that time were mostly oriented towards attaining soft energy paths and continued its usage in energy related studies ever since (Quist, 2007). The first 'oil price shock' during the 1973 served as the initial concern that propelled in the development of this methodology. Its central premise was to make an attempt in developing a range of desired futures rather than trying to analyse the complexities in supply and demand trends. It was then called as 'Backward-looking analysis' (Anderson, 2001). Later on, Robinson coined the term 'Backcasting Analysis' and also developed a six-step formal methodology. The six-step methodology were developed as elaborations of the principles set by Lovins. Robinson's ideology was not to merely produce blueprints, but to investigate the feasibility and implications of various energy futures. This also includes the aspect of analysing the extent to which undesirable futures can be avoided. These futures are then analysed based on various political, social, environmental and economic implications. These features made this methodology ideal for analysing various policy decisions, thereby aiding policy makers and planners (Quist et.al, 2006).

Backcasting methodology has been widely used in the field of energy and sustainability. Apart from these topics, they are also used in urban city planning, transport system and strategic planning in Scandinavian countries and Netherlands (Phdungsilp, 2011).

2.4.2. Backcasting in Comparison with Other Future studies for Sustainability

When it comes to the issue of sustainability and transitions to a sustainable future, the society and various stakeholders have to undergo a socio-technical transition to get there. According to Quist et.al (2006), any approach analysing such a transition must involve a wide range of stakeholders and actors, incorporate the social and economic aspects of the transition and also incorporate the demand and supply chain of the related system. Backcasting is one such normative method that has the aforementioned characteristics. A study of Steen and Akerman had similar conclusions that backcasting is favourable when the topic being studied is a major societal problem that spreads over many sectors and levels of the society, needs major change away from the current dominant trends, the problem is a matter of externalities and the timeline is long enough to support any action away from the core problem (as cited in Dreborg, 1996).

This falls in line with Robinson's ideology of having usually 25-50 years as time horizon for backcasting.

The other future studies methodologies such as forecasting cannot address all the issues needed for a transition to a sustainable future as they primarily depend on the dominant trends by merely extrapolating current trends but do not work on moving away from them (Dreborg, 1996). According to Robinson (1982), backcasting has a design that can aid in policy design process. However, the same cannot be said about other methods, as they usually are not driven by an explicit image of the future. Nevertheless, forecasting can work well in tandem with backcasting. Backcasts work on a certain degree along with forecasts. Backcasting starts with a series of forecasts that help in attaining a vision of desired future. Apart from this, forecasting can be used in a complementary sense along with backcasting to scrutinize the progress of backcasting analysis. The forecasts can be used to check if the desired futures are attainable or not at various time segments of the backcast. In case the progress is not satisfactory and the desired futures do not align with forecasts, then different images of the futures can be derived and scenarios that can fulfil these visions can be planned (Höjer et.al, 2000). Figure (2.3) shows the difference in approaches in the issues relating to sustainability.

The normative features of the backcasting analysis go in hand with the descriptive and analytical features. The normative side of the backcasting answers the question 'What does the desired future look like?'. While the descriptive and analytical side of the approach the question 'how to reach the desired future?'. In addition to this, backcasting also has a 'designing approach' to the modelling of different desired futures and simulate alternative scenarios. This modelling aspect gives the backcasting analysis a quantitative side. The building of scenarios through the design approach has to be employed in a bottom up model by taking in the values and preferences of various stakeholders into consideration (Robinson, 2003). This has become one of the basis for many participative backcasting studies.

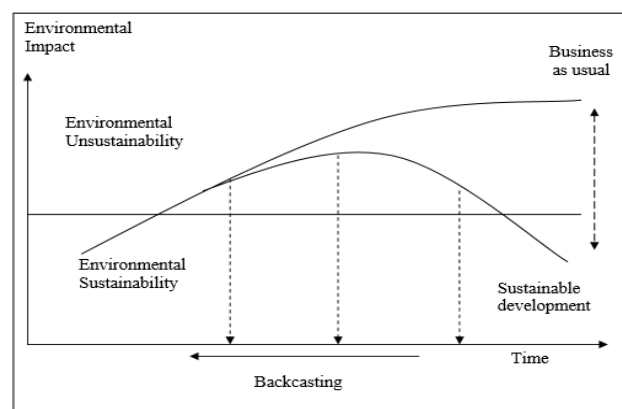


Figure (2.3): The difference in approach between forecasting and backcasting in environmental sustainability (Miola, 2008)

2.4.3. Introduction to Participative Backcasting

In the early 1990's, the usage of participative backcasting has increased in the Netherlands. It has been used for governmental programmes initially and then later on has been adopted in

other projects in Canada and Sweden too (Quist, 2007). Participative backcasting is essentially a wider version of the former approach built on the central idea of integrating the stakeholders into the backcasting process. This involvement of stakeholders can be in the development of sustainable futures, policy making, technological research and development in the design phase (Quist et.al, 2011). The idea behind having a wider range of stakeholder participation is to promote interaction and exchange of knowledge and values amongst the various stakeholders involved leading to a ‘social learning’ and thereby further helps in a better ‘social shaping’ of future visions (Quist et.al, 2002). According to Quist (2007), these factors can overall help in creating more legitimacy and accountability in the backcasting process. The former versions of this approach were iterative nature but had no space for any interactive nature (Quist et.al, 2006). But, in participative backcasting which has been referred to as ‘second order backcasting’ by Robinson, ‘interactive social science’ would be crucial in the stakeholder knowledge of sustainability analysis (Robinson, 2003). This feature would make the backcasting process both iterative and interactive.

In order to facilitate participatory backcasting, different kinds of tools and methods have to be developed in order to systematically include the various stakeholders into the process for the sake of future vision and scenario construction (Quist et.al, 2006). Several methods and tools are developed in order to facilitate interaction. Some of them are used in the ‘*toolsus*’ developed for the involvement of stakeholder to develop and implement tools for sustainable households in the city of tomorrow (SusHous Project), ‘The natural step’ (TNS) methodology, Georgia river basin project in Canada, ‘Sustainable technological development’ (STD) in Netherlands, Sushouse project initiated in Netherlands and other projects (Quist, 2007; Kanyama et.al, 2008).

2.4.4. Backcasting Approaches

In this section, based on various literary sources dealing with backcasting, five widely used backcasting approaches have been selected and will be analysed. The five approaches identified are the Robinson approach, the Natural Step approach (TNS), Sustainable Technology Development approach (STD) and the Quist approach. Apart from these five approaches, Anderson approach which is woven primarily around the Robinson approach will also be studied briefly. This section will end with a comparison between all the five approaches.

However, before discussing about the different approaches in backcasting, it is essential to understand the different kinds of backcasting. Quist (2016) classifies the backcasting processes as follows

- 1) Target oriented backcasting: This kind of process involves the development and analysis of different images of the future in which the targets are usually expressed in quantitative terms.
- 2) Process oriented backcasting: In this kind of backcasting rather than the end goal, the way in changes take place are given more importance. These usually include study of various measures and policy recommendations that can stir up a change.

- 3) Action-oriented backcasting: In this kind of backcasting the focus is on the actors and stakeholders who can bring about the change. The final target of this kind of study would be to develop an action agenda or plan for different stakeholders.
- 4) Participation-oriented backcasting: In this kind of backcasting, the stakeholder participation is given higher importance and the backcasting here is used as a creative workshop tool to involve all the stakeholders into the process.

It is important to note that most of the approaches mentioned below have different aspects of the above-mentioned types and do not stick to any single type.

The Robinson Approach: Robinson Approach has formulated a six-step formal methodology that is explicitly normative and design oriented. Robinson (2003) mentions that the normative nature will have an added advantage of investigating the implications of various policy measures and cannot be used to justify various unfavourable policies citing scientific reasons. The normative scenario analysis approach applied in this methodology forms as a basis for its design oriented nature. The first step involves defining the future goals and constraints that would form the social context of the analysis. These would be the goals towards which the backcasting analysis will work. This will then be followed by defining the end-points and building scenarios based on criteria set externally to the analysis (Robinson, 1982; Quist, 2007). Anderson (2001) mentions that the appropriate endpoints would be in the range of 30-50 years in the future. Then the scenarios are evaluated based on various aspects like socio-economic, policy, physical and technological feasibility. This analysis is usually required to be done in multiple iterations to resolve the inconsistencies and also to rectify the adverse impacts revealed in the previous iterations (Phdungsilp, 2011). However, Quist (2007) mentions that the approach does not explicitly mention who is responsible for setting these future goals and other criteria. The outline of the Robinson approach is presented below in figure (2.4).

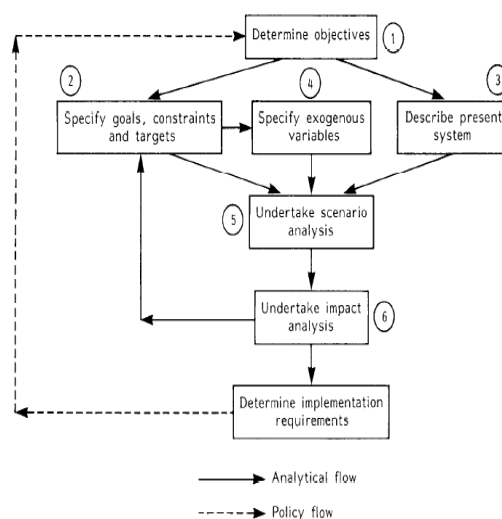


Figure (2.4): Outline of the Robinson backcasting approach (Robinson, 1990)

The six-step methodology suggested by Robinson (1982) is as follows.

- 1) Specify goals and constraints

- 2) Describe current energy consumption and production
- 3) Develop outline of future economy
- 4) Undertake demand analysis
- 5) Undertake supply analysis
- 6) Determine implications of the analysis.

The Natural Step Approach (TNS): The natural step approach is primarily directed towards successful organizational planning in sustainability. Its main role is to help decision makers in planning and designing criteria that can be used to develop sustainable solutions by providing direction for actions relating to socio-economic and environmental aspects (Tang et.al, 2012). Phdungsilp (2011) mentions that this is based on the belief that the future can be envisioned based on a set of principles formed by viewing the physical principles of the ecosystem. These principles are mentioned in table (2.3). The four-step approach aimed towards organizations was described by Holmberg (1998). The four steps are as follows (Holmberg, 1998; Quist 2007)

- 1) Define the sustainability criteria for the organization based on the set of principles.
- 2) Analysing the current situation in the organization and the supply chain of which the organization is a part. This is crucial in identifying the bottlenecks for sustainability.
- 3) Envisioning the future options using employee involvement and creative techniques.
- 4) Developing strategies to move to towards the visions from the future.

STD backcasting approach: The Sustainable Technological Development (STD) is a government programme in Netherlands that ran between 1993 to 2001. The aim of this program was to explore system innovations towards sustainability and also to explore opportunities for developing sustainable technologies. A highly interactive backcasting approach involving a wide range of stakeholders has been applied for the sake of technological development that can aid in a factor 20 increase in environmental efficiency and addresses a number of social needs such as nutrition, water, mobility and housing (Quist et.al, 2004).

Weaver et.al (2000) described a seven step backcasting approach for this case. The seven steps and their relative time frames are described in figure (2.5). Steps 1-3 are essentially to establish the main problem, develop the long-term visions that can be helpful in addressing the social needs that lead to the sustainable need fulfilment.

Steps 4-5 deal with the establishment of short term solutions that can lead to the desirable futures, forming joint action, required research and development (R&D) and supporting policies. Steps 6-7 deal with the implementation phase of the action plan by involving various stakeholders and establishing cooperation amongst them. This stakeholder participation is not only needed in the implementation phase but also in the development of visions of ideal futures (Weaver et al, 2000; Quist, 2007).

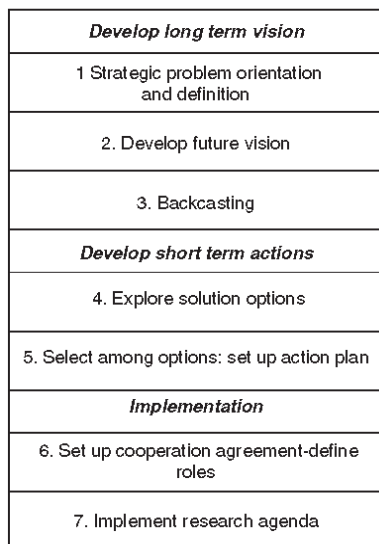


Figure (2.5): Outline of the STD backcasting approach (Quist et.al, 2006)

The Sushouse Approach: The primary ambition of the Sushouse project is to develop strategies for sustainable households in Netherlands. Vergragt (2005) mentions that the former STD program dealt with the supply side of the innovations such as technology developers, policy makers and intermediate institutions. However, the Sushouse approach is said to be dealing with the demand side by focussing on three primary household functions of clothing care, shelter and nutrition. The seven steps in this approach are presented in figure (2.6).

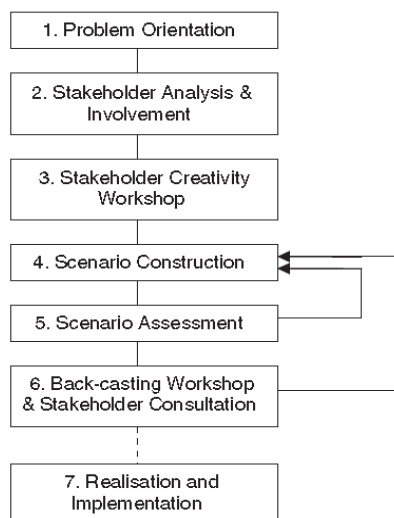


Figure (2.6): Outline of the Sushouse backcasting approach (Quist et.al, 2006)

Vergragt et.al (2002) describes the main aim of Sushouse project was to develop and test a methodology that can enable various stakeholders to conduct their analysis of the current situation, identify plausible technological and social innovations, develop normative scenarios and assess the viability of fulfilment of these scenarios. The backcasting methodology is primarily derived from the STD methodology. However certain changes such as increased emphasis on technology as the main agent for development, higher involvement of non-governmental stakeholders and the selection of design oriented approach over a policy oriented approach has been done (Vergragt et.al, 2002). The scenarios were assessed and then discussed

along with the stakeholders and follow-up agendas, recommendations were made. The iterative nature of this approach allows the scenarios to be adjusted after every iterative cycle and assessments are made for the readjusted scenarios (Quist, 2007).

Quist Backcasting Framework (2007): The Quist framework has been derived based on various other existing backcasting approaches and a generalised five-step participatory backcasting approach has been formulated (Quist et.al, 2004). The five-step methodology can be seen in figure (2.7).

The first step deals with analysing the main problem at hand and then setting up of normative assumptions and targets based on stakeholder participation. However, in a few cases the assumptions and targets are set-up even before analysing the problem. As a result of the problem orientation, alternate future visions are made in step 2. In step 3, backcasting is done to bridge the gap between the current state and desirable future. This is done by looking backwards in the search for ideas and leapfrogging technologies. In the next step, elaboration of these ideas using assessments and feasibility studies are done and follow up agendas are defined. These follow up agendas help in realising the future visions. In the final step, the outcomes of the analysis are embedded and taken further by the stakeholders (Quist et.al, 2004).

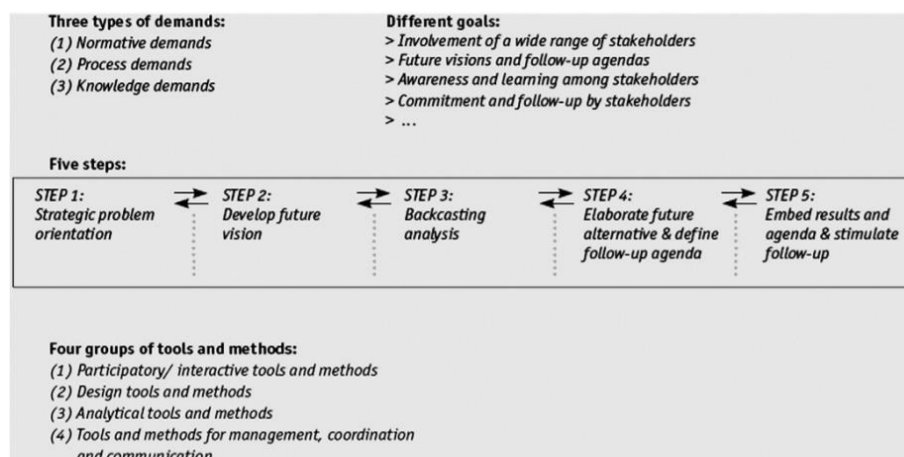


Figure (2.7): Outline of the Quist Backcasting framework (Quist et.al, 2011)

Quist et.al (2006) mentions different kinds of methods and tools that are usually employed such as participatory, design, analytical, management and coordination methods and tools. Each step of the participatory backcasting approach can employ different kinds of tools and methods. Quist (2007) also mentions that even though the approach is described in a linear fashion, it is iterative and dynamic. There could also be mutual influence between two consecutive steps. This framework enables stakeholders to enter or leave the process which forms the crux of its dynamic nature. The main recognized social groups are companies, research bodies, government, public interest groups and the public themselves.

Even though the Quist framework has been presented previously, there is certain ambiguity on its usage due to its flexibility and wide range of methods. Quist (2016) gives an outline of all the relevant activities that will be performed in a non-participatory backcasting. The figure

(2.8) presents the guiding questions used for mapping relevant activities for the above-mentioned study.

<i>Step 1: Strategic problem orientation</i>	
1A	Setting requirements/criteria, basic assumptions, process plan, methodology.
1B	System and regime analysis.
1C	Stakeholder analysis.
1D	Trend and problem analysis.
<i>Step 2: Generating future visions</i>	
2A	Detailed (normative) standards/criteria and targets.
2B	Idea articulation and elaboration.
2C	Generation of one or several visions.
<i>Step 3: Backcasting analysis</i>	
3A	WHAT-HOW-WHO analysis part 1: WHAT are the (technological, cultural-behavioral, organizational and structural-institutional) changes?
3B	WHAT-HOW-WHO analysis part 2: required actions and stakeholders.
3C	Drivers and barriers analysis.
<i>Step 4: Elaboration and follow-up agenda</i>	
4A	Scenario elaboration (e.g., turning vision into quantified scenario).
4B	Scenario sustainability analysis.
4C	Generation of follow-agenda and proposals.
4D	Develop transition pathway.
<i>Step 5: Embed results and stimulate follow-up</i>	
5A	Dissemination of results and policy recommendations.
5B	Stimulate follow-up activities.
5C	Stakeholder learning evaluation.

Figure (2.8): The overall scheme for backcasting (Quist, 2016; Quist,2013)

Comparison of Frameworks: In this subsection, the overview of all the five backcasting approaches studied will be presented in table (2.2) and the approaches are compared against each other in terms of similarities and differences.

Quist et.al (2011) describes the building blocks for conceptualizing the backcasting process. The building blocks for the backcasting process are stakeholder participation, future visions, learning and setting and methodological aspects. These blocks can be used as a few indicators to differentiate the five backcasting approaches.

On a general note, even though the methods that can be used are mentioned in all of the approaches, in some cases the usage of particular methods are not explicitly suggested. On comparing with the indicator of setting and methodological aspects, it can be seen that an explicit backcasting step is suggested only in STD, Sushouse and Quist frameworks. In the Robinson and TNS frameworks, the entire process is considered as backcasting. The background setting of some approaches differs. As in the case of TNS which is directed at companies and organizations. On comparison using the indicator of stakeholder participation, only Robinson approach stands out as it does not use any participatory methods. This criterion also spreads onto the indicator of future visions as in the case of Robinson approach, there is some ambiguity over who is responsible for setting the criteria and future goals. In the other approaches where stakeholder participation is involved, future visions are considered as a collective responsibility and also have an interactive element in them apart from the iterative nature. All the methods value the aspect of learning, but the stakeholder participation influences the degree of learning. This is usually because with higher stakeholder involvement there can

be higher social learning and the absence of participatory methods have their impact on the degree of learning.

The Robinson approach also stands out from the rest due to its quantitative approach whereas the other approaches are aligned along the qualitative side. However, Quist framework offers some degree of flexibility by having scope for combining itself with other frameworks which can vary the degree of its qualitative nature. Even though all the frameworks use scenario analysis, only Sushouse approach employs an explicit scenario analysis step. In the other cases the iterations provide with some amount of assessment.

Robinson approach does not deal with the implementation and follow-up phases. Even though they are mentioned in the other frameworks, the methods used for these are only specified in the STD, Sushouse and Quist frameworks. Communication and management are the commonly specified methods for follow up and implementation in these three frameworks.

Anderson Approach: Apart from the above mentioned five approaches this additional approach is presented due its usage for developing sustainable electrical energy policies. However, this approach derived by Anderson (2001) is largely derived from the Robinson approach and hence was not included in the comparison. It varies from the Robinson approach in terms of considering energy demands as endogenous factors and removing the retention of long term forecasts. This approach is conceptualized for having a higher focus on energy policy. The steps involved are as follows

1. Specify the strategic objectives
2. Describe present generation and consumption
3. Choose end-point year
4. End-use analysis
5. Supply analysis
6. Policy development
7. Review Procedure (Anderson, 2001).

This approach differs from the Robinson approach especially when it comes to the issue of deriving policy recommendations. Review procedure and iterative flexibility have been provided in this framework to evaluate the effectiveness of the policy and also to incorporate any new knowledge derived from the initial backcasting process.

Table (2.2): Overview of the five backcasting approaches. Derived from Quist (2007) and Agarwala (2017)

	Robinson Approach	The Natural Step Approach	STD Approach	Sushouse Approach	Quist Framework
Key Assumptions	- Criteria for social and environmental desirability are set externally to the analysis - Goal-oriented - Policy-oriented - Design-oriented - System Oriented	- Decreasing resource usage - Diminishing emissions - Safeguarding biodiversity and ecosystems - Fair and efficient usage of resources in line with the equity principle	- Sustainable future need fulfilment - Factor 20 - Time horizon of 40-50 years - Co-evolution of technology and society - Stakeholder participation - Focus on realising follow-up	- Sustainable participation - Factor 20 - Sustainable households in 2040 - Social and technological changes are needed - Achieving follow-up is relevant	- Stakeholder participation - Goal-oriented - Stakeholder learning - Achieving follow-up is relevant
Methodology	- Determine objectives - Specify goals, constraints and targets. Describe present system and specify exogenous variables - Describe present system and its material flows - Specify exogenous variables and inputs - Undertake scenario construction - Undertake scenario impact analysis	- Define a framework and criteria for sustainability - Describe the current situation in relation to that framework - Envisage a future sustainable situation - Find strategies for sustainability	- Strategic problem orientation - Develop sustainable future vision - Backcasting- set out alternative solutions - Explore options and identify bottlenecks - Select among options and set up action plan - Set up cooperation agreements - Implement research agenda	- Problem orientation and function definition - Stakeholder analysis and involvement - Stakeholder creativity workshop - Scenario construction - Scenario assessments - Stakeholder backcasting and strategy workshop - Follow-up and implementation	- Strategic problem orientation - Develop future visions - Backcasting analysis - Elaborate future alternatives & define follow up agenda - Embed results and agenda & stimulate follow-up
Method Used	- Social impact analysis - Economic impact analysis - Environmental analysis - Scenario construction - System analysis and modelling - Material flow analysis and modelling	- Creativity techniques - Strategy development - Employee involvement - Employee training	- Stakeholder analysis - Stakeholder workshops - Problem analysis - External communication - Technology analysis - Construction of future visions - System design and analysis	- Stakeholder analysis - Function & system analysis - Backcasting analysis - Stakeholder workshops - Scenario construction - Scenario evaluation (consumer acceptance, environmental, economic)	- Scenario construction and analysis - Stakeholder Workshops - Backcasting Analysis - Process Design - Communication and management methods

2.5. Development of Scenarios

The different kind of scenarios have been mentioned in section (2.3). However, that section does not deal with the development of the scenarios. Börjeson et.al (2006) studied the development of scenarios as well as the classifications of scenarios. In their study, they have mentioned that the three techniques of generation, integration and consistency of scenarios have to be used for the development of different types of scenarios. Different kinds of scenarios require different techniques for development and are presented in figure (2.9).

It can be seen in the figure that most of the generating techniques for backcasting or normative scenarios as a matter of fact require surveys, workshops or backcasting delphi for scenario generation. However, all of the above-mentioned techniques require the participation of stakeholders. In the case of non-participatory studies, these techniques cannot be used as there will not be any stakeholder participation. General morphological analysis is one such case where it can be used for scenario development irrespective of scientific discipline. Morphological analysis has already been used for the sake of development of internal consistency and can also be further used for entire scenario development process.

Scenario types	Techniques		
	Generating	Integrating	Consistency
<i>Predictive</i>			
Forecasts	• Surveys • Workshops • Original Delphi method	• Time series analysis • Explanatory modelling • Optimising modeling	
What-if	• Surveys • Workshops • Delphi methods	• Explanatory modelling • Optimising modeling	
<i>Explorative</i>			
External	• Surveys • Workshops • Delphi modified	• Explanatory modelling • Optimising modeling	• Morphological field analysis • Cross impact
Strategic	• Surveys • Workshops • Delphi methods	• Explanatory modelling • Optimising modeling	• Morphological field analysis
<i>Normative</i>			
Preserving	• Surveys • Workshops	• Optimising modeling	• Morphological field analysis
Transforming	• Surveys • Workshops • Backcasting Delphi		• Morphological field analysis

Figure (2.9): Techniques for development of scenarios (Börjeson et.al, 2006)

General Morphological Analysis

Different forms of morphological analysis are applied in different kind of scientific disciplines such as astronomy, linguistics, geology and zoology. The first typology analysis has been developed in Caltech by Fritz Zwicky (Ritchey, 2002). Later on, general morphological analysis (GMA) has been applied widely for policy analysis and future studies (Ritchey, 1998). GMA is a method that can be used irrespective of scientific discipline for structuring and analysing complex problems that are not quantifiable, contain a wide range of uncertainties and cannot be simply modelled (Ritchey, 2002). This method can be used to analyse the strong unquantifiable socio-political systems and relations between various actors.

The analysis starts with the identification and defining the parameters that can influence the system. Later on, the values and boundary conditions for these morphological parameters are specified. This exercise can be done using a morphological box known as the ‘Zwicky Box’ that contains a matrix and each cell contains a value corresponding to the parameter. The usage of this matrix is helpful for developing configurations for complex problems and also contains the aspects of generation and integration based techniques that are required for scenarios development (Ritchey, 2011).

After the generation and integration step is done, a cross consistency step will have to be done in order to filter the number of possible configurations and to reduce internal inconsistency. This process is termed as the principle of contradiction and reduction by Zwicky. This step is important in removing the configurations that are mutually inconsistent. All the parameter values in the morphological field are compared to each other to achieve consistency. The three primary types of inconsistencies that have to be removed are the purely logical contradictions, empirical inconsistencies and normative inconsistencies. The logical inconsistencies are the configurations that are mutually repealing. The empirical inconsistencies are the ones that are unviable based on empirical grounds and the normative constraints are the ones that are ruled out due to socially unacceptable preferences (Ritchey, 1998)

2.6. Transition Pathways

According to Moradi et.al (2017), transition pathways are used to describe the development of technologies along with the influence of various actors and its contribution in the shift from the current regime. The shift from the current regime could be a complete phase shift to a desired regime or could be a minor shift to rectify the shortcomings of the existing regime. These innovations and the shift from current regime define the dynamics of the sociotechnical system where the already adopted dominant system (locked-in system) is in competition with a new niche system that tries to become the dominant sociotechnical system. The dominant sociotechnical system also undergoes a certain degree of changes and coexists with the help of a coalition of actors who are internal to the dominant system (Marletto, 2014). However, when a new system tries to become the dominant system, there must be strong interactions between various actors at various levels in order to develop transition pathways that can replace the locked-in system (Rip et.al, 1997).

Transitions can often be mistook for incremental changes in the socio-technical system. However, they differ with each other in many aspects. Transitions are long-term processes with radical shifts requiring multiple changes in the societal systems among multiple actors. Incremental changes differ in this very fundamental aspect as they are slow processes that only partly modify the landscape (Moradi et.al, 2017).

In order to develop transition pathways and analyse transitions in the case of sustainability, multi perspective analysis has been widely used. This can be attributed to the fact that this method signifies the importance of various actors and their interactions as a coevolutionary process that can shape up the transition (Foxon et.al, 2013). According to multi-level

perspective, there is no single driver of transitions and it occurs dynamically over different levels. The three main levels of multi-level perspective analysis that influence the transition are the niche level, the landscape level and the regime level and are seen in figure (2.10).

- **The macro level or the landscape:** This level is the representation of the existing scenario in terms of how the various variables involved play out and influences other actors which might trigger a transition or the need for a transition. The political, economic and cultural set up primarily define the socio-technological landscape. However, transitions in this level occur at a slower pace than in the regime level.
- **The meso-level or the regime:** Regime is a set of rules or practices or trends that these technologies follow and would result in shaping up a technology. These regimes provide stability and form the crux of the existing socio-technical landscape. (Nelson et.al, 1982). In the regime level the innovations are incremental innovations and form a platform for the successful niches. The regime would then configure itself for the successful niches, but the pace of this change would not be rapid as it might jeopardize the stability of the system. However, the changes are faster than the changes in the landscape level (Rip et.al, 1998). This regime level is the passage between the landscape level and the niche level and this level primarily focuses on optimization.
- **The micro level or the niche level:** This niche level is where all the innovations start budding and the niches find windows of opportunities and various driving forces due to the various variables involved in the landscape level and the regime level. The successful niches then continue to progress to the landscape level through the regime level and the unsuccessful ones are screened at the regime level. In the last century, the military has provided many chances for the development of many successful niches such as computers, radios, internet and aircrafts (Geels, 2002).

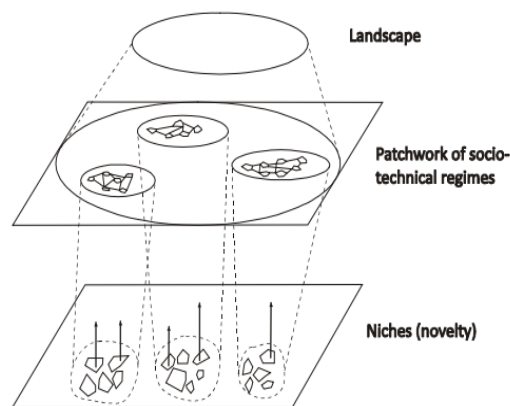


Figure (2.10): Multiple levels in the hierarchy (Howarth, 2012)

The multiple levels in this theory and the S-curve that represents the transition process seen in figure (2.11) were developed by Geels et.al (2007). The S-curve perfectly represents the innovations in the niche level and the influence of actors and variable in the other levels. It also shows how all successful niches progress from the regime level and then influence the entire landscape itself.

Geels et.al (2007) developed different types of transition pathways based on the timing and nature of interactions between various actors at various levels.

- Transformation path: If there is moderate pressure in the landscape (disruptive change) where outsiders criticize the incumbents and ask for change and the niche innovations are still not mature enough, then the regime actors respond by modifying their direction of innovation activities.
- De-alignment and realignment path: This occurs when there is high pressure in the landscape (avalanche change) and the niches are not developed. There is no direct alternative and several niches coexist until a dominant one surfaces.
- Technological Substitution path: This occurs when the niches are developed and there is an avalanche change in the landscape thereby making the niche a direct alternative.
- Reconfiguration pathway: This occurs when several niches symbiotically are employed in order to solve local regime problems and they subsequently make changes to the regime itself (Geels et.al, 2007).

However, several authors argue that transition pathways still consider the political and policy influence as an exogenous factor and fail in integrating it as a part in the pathways. The absence of these factors makes the analysis of the sociotechnical system incomplete especially in the mid-term and long-term future studies (Marletto, 2014).

Smith et.al (2010) mention a four-stage iterative cyclical framework for transition management. The four stages are problem structuring, transitional pathways, learning and adaptation and institutionalization. Under the backcasting process, the first two steps are done and the last two stages can be helpful in realizing the transition and could be a nice follow-up after drawing the transitional pathways. Learning and adapting would help establish a link between long term goals and short-term actions and institutionalization would require some serious commitments to a change from the incumbent regime.

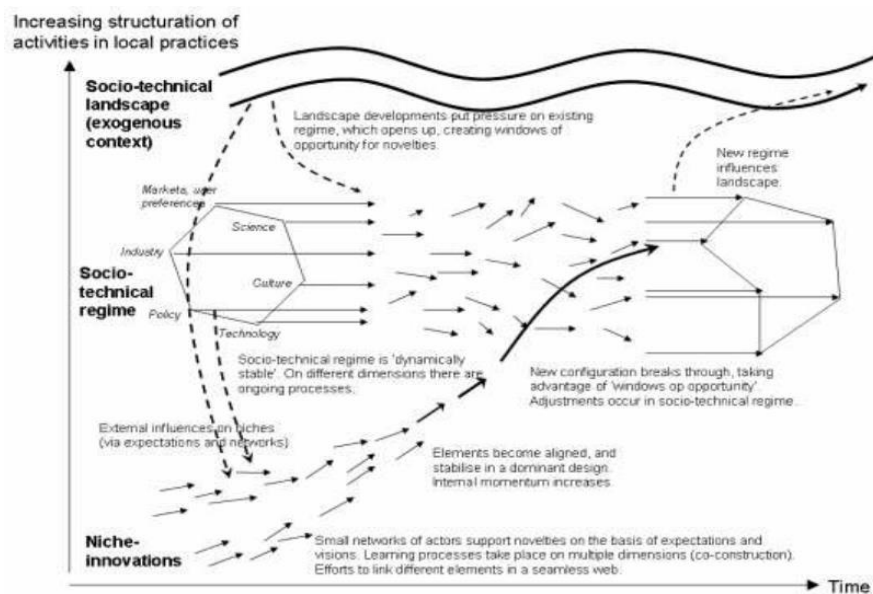


Figure (2.11): S-curve representing the transition process (Geels et.al, 2007)

2.7. Learning Rates and Future Cost Estimation

Learning rates are essentially used to describe the cost decrease of products or services that occurs with increasing experience. Technically, it is defined as the percentage decrease of unit costs with the doubling of experience. McDonald et.al (2001) further mentions that it does not exactly depend on the time period considered for experience growth but the overall accumulation of experience. In the case of energy sector, this experience translates into a cumulative installed capacity or the cumulative energy production depending upon the type of learning rate considered.

Winskel et.al (2014) mentions that cost reductions could be a result of either market growth which represents learning by doing or a driver to market growth which usually is learning by research. The two factor learning rates considers both the categories of learning while the one factor learning considers only learning by doing. However, estimating inputs for two factor learning rates is quite complex and the time factor plays a more important role than cumulative deployment in research as opposed to the views discussed earlier from McDonald et.al (2001). Even though one factor learning rates are much easier to use, it oversimplifies the diverse aspects such as geographic diversity, influence of individual components on costs and time variation of learning rates (Winskel et.al, 2014).

In the case of one factor learning rate, the future costs of technologies can be estimated if the future market growth is known using the following model from Ruffini et.al (2018).

$$C_t = C_0 * \left(\frac{Q_t}{Q_0}\right)^{-b}$$
$$PR = 2^{-b}$$
$$LR = 1 - PR$$

Where,

C_t = Cost of technology at time t.

C_0 = Initial cost of technology.

Q_t = Cumulative installed capacity or production at time t.

Q_0 = Initial cumulative installed capacity or production.

b = Experience Index.

PR= Progress Ratio.

LR= Learning Ratio.

The progress ratio is a parameter used to describe the experience index and also represents the relative amount of cost decrease with production or capacity.

Chapter 3: Methodological Framework

In this chapter, the overall methodological framework of this research will be presented. The chapter begins with the introduction of the chosen backcasting framework in relation to this research. An overview of the relevant activities that will be conducted in this research will be presented. Later, a brief introduction about the archipelago and the criteria for identifying the islands on which this analysis will be done is presented.

3.1. Backcasting Framework

Backcasting as a tool has been widely used in the field of soft energy futures and sustainability making it ideal in the case of planning a transition to a sustainable energy future. Considering all the frameworks studied in the literature review, the Quist framework deemed suitable for this research study primarily due to its flexible nature which offers the possibility of integrating a wide range of concepts and use them to suit the case of these islands. However, the generic framework developed by Quist uses participatory methods. In this research study, the inclusion of participatory methods would be exhaustive and beyond the scope of the thesis. Furthermore, getting access to various stakeholders in the group of islands and involving them in the process would be extremely difficult. Therefore, a non-participatory version of the Quist framework was used. Since the participatory aspects are absent, a design-oriented aspect from the Robinson (1982) approach can be borrowed in this case. Apart from the design aspects, the Robinson approach also focuses on governmental interventions. Hence this combination of approaches would be helpful in deriving concrete future scenarios and interventions for the islands. A similar study has been performed by Agarwala (2017) which will be used as the basis for the methodological framework of this research.

Apart from the methods and activities suggested in the methodologies, the overall backcasting scheme mentioned in Quist (2016) has been helpful in mapping required activities and can be seen in figure (5.8) of the previous chapter. This scheme was adapted for this case and the ones that involved interactive or participatory methods were not considered. While most of the activities or tasks that were identified were derived from the Quist framework, there were certain ones that were missing in the Quist framework and were adopted from the Robinson approach. The activities that are derived from the Robinson approach are as follows:

1. Identifying Exogenous Variables
2. Defining Exogenous Variables
3. Identifying Renewable Energy Potentials

Identification of renewable energy potentials has not been explicitly mentioned in the Quist framework even though there was some mention about them. However, in the Robinson approach, the identification of renewable energy potentials is not mentioned as a separate step but is mentioned as a part of supply analysis. The usage of the optimization model based on Illoldi (2017) and the integration of learning rates in this model to suit this case would be a

novel idea. On studying Agarwala (2017), Quist approach, Robinson approach and the scheme mentioned in Quist (2016), the following activities have been mapped and presented in the table (3.1). The methods used to perform these tasks and the frameworks from which these aspects are derived are also presented in tab

Table (3.1): Overview of the Methodological Framework

Backcasting Steps	Tasks/Activities	Research Methods and Techniques	Quist Framework	Robinson Approach
Step 1: Strategic Problem Orientation	- Analyse Current Energy Scenario - Analyse Demand and Supply Trends - Analysing External Environment - Stakeholder Analysis - Renewable Energy Potential Mapping - Identification and Defining Exogenous Variables - State assumptions and constraints	- Desk Research and meta-analysis - Estimations based on indicators - PESTEL Analysis - Desk Research - Estimations using meteorological data	- Yes - Yes - Yes - Yes - No - No - Yes	- Yes - Yes - No - No - Yes - Yes - Yes
Step 2: Future Visions	- Specify Goals and Targets - Specify End-points - Elaboration of Visions - Development of Scenarios - Development of cost-optimal renewable energy configurations	- Desk Research and trend extrapolation - General Morphological Analysis - Modelling based on Illoldi (2017)	- Yes - Yes - Yes - Yes - No	- Yes - Yes - Yes - Yes - No
Step 3: Backcasting Analysis Elaboration and defining follow-up	- Identification of interventions - Defining necessary changes - Identification of drivers and barriers - Derive Policy Recommendations	What-Who-How Analysis	- Yes - Yes - Yes - Yes	- No - No - No - Yes
STEP 4: Implementation	- Define Possible Transition Pathways - Follow-up Agenda	Desk Research and Timeline development	- Yes - Yes	- No - No

Step 1: Strategic Problem Orientation

This step primarily deals with establishing the main issue at hand by conducting a detailed study of the energy landscape in the location. Step 1 starts by investigating the total final energy consumption in the archipelago. This consumption can be further classified in the terms of

sector-wise consumption, end use services the energy provides and energy sources. Simple calculations of renewable energy potentials will be made based on the meteorological data of the location in order to establish a supply analysis. A stakeholder analysis will be performed to map various actors and their roles in the energy landscape. This will be helpful in developing transitional pathways and policy recommendations in the later stages. These aspects will remain similar to all the islands under consideration. To help understand the external environment, PESTEL analysis will be used. This analysis allows the study of the macro environment by analysing the political, economic, socio-cultural, technological, environmental and legal aspects of the energy landscape (Dočkalíková et.al, 2014). Towards the end of this step, the constraints on the study and the assumptions made in this study are mentioned.



Figure (3.1): PESTEL analysis (Paypervids, 2017)

Step 2: Generating future Visions

After getting an elaborate insight into the problems in the energy landscape, future visions are developed. The final target for which this backcasting analysis will work to fulfil will be mentioned along with the establishment of the final end point. Scenario construction will be performed which will give us insight into how these visions will be shaped up. General morphological analysis was used for generation of the scenarios and these scenarios were checked for internal consistency using cross consistency analysis. The geography and resource potentials of individual islands will be taken into consideration for the development of realistic scenarios.

In order to develop detailed scenarios, an optimization model based on Illoldi (2017) will be used. The main aim of this optimization model is to determine how the energy configurations for the desire future will look like. Illoldi (2017) deals with cost optimal combinations at different levels of renewable energy penetration. In our case, only 100% of renewable energy penetration will be considered. As an input for the optimization model, energy demand schedules and costs of technologies for the year 2040 have been estimated. The influence of learning rates of technologies on future energy configurations is also studied using the model. Section (5.5) discusses in detail about the model used. The results obtained from this model will be used as the basis for the subsequent steps in the backcasting analysis.

Step 3: Backcasting Analysis

This step works on answering the question, ‘how can the scenarios constructed be achieved within the specified end-point ?’. In this step, the major changes and interventions necessary for each of the scenarios to be materialized are laid down. This is done using the ‘What-How-Who’ analysis mentioned in Quist (2013). This analysis points out the kind of changes needed, how can these changes be made and who are the most responsible for the changes to take place. This analysis is used to identify the technological, cultural-behaviour, organizational, institutional and structural changes needed. The main drivers and barriers to the transition are also identified in this process.

Step 4: Implementation

This step represents the unified step 4 and 5 of the Quist five step backcasting framework. This step answers the question of ‘by-when’ can these changes occur. Based on the changes identified in the previous step, long-term and short-term actions required are laid down. Eventually, this will lead to the development of comprehensive transitional pathways and timeline development for the archipelago. Based on technological and economic considerations, the most suitable scenarios for each of the islands in the archipelago are chosen. Transitional pathways and implementational timelines were developed for the chosen scenarios.

3.2. Location Study

In this section, basic information regarding the Andaman and Nicobar Islands such as geography, demographics and economy will be provided.

3.2.1. Introduction to the Archipelago

The Andaman and Nicobar Islands are a group of 572 islands located at the juncture between the Bay of Bengal and the Andaman Sea. This island group is recognized as a Union territory (Federal Territory) of India and are located towards the east of the Indian mainland. They are separated from India by the Bay of Bengal and the nearest city of Chennai is about 1190 km away (Ministry of MSME, 2012). These islands exist in a long arc shaped broken chain with a length of about 800 km in the North-South Direction (National Informatics centre, N.d.). Geographically, they exist in the range of 6°- 14° North and 92°- 94°East latitudes and longitudes respectively. The country experiences tropical climate due to its presence in the equatorial region. These islands do not usually experience extreme climates while the rainfall is divided in the time periods of May to Mid-September and November to Mid-December (Maps of India, N.d.). These climatic conditions make them home for evergreen tropical rainforests that cover about 86% of the present land area (Ministry of MSME, 2012). In most islands, a high degree of hilly terrain is observed.

Out of the 572 islands in total, only 38 islands are permanently inhabited out of which only 19 are electrified for general use (Ministry of MSME, 2012). The rest of the islands are electrified by the army, forest department and police for their own activities. Few of the inhabited islands

have very sparse populations, while some of the islands have an untouched tribal population. Due to the strategic importance of these islands for India, few islands are used for military purposes with less or no access to outsiders. The island groups are divided into three revenue districts for administrative purposes. These districts are North and Middle Andaman, South Andaman and the Nicobars. The South Andaman district is home to the capital of Port Blair.

3.2.2. Demographics

The total population of the archipelago from the 2011 census report was found to be 380,581. There has been a decline in the growth of population. In the period of 2001-2011, the growth rate was about 6.86% compared to the 26.94% in the previous decade (Census of India ANI, 2011). A high fraction of population (62%) lives in the rural areas of the islands (Census 2011, N.d). Most of the population is distributed in the districts of North, Middle Andaman and South Andaman. Future predictions reveal that by 2021, the decadal growth rate would be around 4.28%. These island groups are home to different kinds of tribal groups such as The Great Andamanese, Onge, Jarawa, Sentinelese and Shompen. Few of the tribal groups such as the Sentinelese have almost zero contact with the outside world.

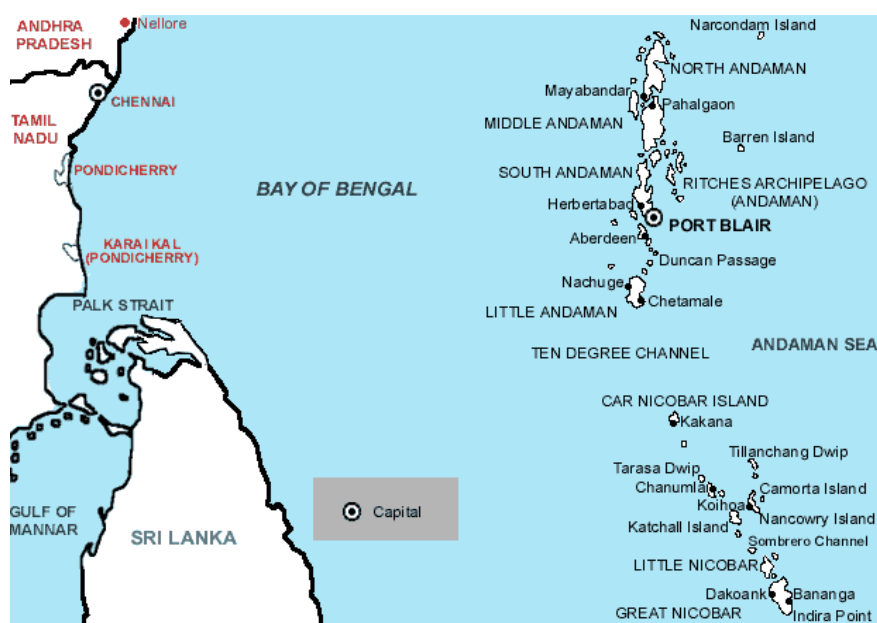


Figure (3.2): Map of Andaman and Nicobar Islands (Sadique, 2015)

Table (3.2): District wise population data (City Population, 2017)

Location	Population (2011)	Area (Sq.Km)	Population Density (per Sq.Km)
Total	380,581	8,249	46.1
North and Middle Andaman	105,597	3,227	32.7
South Andaman	238,142	3,181	74.9
Nicobar	36,842	1,841	20.0

3.2.3. Economy

The economy of Andaman and Nicobar Islands primarily depends upon agriculture and agro-based industries. Large scale industries are absent in this region. There is almost zero activity in the manufacturing sector. This could be due to limitations in land availability and the presence of large reserved forests (Ministry of MSME, 2012). The agriculture sector also has its own limitations as some of the islands have hilly topography and the soil in these places is not very fertile. This concentrates the agriculture in the islands or regions of Havelock, Neil and some other pockets in South Andaman. The crops usually cultivated are paddy, pulses, vegetables, banana, sugarcane, chillies, sweet potato, tapioca etc. Apart from these cultivations, other fruits and spices are used for Agro-based industries (Katara, 2015).

The presence of pockets of deemed forests make it ideal for the production of timber from dying trees. Therefore, sawmills and wood based industries are also few of the flourishing small-scale industries (Katara, 2015). A report released by the Ministry of MSME (2012), maps out the high potential for other agro based industries such as rubber products, fruit processing, fish processing, coconut oil extraction etc. From an energy perspective this can be translated into a high potential for bioenergy. Apart from the aforementioned sectors, tourism also plays a key-role especially in the Andaman region. The Nicobar region has its own restrictions due to the presence of certain hostile tribal groups. These islands have been attracting a large number of domestic tourists and the government has been keen on promoting the tourism sector for a large number of international tourists too (Katara, 2015).

3.3. Islands Selection

The primary reason for choosing these islands is the complexity of its background. These islands also possess similar problems to that of small island developing states (SIDS) such as heavy dependence on imports, trade for electricity, underutilization of renewable energy potential, lack of economics of scale and very high cost of electricity generation. These reasons have motivated the government of India to make plans to make a transition to renewable energy futures but there has been very little action. Various socio-technical reasons such as the poor condition of the grids, very little presence of the private sector and a lack of serious roadmaps from the government's end could be some of the reasons acting as bottlenecks for this transition. Even though numerous studies are being performed on other smaller island nations, these island groups have been largely neglected by various researchers and studies as these islands are not autonomous and are an integral part of India. Therefore, a study on this topic would be of great interest and might yield helpful insights that can ultimately aid in the transition to a sustainable energy future.

In the Literature, it has been mentioned that there are about 19 islands. However, few of the islands are home to very sparse populations. The process of gathering data and performing backcasting analysis would become very difficult for these smaller islands. Therefore, 8 islands have been chosen on the basis of their population in such a way that they would cover a little more than 95% of the population of the entire archipelago. This demographic filter caters to

islands with population ranging from a minimum of 5,691 to a maximum of 209,602. Table (3.3) will provide with the list of islands, their populations and their percentage contribution to the entire archipelago using the census data of 2011. Except for the islands of Car Nicobar and Great Nicobar, all of the other islands considered in this study belong to the Andaman region. For simplicity of this study, the first three islands will be known as the ‘main islands’ as they contain almost 80% of the population. The other 5 islands will be referred to as ‘small islands’.

Table (3.3): The islands selected for the analysis and their populations (Demographics ANI, N.d.)

Islands	Population (2011)	Area (Sq.Km)	Percentage population
North Andaman	42,541	1,317	11.2%
Middle Andaman	55,632	1,523	14.6%
South Andaman	209,602	1,262	55.1%
Little Andaman	18,823	707	5.0%
Car Nicobar	17,841	126.9	4.7%
Great Nicobar	8,067	921	2.1%
Batarang Island	6,351	92.2	1.7%
Havelock Island	5,691	242.6	1.5%

Chapter 4: Strategic Problem Orientation

In this chapter and the following few chapters, the methodological framework derived in chapter 3 will be applied. This chapter deals with analysing the energy situation in the archipelago and framing the main problem. This step presents with the motivation to perform this analysis on these group of islands. Table (3.1) has been taken as a reference to map out the required activities. This chapter starts with analysing the current energy sector in these islands. Later on, a stakeholder analysis will be performed to understand the role of various actors in the energy system. PESTEL analysis will be used to get an understanding about the external environment that influences the energy sector in these islands. The assumptions and constraints that define the scope of this analysis will also be specified. This section ends with the presentation of the renewable energy potentials in the islands that were calculated based on real meteorological data and the local geography.

4.1. Energy Scenario

Ideally, International Energy Agency (IEA) databases provide the energy balances for countries that can be used in analysing the energy scenario of location. However, in this case such databases are not available since this archipelago is not an individual nation by itself and IEA does not provide data for individual states or territories of a country. Therefore, mapping the entire energy system and finding the primary energy use is very difficult. Most of the data currently available is regarding the electricity system and data regarding other energy carriers is poor. These carriers are used for a wide range of applications such as transportation or heating and should be considered since they can be quite energy intensive. For example, Illoldi (2017) mentions based on his study on 14 islands that around 30-40% of the final energy consumption would be from the transportation sector and in certain regions such as the Caribbean this share can be much higher.

Therefore, in order to deal with this data void, all the consumer sectors and services that are likely to consume a significant amount of energy are identified and the final energy consumption for all these services and sectors are estimated and used for this analysis. Each sector can potentially employ a wide range of energy carriers and fuels for fulfilling various needs. Figure (4.1) represents the identified consumer sectors and the kind of energy demands that can be anticipated in the case of this archipelago for each sector.

The dominant sector in the archipelago is the residential and commercial sector. The main demands in this sector are for the electric appliances, heating and cooling purposes. Heating can be further categorized into cooking, space heating and water heating. Different kinds of fuels are generally used to satisfy these demands. The cooking demands are met by fuels like firewood, LPG or kerosene. Owing to the tropical climate in these islands, space heating can be neglected as it is not usually used. Water heating demands on the other hand are mostly met by electricity. The cooling demands of space cooling and refrigeration are also satisfied by electricity. The final consumption of electricity data reflects the electrified cooling and heating demands as well.

The industrial sector is not very active in the archipelago and consumes much lesser than the residential sector. The main services taken into consideration here are the machinery or

equipment used in the industries and the heat demands. It is assumed that since most of the industries are small scale agri-based industries, these demands are satisfied by electricity. There is not much information available regarding the non-electrified heat demands in these industries and therefore has been neglected. Most of the agricultural and public service demands in this region are electrified as well with the exception of non-pumping machinery in agriculture which is mostly done by primitive methods that do not consume much energy.

The transport sector can be categorized into air transport, road transport and maritime transport for both passenger and freight transportation. Since, railways are absent in this archipelago, they can be neglected. Analysing the air transport and maritime transport with very little data would be extremely complex and therefore has not been considered in this study. Moreover, according to Illoldi (2017), most of the energy consumption in the transportation sector can be anticipated from road transport. Therefore, calculations have been made to estimate the annual consumption of energy for road transport only.

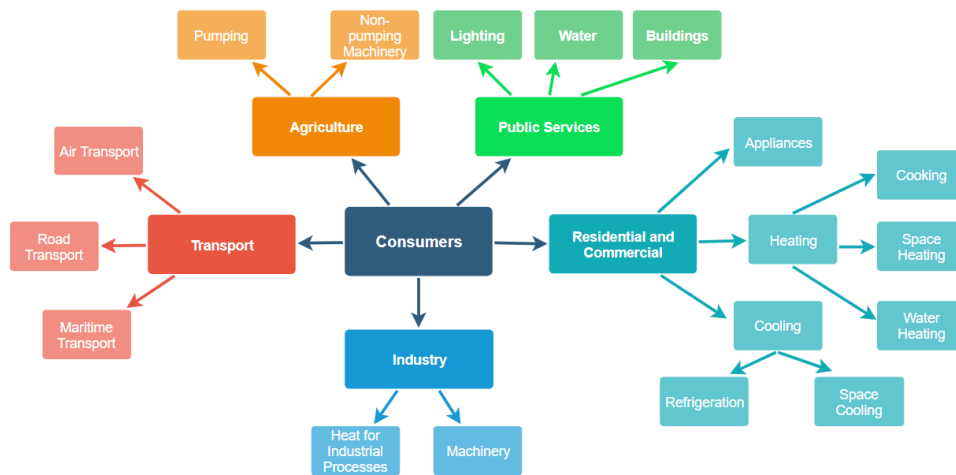


Figure (4.1): A Summary of the Main Energy Consumers (Own illustration)

Based on this classification, the final consumption of energy annually for the archipelago has been estimated to be around 4.4 PJ. The final energy consumption can be classified on the basis of the energy carriers. The main energy carriers observed in this energy system are electricity, firewood and other liquid organic fuels such as diesel, petrol, LPG and kerosene. The contributions of electricity, firewood and other liquid fuels put together are 23%, 38% and 39% respectively. It can be surprising to find that the most dominant energy carrier is firewood. This is mainly due to the high amount of losses involved during the conversion to heat and the heat transfer to the vessel during cooking. It has been estimated in this study that if the consumers switch to electricity as a source for cooking, then the annual final consumption would fall by around 1.5 PJ. It can also be seen that electricity as a carrier has relatively lower contribution in the final consumption and this can be attributed to two reasons. The first reason is the absence of a strong industrial activity in the region. The second reason could be the usage of electricity only for basic purposes such as lighting. The majority of the liquid fuels are used for transportation and these estimates coincide with the estimate of 30-40% energy consumption by transport sector in Illoldi (2017). The calculations leading to these values and the amount of fuels required are discussed in detail in the subsequent sections. It is also important to note

that consumption estimates for only energy purposes were made in this study and the value of the total final consumption might vary significantly in reality.

4.1.1. Electricity System

Under this category, the electricity sector will be analysed based on the installed capacities, consumption profile, distribution systems and demand profile. This section is heavily derived on the data derived from the report Power for all (2016). The organization of the electricity systems is shown in the figure (4.2). It can be seen from the figure that there exists no long range or high voltage transmission system since most of the systems are small scale stand-alone systems. The supply of electricity occurs through the distribution systems and a single buyer procures the energy generation from power houses and independent power producers.

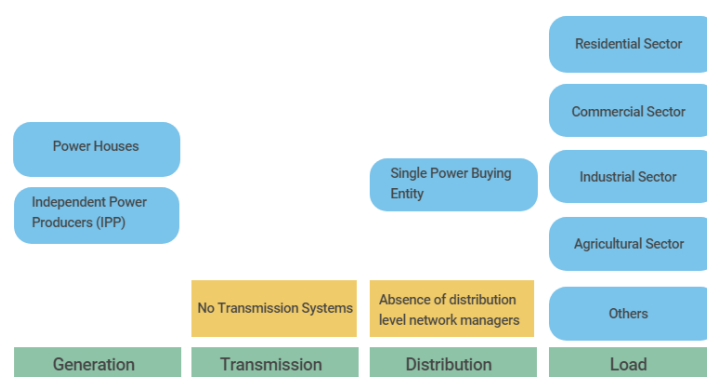


Figure (4.2): Organization of the electricity sector (own illustration)

Installed Capacity

The power generation in these islands is primarily being done using power houses (individual generators) that work in tandem with stand-alone distribution systems. Diesel generators are used for the purpose of power generation in these power houses. They work in a stand-alone system because of the absence of a single electric grid connecting all the islands. The total installed capacity of the archipelago is about 109 MW as of financial year (FY) 2015. Diesel based generation accounts for slightly more than 90% of the installed generation. Renewable energy generation accounts for the rest of the installed capacity. This renewable energy capacity includes a 5.25 MW hydro power project built on the Kalpong river in the North Andaman Island and a 5 MWp solar power plant in Port Blair belonging to the South Andaman.

Table (4.1): Ownership of Installed Capacity (Power for all, 2016)

Ownership	Diesel	Hydro	Solar	Total
State	63	5.25	0	68.25
Private	36	0	0	36.00
Central	0	0	5.00	5.00
Total	99	5.25	5.00	109.25

Regarding the ownership of the installed capacity, about 62 % of the total installed capacity belongs to the state government of Andaman and Nicobar Islands which includes 63 MW of diesel-based generation and 5.25 MW of hydro based generation. The rest of the diesel-based generation capacity (i.e. 36 MW) is owned by the private sector in the form of community generation or individual power production. The power from the plants in the private sector are usually procured by the state government in the form of power purchase agreements (PPA) for fixed periods of time. The 5 MWp solar power plant in Port Blair is owned by the central government agency of National Thermal Power Corporation Limited (NTPC) (Power for all, 2016). The table (4.1) presents the classification of installed capacities based on the ownership.

There are 53 power houses in total electrifying the 19 inhabited islands out of which 12 power houses are located in the North and Middle Andaman district, 16 power houses are in the South Andaman district and 25 power houses are in the Nicobars. The large number of power houses in the Nicobar district is due to the scattered nature of the islands and as a matter of fact they have a very low installed capacity in comparison with the other two districts. The number of power houses and their cumulative installed capacities for each island can be seen in Appendix (A1). A key aspect to note here is that more than 52% of the diesel-based generators have outlived their recommended life span and need either refurbishment or complete replacement. The Electricity department of state carries out monitoring of the generators and found that the generators that have aged beyond 25 years usually require very high repair and maintenance costs. The generators aged beyond 20 years are found to have a specific fuel consumption of more than 0.3 litres of diesel per kWh of electricity produced, making the cost of electricity generation even higher. The state government has made plans to replace such generators.

Consumption Profile

Based on the data from National Informatics centre (2017), the total electricity consumption in the archipelago during the year 2016-2017 was about 253 GWh. It can be seen in figure (4.3) that the island of South Andaman alone accounts for almost 80% of the entire consumption. The presence of urban regions in South Andaman such as Port Blair and Ferrargunj is the reason for the high consumption. All the urban regions in the archipelago put together accounted for about 72.5% (i.e. 184 GWh) of the total consumption in 2016.

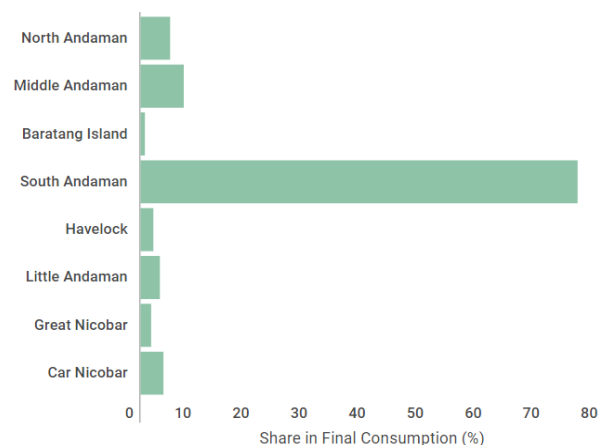


Figure (4.3): Island-wise share in electricity consumption (Power for all,2016)

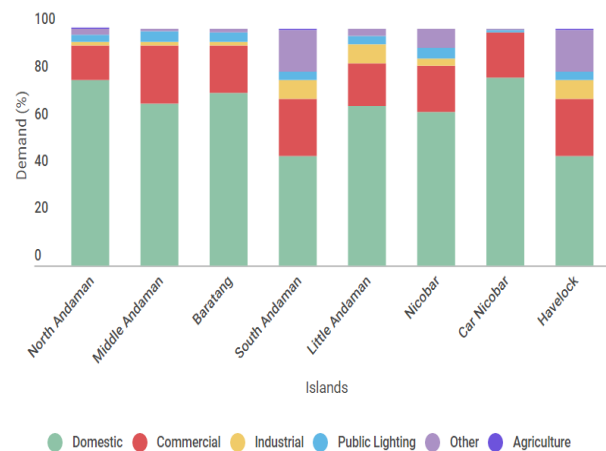


Figure (4.4): Island-wise end sector consumption (National Informatics Centre,2017)

The primary consumer of electricity is the domestic sector which averaged at 51% for the archipelago. This high consumption of the domestic sector in terms of percentage can be attributed to the absence of large scale industries. Apart from the domestic sector, the commercial sector also consumes a significant chunk of electricity. The share of consumption of each sector in the islands can be seen in the figure (4.4).

In order to make an approximation of the amount of diesel needed, a specific consumption rate of 0.3 litres/kWh is considered. Considering the annual consumption and the specific consumption rate, the amount of diesel needed for electricity alone is found out to be 73 ML (Megalitre).

Distribution Systems and the Cost of Electricity Generation

The distribution and supply of electricity to consumers is done by the electricity department of Andaman and Nicobar Islands (EDA&N) which is a state-owned company. As mentioned earlier, transmission systems are absent in the archipelago. The distribution system in South, North and Middle Andaman comprise of 33kV, 11kV and Low-tension systems. However, in the rest of the islands only 11 kV and low-tension systems are used. The distribution systems are in a very primitive stage and do not have energy monitoring systems or bi-directional flows. This has been one of the major roadblocks for installation of grid-connected small scale renewable energy systems such as rooftop solar power plants. The lack of energy monitoring systems that acquires data from consumers, generators and distributional sub-stations result in frequent blackouts due to difficulty in managing power flows.

The transmission losses are also quite high in the range of 18-20%. These high transmission losses can be due to heat losses, illegal power thefts from the lines and faulty meters that undermeasure the consumption. About 4% of the consumers are said to have faulty meters making it a legitimate reason for high losses. Similar trend is seen in the Indian mainland also where the transmission losses are very high due to similar reasons. The government has made plans to reduce the transmission losses to about 16% by the financial year 2019 and later decrease the losses further (power for all, 2016).

Including the overhead costs and the cost involving distribution, the cost of generation is somewhere about 0.32 €/kWh using an average conversion rate of 77.3 Indian Rupees (INR) per Euro (OANDA, N.d.) Due to the high costs of generation, the electricity was being sold at a subsidized cost of 0.06 €/kWh for the financial year 2015. The cost of procuring diesel alone accounts for about 80% of the cost of electricity generation (EDAN, N.d.). The cost of electricity generation is also subjected to constant change. From a price around 0.19 €/kWh in 2013, the price rose to about 0.32 €/kWh in the financial year 2016 due to the fuel price volatility in both the domestic and international markets (Power for all, 2016).

Electricity Demand

In the financial year 2016, the cumulative peak load of the Andaman and Nicobar Islands was about 58 MW. Even though there is enough installed capacity to deal with the peak demands when we look at the cumulative figures, there is a power deficit in certain islands leading to frequent power outages. Few online databases such as Open Government Data (2014) have put the power deficit in the range of 20% of the peak demand. This is very evident in the case of islands such as the Neil Island and the Havelock Island. These islands are popular tourist

destinations and have growing tourist inflows. Power outages are quite common during the high demand periods in these islands.

The load demand usually stays consistent throughout the year without lots of seasonal variations due to the fairly unchanging tropical weather (Power for all, 2016). However, there will be load changes throughout the day based on user activities. Since the main two contributors to the demand profile are the domestic and the commercial sector, an analysis of different appliances and their timings could be of good use in understanding the load variation on the daily basis. Since the load variation data or appliance wise consumption statistics of these islands are not available, the data obtained from the analysis of the residential sector on the Indian mainland will be used and similar consumption patterns are assumed. This data is derived from Chunekar et.al (2016). Figure (4.5) presents the end use consumption of various appliances.

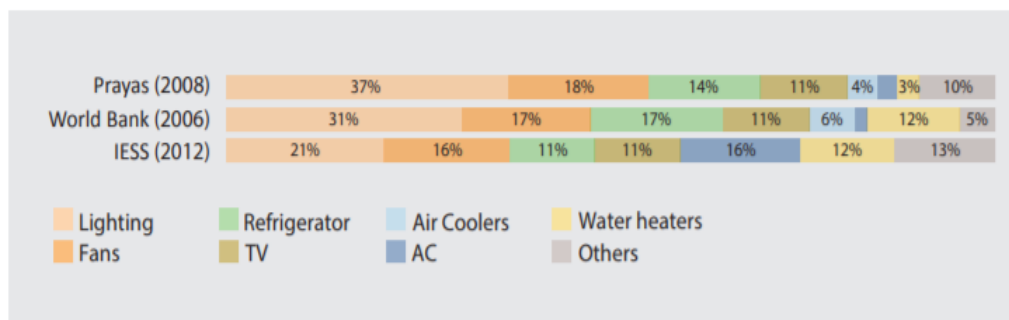


Figure (4.5): Consumption Statistics of Appliances in the Residential Sector (Chunekar et.al, 2016)

It can be observed that the primary source of consumption is for lighting. The share of lighting has decreased in the last study by IESS in 2012 compared to the earlier studies. This could be attributed to two reasons. Firstly, it could be due to the availability of technologically superior energy efficient lighting. Secondly, the growth in living standards increases the usage of other appliances which were not available previously thereby decreasing the share of lighting. The cooling demands are quite high according to this study. The electricity consumption by fans, refrigerators, air coolers and air conditioners serve the purpose of cooling. The space cooling systems comprising of fans, air coolers and air conditioners account for about 27% of the electricity consumption on average. If refrigeration is also included into the cooling demands, the percentage would increase to 41%. This high percentage is quite reasonable considering the tropical temperatures.

The electrified heating demands are only represented by water heaters and not cooking. This is because electricity is not a popular option for cooking in India and is mostly done using LPG or firewood in this case. Water heating accounts for about 9 % of the electricity demand. As far as the timings of the appliances usage and demand profile are considered, Chunekar et.al (2016) provides a good analysis based on the usage pattern of a South Indian state which has some-what similar climatic conditions.

The commercial sector will be active in the usual working hours when the demand from the residential sector is relatively lower. The major activity in the commercial sector are from restaurants, shopping centres, hospitals, banks, offices and other services. Gautam (2009) provides some insights into the energy usage patterns in commercial sector in India. Most of

the demand can be expected from lighting and HVAC. It can be assumed that the cooling demands would be much higher than the heating demands in this case.

Island-wise Electricity Demand and Future Trends

Power for all (2016) has provided the electricity demands considering the consumption profile, transmission and distribution losses for individual islands and also mapped the electricity demands until the FY 2019. The primary increase in energy demand in the near future will be due to the increase in per capita consumption in the households and also due to the expected increase in commercial and industrial activity. The constant outages and power deficits are to be dealt with which can increase the energy demand further. The average growth rate from the consumption side from FY 15 to FY 19 is about 9.55%. However, the growth rate of energy input side is about 7.33% due to the planned improvements in the grid infrastructure and decrease in the aggregated transmission and distribution losses (Power for All, 2016). The data regarding annual growth rate and peak demands until FY (2019) can be seen in Appendix (A2).

When looking at an island perspective, South Andaman accounts for about 70% of the peak demand and the annual growth rate is expected to be around 11% until FY 2019. The peak demand of these islands is expected to be 51 MW in FY 2019 as opposed to 42 MW in FY 2015. However, the tourist destinations of Neil Island and Havelock Island stand out with a very high growth rates of 22% and 15% respectively. The growth rates for individual islands ranged from 3% to 15% per annum based on the local economy and the anticipated financial growth. High growth rates are expected in the islands of Middle Andaman, South Andaman, Baratang and Havelock Island. In the islands of Little Andaman, North Andaman, Car Nicobar and Great Nicobar, a growth rate of only 3% is expected due to lower economic activity. Figure (4.6) shows the peak demands for the individual islands.

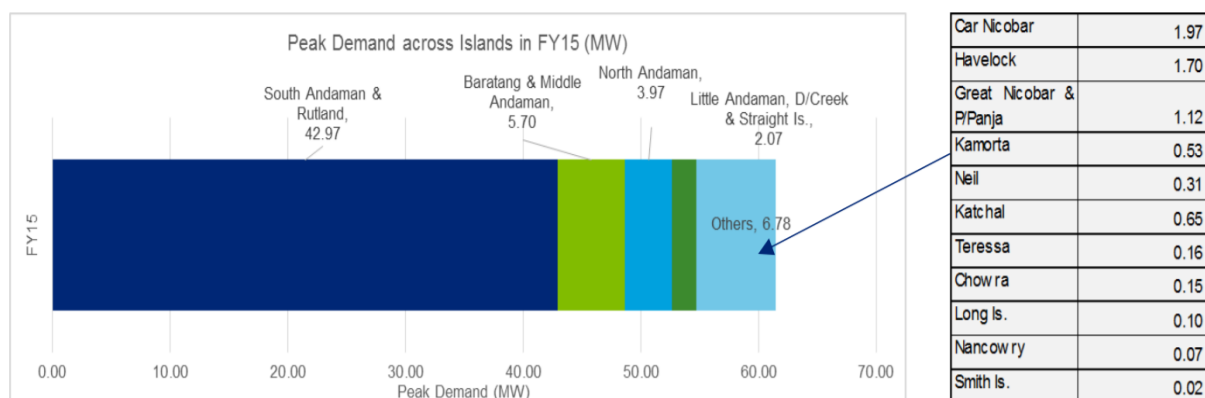


Figure (4.6) Peak Demands of Islands in FY 2015 (Power for all, 2016)

4.1.2. Heat Energy Consumption

The heating requirements usually include space heating, water heating and cooking purposes. Space heating is neglected for this case and the electrified water heating demands are already discussed in the previous section. This section deals with the heating demands for cooking purposes.

The highest contribution in the heat demands would be from cooking. The main fuel used for cooking in the 93,376 households is LPG as seen in table (4.2). Apart from LPG, firewood is

also popularly used for cooking purposes. Few of the households use other primitive fuels such as crop residue, cow dung cakes and kerosene. These could have adverse effects on the health of the consumers and the government has been very keen on increasing the usage of modern fuels. The number of households using electricity for cooking were very low (Niti Aayog, N.d.)

Firewood: In order to measure the energy consumption for cooking purposes, the consumption per type of fuel has to be calculated. According to MSSRF (N.d.), the annual consumption of firewood per household is in the range of 423 to 1320 kg in the Indian mainland. The consumption largely depends on the proximity to the forests and the nature of firewood procurement. In case the region is nearby a forest, the people were found to be freely exploiting it and consumption was higher. If that is not the case, the firewood consumption is expected to be much lower and cow dung cake, crop residue were used as additives to the fuel. Most of the rural areas in the archipelago are in proximity to forests. Therefore, an average value of 876 kg per capita per year is considered. Considering the average number of people in a household and the calorific value of firewood, the annual energy consumption is found to be 1.7 PJ or 476 GWh (Knoema, N.d.; Kominkowe, N.d.). The amount of firewood annually required would be 110,589,744 kg.

Table (4.2): Percentage of Households Using Each Type of Fuel (Niti Aayog, N.d.)

Fuel	Firewood	Crop Residue	Kerosene	LPG	Other	No Cooking
Percentage of Households	33.8%	0.4%	19.8%	44.5%	0.1%	1.4%

LPG Demand: Niti Aayog (2015) puts the average consumption of LPG for a household at about 7MJ / day. According to Total (n.d.), the amount of LPG needed for 1 kWh of energy is about 0.09 kg after incorporating the efficiency. This marks the entire demand for LPG at 2,518,498 kg annually. Considering the 44.5% of households, the overall annual energy consumption would be 0.1 PJ or 29.5 GWh.

Kerosene Demand: MSSRF (N.d.) establishes that the annual consumption of kerosene is about 11.5 litres per capita. This would make the annual consumption of 850,494 litres of kerosene and in terms of energy this would be 0.03 PJ or 8.4 GWh. The energy consumption for cooking is summarized in table (4.3) and the calculations are shown in Appendix (A3).

Table (4.3): Summary of Energy Consumption for Cooking

Types of Fuel for Cooking	Number of Households	Calorific Value (MJ/kg)	Energy Demand (PJ)
Firewood	31,561	15.5	1.70
LPG	41,552	49.0	0.10
Kerosene	18,489	43.1	0.03
Total	91,602	-	1.83

It is important to note that the very low energy efficiency of firewood leads to this abysmally high value of energy requirement. LPG has a higher efficiency and therefore has lower demand even though a higher percentage of households are using it. In case, electric cooktops are used to replace these inefficient traditional fuels the demand would be much lower than the current demand.

4.1.3. Transport Consumption

As discussed in section (4.1), only the final energy consumption of road transport will be estimated here. As of 2017, there are 121,558 vehicles in the entire archipelago out of which a majority are two wheelers (National Informatics centre, 2017). The annual growth rates during this time periods were 8.63 and 9.38% in the years 2016 and 2017 respectively and the corresponding data can be seen in Appendix (A4).

The information regarding the transport sector in these islands is very sparse and the energy demands of the road transport sector would be made based on the indicators provided in various studies. Initially, to understand the type of fuel used in the sector, a split of fuels used by the transport sector in Indian mainland is used. This is based on the assumption that a similar market pattern is observed in these islands too. According to IEA (2016), the primary fuel used is petrol with a market share of about 70%. diesel stands next with about 25% and the remaining share is filled up with various other fuels such as jet fuels, biofuels, natural gas fuel oil etc. However, in this study since only road transport is considered, the market share is assumed to be split in a 80:20 ratio between petrol and diesel respectively. This can be a valid assumption to make since the majority of vehicles are two wheelers which use petrol as their fuel. The consumption of diesel will be seen in buses, trucks, auto-rickshaws and in some of the cars.

In order to find out the energy consumption of each type of transport, the energy intensity data for each kind of vehicle and the average number of kilometres travelled per capita annually are required. This per capita demand is then appropriated on a population basis for different islands. The energy intensity of vehicle per kilometre travelled data is derived from Rayle et.al (2009). This source derives an average value for the energy requirement in MJ/km based on three studies from Bose (2000), Mittal et.al (2006) and Iyer (2006). The data is provided below in figure (4.7). This data only considers passenger travel but not freight travel. The obtained values are rough approximations and the original energy demand might vary depending upon the number of passengers travelling in the vehicle in the case of passenger transport and the tonnes of cargo being carried by the freight transport.

Regarding the number of kilometres travelled by passenger transport and freight transport, data from EIA (2016) is used. In this source, the number of kilometres travelled per capita for India is provided. This is about 2816 km (1750 miles) of transport kilometer per capita. The data for passenger occupancy rate of vehicles was sparse and the data from the United States were used which can be seen in table (4.4). The appropriated per capita km for each vehicle must be divided by the passenger to give the actual vehicle kilometres power capita. These values will be used to find out an approximate energy demand per capita. From the table (4.4), it can be seen that the kilometres travelled per capita for bus transport is very low. This could be because the availability of bus transport in the islands could be low (especially in the Nicobar region) and when aggregated for the entire population could lead to even smaller values.

Vehicle Type	Bose & Nesamani ^a (MJ/km)	Mittal & Sharma ^b (MJ/km)	Iyer ^c (MJ/km)	Average (MJ/km)	Emission Factor (g CO ₂ /km)
Motorcycle (2-stroke)	0.8	0.48	0.60	0.6	45.2
Motorcycle (4-stroke)	0.54	0.43	0.47	0.5	34.6
Auto-rickshaw (2-stroke)	1.6	0.97	1.06	1.2	87.2
Auto-rickshaw (4-stroke)	1.5	1.14	0.92	1.2	85.6
Petrol car	3.5	3.71	-	3.6	259.9
Diesel car	4	3.94	-	4.0	286.2
Diesel bus	11.25	8.3	-	9.8	704.8
Train (metro)	-	-	-	21.3	1541
Train (suburban rail)	-	-	-	14.7	1063

Figure (4.7): Energy Consumption of Each Category of Vehicle (Rayle et.al, 2009)

Table (4.4): Approximation of Energy Consumption by Road Transport

Passenger Vehicle Type	Number of Vehicles	Market share	Energy demand (MJ/km)	Occupancy rate	Appropriated km/year (per capita)	Appropriated annual MJ/ Capita
Two Wheelers	86,402	72.8%	0.55	1.16	1,766	971.6
Bus	1,088	0.9%	9.8	9.2	3	27.6
Light Motor Vehicle	26,097	22.0%	3.8	1.55	530	2,014.5
Auto - Rickshaw	4,304	3.6%	1.2	1.55	66	78.9
Others	839	0.7 %	3.8	1.55	13	49.0
Total	118,729	100%	-	-	2,378	3,141.7

In the case of freight transport, 80% of the travelled kilometres in non-OECD countries goes to maritime freight and 65% of inland freight is supported by road ways (EIA, 2016; National Transport Development Policy Committee, 2014). Therefore, according to adjustments that makes it 481 km (299 miles) of freight per capita. The energy intensity of the trucks is about 2.43 MJ/km. This makes the energy demand for freight 1,167 MJ/capita. The estimated values of final energy consumption in transport sector for each island can be seen in Appendix (A4).

The total energy demand for the road transport sector is 1.57 PJ annually. However, if the air transport and maritime transport systems are considered this value will be much higher. Based on a split of 80% petrol and 20% diesel for land-based vehicles, the diesel and petrol consumption has been estimated. Engine efficiencies of 50% and 45% for petrol and diesel engines have been used based on Arrow head radiator (n.d.) and Giannelli (2005) respectively. Energy intensities of 73.38 g/MJ and 73.25 g/MJ for petrol and diesel respectively have been used. This puts the annual petrol requirement at about 78 ML and the annual demand for diesel requirement for transport at about 19.5 ML

4.2. Stakeholder Analysis

In this section the stakeholder analysis will be done on the energy sector of the archipelago in order to identify various actor and their roles and influence on the energy transition. Miron et.al (2009) identifies three different kinds of stakeholders in a general stakeholder analysis. They are as follows.

- 1) **Key Stakeholders:** These are the actors who can influence the success of the project or the programme.
- 2) **Primary Stakeholders:** These are the actors who are directly affected by the project or the program.
- 3) **Secondary Stakeholders:** These are the group of actors who can or cannot take part in the decision-making process or also could be affected by the project or the programme.

4.2.1. Key Stakeholders

Policy Makers

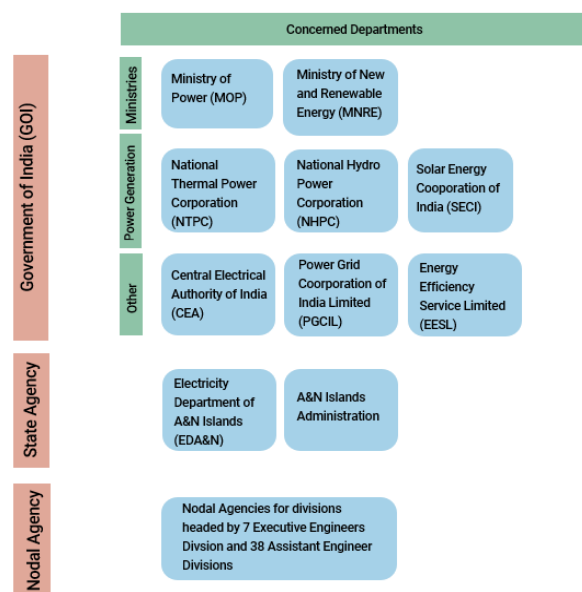


Figure (4.8): Organization Chart of Various Governmental Agencies

In order to understand the role of various governmental agencies in policy making process, the organization chart of these agencies is necessary. Every agency and concerned departments, play a pivotal role in the policy framing process. The Indian central government agencies work in tandem with the state agencies in framing policies and planning the execution of these plans. The state government agencies in return work in tandem with the nodal agencies in order to execute new projects and monitor existing energy systems. The roles of individual agencies are heavily derived from the Power for all (2016) report released by the Ministry of Power.

The main role of Government of India (GOI) and the Ministry of Power (MoP) are in planning new investments and targets in the energy sector and also establish a funding program in order to facilitate these plans. MoP is also responsible for managing the fuel supplies to the archipelago. The Ministry of New and Renewable Energy (MNRE) is responsible for the research, development and promotion of renewable energy sources across the country. In

tandem with other renewable energy agencies such as IREDA, MNRE works for the development of policies and schemes aimed at the growth of renewable energy. The state government electricity department implements these new policies.

The current power generation is owned by the central government, state government and the private sector. Solar Energy Corporation of India (SECI) is an enterprise of MNRE that is responsible for the implementation of the 5 MWp solar power plant which is currently owned by NTPC.

The organisations of Central Electrical Authority of India (CEA) and Power Grid Corporation of India Limited are supposed to work in tandem with electricity department of Andaman and Nicobar Islands (EDA&N) in order to maintain the electric grid, improve grid infrastructure and take up any new investments for the grid.

EDA&N is the state agency that has a pivotal role in the implementation of new projects. It ensures the maintenance of existing generation, development of new generation, replacement of old and defective energy meters, improve grid infrastructure and reduce transmission losses. This body also works in tandem with Energy Efficiency Service Limited (EESL) to promote awareness about energy efficiency and demand side management among the consumers. EESL can be termed as the most important agency that focusses on the diffusion of electric vehicles across the country and the adaptation of modern fuels for cooking in the rural areas.

Apart from the electricity department of these islands, the administration of these island groups is also important for a large scale renewable energy transition as they need to provide with a large scale administrative help such as land, resource allocation and other bureaucratic permissions.

Financers

Most of the public owned investments in the energy sector are financed by both the state government and the central government. GOI and MOP are primarily responsible for providing the required fund allocation needed for undertaking new investments. However, the private or community generation is mostly financed with the help of the banking sector. Since, these islands are an integral part of India, there is access to almost all the large-scale banks in the mainland. There are almost 41 commercial banks and several other public owned banks in the Andaman and Nicobar Islands with good access to loans for capital (MSME, 2015). The government's interest in renewable energy has made banks interested in it as well and offer loans at a lower interest rate for such projects.

4.2.2. Primary Stakeholders

Power Producers

From a legal perspective, eligible power producers can be registered companies, corporations, non-governmental organizations, state and central governments or individuals (Government of Andaman and Nicobar, 2012). The power producers can sign power purchase agreements (PPA) with the electricity department or other bulk consumers. There are significant amounts of diesel-based generation systems owned by individuals or communities. The private sector power producer base can increase widely in the form of small scale investments such as rooftop solar if proper bi-directional grid infrastructure and export meters are developed. Apart from

the local community power producers, large technical companies from the mainland have been keen on investing in the islands.

Users

The consumers as of now have a very passive role due to the nature of the grid and the energy market. The present role of users is limited to the purchase of power and the usage of a energy efficient appliances. The current state of infrastructure is not favourable for the development of prosumer activity. The main consumers are from the residential sector or the commercial sector. They purchase energy from a single buyer (i.e. state electricity board) which in turn buys power from different power generators in the form of power purchase agreements. In this case, the single buyer entity has been largely beneficial for the consumers as the government highly subsidizes the price of energy. There is no possibility of choosing their own power producers as in the case of European Union.

Civil societies in the islands are largely focussed on the development of local ecology. In the recent past, there have been noted cases of protests from the civil society over frequent unscheduled power outages and insufficient action from the administration side over these problems.

Oil Retailers

Oil Managers Companies (OMC) which largely dominated by the public-owned companies, handles the crude oil refining and hand over petrol and diesel to the retail dealers in the island. These companies have their own share of individual private dealers who sell the fuels to the consumers (Chawla, 2017).

4.2.3. Secondary Stakeholders

Research Institutes

There are no technical universities present in the archipelago, but they have full access to all the research institutes and the technical universities in the Indian mainland. The technical universities such as Indian Institute of Technology, Chennai, have been instrumental in analysing the potentials of wave energy and ocean thermal energy conversion. These institutions have also tried developing pilot projects on ocean energies in the islands and across the country. Indian Navy stationed in the archipelago has also been exploring the possibility of developing a 20 MW OTEC plant in tandem with a French company in the island of South Andaman for their own consumption. Several other research institutes are working in tandem with the MoP and MNRE for the betterment of the energy landscape in the archipelago.

Non-governmental Organizations (NGO)

Although there are several NGO's in these islands, most of them oriented towards protecting the environment. They range from forest reserve protection to coral reef protection and other varied range of fields. These organizations are eligible to be individual power producers and some of these organizations own small capacities of power generation. As of now, there a few organizations aimed at the upliftment of the rural areas. These organizations can be utilized to persuade the rural populations to shift to cleaner cooking and can help in the development of rural energy systems.

4.3. PESTEL Analysis

The PESTEL analysis will be used to analyse the external environment engulfing the energy sector in the islands. This analysis will be crucial in understanding the external influences on the energy transition. The analysis concerning the six factors is laid down below.

Political: The government entity responsible for the development and undertaking of renewable energy projects is the central government ministry of MNRE. This ministry provides with economic incentives that exempt taxes such as customs duty, electricity duty and local import duty (known as octroi) on the renewable energy systems, equipment and devices (IREDA, 2012). The same ministry in tandem with the state agencies developed renewable energy targets and roadmaps such as having 25% of electricity from renewable energy sources by the year 2017 (Power for All, 2016). However, these targets have not been reached yet. There seemed to be a lack of seriousness over these targets and there were many instances where private companies have signed contracts for development of renewable energy systems and then these contracts were completely scrapped off by these concerned agencies citing various reasons. These kinds of mixed signals from the government's end have been causing great inconvenience to the private companies who were interested in developing renewable energy projects in the islands (Kenning, 2018). The ministry of power also announced plans of investing large scale LPG facilities for electricity generation in order to replace the large scale obsolete diesel generators. In order to promote cleaner cooking in the islands, MNRE through EESL has been distributing highly subsidised (75%-90%) solar cookers, solar lanterns and efficient biomass cookers for backward tribes and the people below the poverty line. The government has been considering the implementation of a ban in the sale of diesel cars (not petrol) by the year 2030 due to their impacts on public health and air quality. No concrete policy initiatives have been implemented yet in order to steer the transportation sector towards electric vehicles in the archipelago or across the country.

Economic: Financial incentives have been declared for the investors in renewable energy systems. Rooftop solar systems in the archipelago are granted 70% capital investment subsidy. Commercial systems larger than 500 kW_p are granted a 10-year value added tax exemption in addition to the other tax exemptions discussed in the political aspects. They are also eligible in claiming clean development mechanism (CDM) benefits such as renewable energy credits. The large-scale investors in energy generation can make long term power purchase agreements with EDA&N for a period of 20 years with the possibility of extending it for further 10 years (mySun, 2018). The feed in tariffs are decided by the Joint Electricity Regulatory Committee (JERC) based on competitive bidding. The usual feed in tariffs observed for solar is around 0.08 €/kWh (Power for All, 2016). In order to facilitate better access to capital, the renewable energy sector has been classified under the priority sector lending that provides loans at a much lower interest rate from the banks. The presence of almost all major governmental and commercial banks across the nation in these islands, provides them with good access to the banking sector. However, the GDP per capita was around USD 2100 in the year 2014-2015 (Central Statistics Office, N.D). Therefore, investments from the consumers can be low owing to the economic conditions (especially in the rural areas). As far as cooking fuels are concerned, modern fuels such as LPG have about 40% subsidy per cylinder to increase affordability.

Social: According to the regulations, eligible private investors in energy generation can be companies, co-operatives, partnerships or individuals. The major investments in the private

sector is seen from co-operatives in the form of community generation. Overall, there lacks a wide spread awareness about the threats of using conventional and primitive fuels. Currently, there is no incentive for individuals to switch towards energy efficient appliances as the tariffs are highly subsidized. The adoptability of newer technologies is also quite difficult in the current state of the energy sector. Apart from affordability of these technologies, the lack of reliability is also deterring a high uptake of these renewable energy devices. Such issues were observed in a few rural places in the mainland, where electric cooktops were provided for subsidized prices and the rate of permanent adoption was quite low due to frequent unscheduled power outages.

Technological: Most of technological aspects related to energy sector have been discussed in the previous sections.

Environmental: These island groups are environmentally very fragile. There exist large scale reserved forests that take up most of the landmass. These protected forests restrict the available land area for each of the island at around 5-6%. Detailed calculations of land area availability can be seen in Appendix (A6). This limits the renewable energy potentials as well. However, in the rural areas these forest areas are illegally exploited. The increasing temperature and other human activities such as surface run-off is causing high amounts of coral bleaching. The large amounts of consumption of diesel for both electricity and transport is also causing large emissions of PM 2.5.

Legal: Currently, there exist a lot of red tape to get clearances for new investments in the energy sector. Clearances from various authorities such as environment, forests, airport, pollution, water and investment clearances are necessary. The have been plans of introducing single window clearances from all these authorities is being proposed but no actions have been taken yet. In the case of transport fuels, better emission standards and proposed removal of diesel subsidies has dipped the share of diesel cars from 50% to 23% by the year 2013 These legal aspects together with discussions on banning the sale of diesel cars have allowed the society of Indian automobile manufacturers to develop targets of achieving 100% EV penetration by 2047 across the country and to achieve 60% penetration of hybrids and EVs in the sales by the year 2030 (Roychowdary, 2018).

4.4. Assessment of Renewable Energy Potentials

In this section, the renewable energy potentials of all the islands will be calculated. This will be essential in developing scenarios without logistical inconsistencies. Different kinds of sizable renewable energy sources that are being utilized across the globe will be considered except for geothermal energy due to the lack of technical data to assess it's potential.

4.4.1. Data Gathering

The assessment of technical potentials for different sources would require a wide range of meteorological datasets. These required datasets must be for the entire year on an hourly basis in order to factor in the seasonal fluctuations of the meteorological conditions in the location and identify the kind of energy production fluctuations that can be anticipated throughout the year. Each kind of energy sources required different kinds of datasets.

Table (4.5): Data sources used for energy assessment

Datasets	Databases	Energy Sources
Temperature	Meteonorm 7, Atmospheric Science Data Centre (NASA)	Solar Energy
Irradiation	Meteonorm 7, Atmospheric Science Data Centre (NASA)	Solar Energy, Concentrated Solar Power
Wind Speeds	Meteonorm 7, Atmospheric Science Data Centre (NASA)	Wind Energy
Ocean Surface Current Speeds	Ocean Motion (NASA)	Tidal Energy
Ocean Surface Temperature	Ocean Motion (NASA), Charis (2017)	Ocean Thermal Energy Conversion (OTEC)
Agro based residues	(Government of Andaman and Nicobar, 2017)	Bioenergy

Apart from the meteorological data, data regarding agricultural residues are also collected in order to assess the potential for bioenergy. The datasets acquired, the databases used and the kind of energy potentials that are assessed are specified in table (4.5). Appendix (A7) shows the models used to estimate the renewable energy potentials and Appendix (A6) shows the estimations on available land area for each island.

4.4.2. Solar Photovoltaic Technologies

According to EIA (2018), the capacity factor of solar photovoltaic technology is about 27 % in the year 2017. The low capacity factor implies that a largely scale intermittency can be anticipated in the case of grids with large amounts of solar power without backup or storage. In our case, the Tata TP260 module is considered and has an efficiency of 15.6%. The efficiency of the module largely depends upon the irradiation and the temperature. Therefore, when an hourly data from Meteonorm is used, the efficiency varies every hour due to the meteorological conditions.

In order to convert the available land area in the islands into a module area for this case, a land use efficiency of 33% is considered so as avoid the casting of shadows on panels due to other panels. Using this model and the meteorological data the potential for solar energy is calculated and tabulated in table (4.6) for all the islands. The total potential for all the islands is found to almost 108 PJ/yr

4.4.3. Concentrated Solar Power (CSP)

According to Breyer et.al (2009), there is a huge potential and economic feasibility for CSP plants if the direct normal irradiation is around 2,000 kWh/m²/year based on current technology and is expected to become viable for regions with 1800 kWh/m²/year as well in the future. This technology has a capacity factor of about 20-25% (IRENA, 2012). The direct normal irradiance in the islands varies in the range of 1961 kWh/m²/year to 1636 kWh/m²/year. Relatively lower irradiance is seen in the Nicobars and little Andaman.

According to (Breyer et.al, 2009), the average land use efficiency of CSP technology is roughly around 10% although it keeps varying around 4.5% to 20% based on various factors. IRENA (2012) marks the overall efficiency of conversion of solar energy to electricity through thermal energy 13 % (on average) and varies based on the kind of technology chosen such as parabolic trough, solar tower, linear fresnel or dish stirling. Therefore, using this data, the technical potential is found out and tabulated in table (4.6). The total potential for all the islands is found to be about 29 PJ/yr.

4.4.4. Wind Power

The average wind speed in these islands is around 4 m/s. Based on the local windspeeds, Vestas V110 2.0MW turbine model has been chosen due to it's low cut in speed. The wind speed data for the entire year has been measured at an altitude of 50 m. The hub height of the turbine is 110 m. Therefore, logarithmic law is used to convert the wind speeds from 50m (height of recorded windspeeds) to 60 m and the power law is used to convert the wind speeds to 110 m from 60 m. Phadke et.al (2011) marks the capacity factor for India at about 20% in the case of onshore wind farms and is the offshore wind farms are expected to be much higher depending upon the location of study. The number of turbines on individual islands is calculated by considering the optimum spacing factor. Mitchell (2014) puts the optimum spacing distance as 7 times the rotor diameter in the downwind direction and 5 times the rotor diameter in the secondary direction. The total number of turbines is calculated by dividing the available area with the spacing area required for individual islands. This lead to an assessment of 4.4 PJ per annum onshore wind potential.

In the case of offshore potential, Ramachandra et.al (2005) marks that the winds speeds of about 5-6 m/s could result in a good potential. This kind of wind speeds can be seen around the coastlines of these islands. The existing technology for deep offshore plants are limited to 50 m depth itself. Therefore, wind plants nearby the coast would be feasible. Therefore, the coastlines of individual islands and a spacing factor of 7 times the rotor diameter is used to determine the number of turbines. In the case of offshore bigger wind turbines can be used since higher wind speeds can be expected. Vestas V126 3.45 MW is chosen for this reason. This has led to the assessment of 17 PJ per annum of off-shore wind potential. The potential of individual islands is presented in table (4.6).

4.4.5. Biomass

Biomass offers flexibility and reliability in terms of energy supply. Usually, the biomass potential in islands is quite low due to the limited land area. However, in the case of these islands, the presence of evergreen forests and plantations have been a boon for biomass. Large scale plantations of coconut, paddy and arecanut have been the biggest source of biomass. The main industries in the region are agro-based industries which is an additional advantage. Government of Andaman and Nicobar (2017) has been largely helpful in identifying providing details regarding the main agro-residues. In the year 2004-2005, 29,192 tonnes of paddy is produced. If 20% of it is considered to be rice husk, then generation is supposed to be 5,832 metric tonnes. In the case of coconut for the same time period 89 million coconuts were produced. This can be translated into 56,610 tonnes of dried fronds, 40,000 tonnes of coconut husk and 10,680 tonnes of coconut shells. Similarly, 2,589 tonnes of arecanut husk is produced. Assuming a specific calorific value of 1.3 kg/kWh, Government of Andaman and Nicobar

(2017) implies that the annual production can be around 0.5 PJ. It has to be noted that only agro based biomass is used and not waste or wood due to the lack of data. Energy crops would not be feasible due to shortage in land availability. In the case of individual islands, Car Nicobar leads the pack with highest potential due to its big coconut plantations. Power for all (2016) identifies a potential of about 2.25 MW in this island. Therefore, the potential in other islands will be appropriated based on their land area as it can be considered as an indicator for biomass feed.

4.4.6. Hydro Power

In the case of these islands, there are a few seasonal rivers but the Kalpong river is the only annual river present. There exists already a 5.25 MW power plant harnessing energy from this river in the North Andaman Island. Considering a capacity factor of 50% it would produce 0.1 PJ/yr. It could possibly have a higher potential but required data such as the flow rate of the river are missing. Therefore, assessing the complete potential of hydropower is not feasible.

4.4.7. Wave Energy

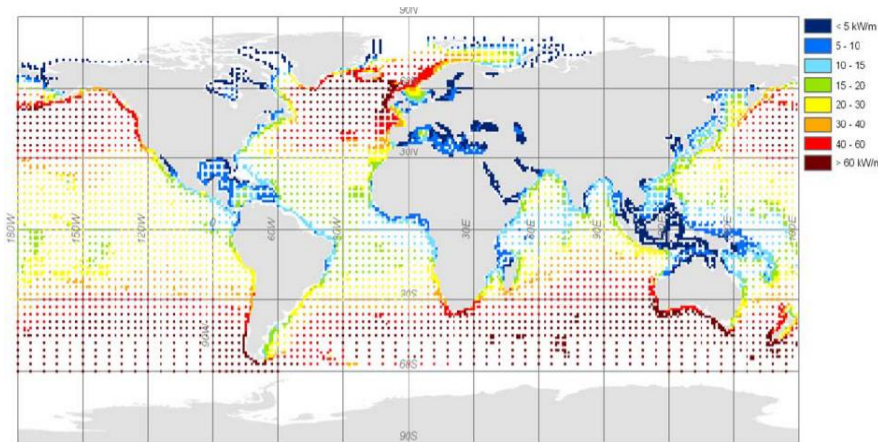


Figure (4.9) Global Wave Energy Potential (Mork et.al, 2010)

Mork et.al (2010) assesses the global potential of wave energy in the range of 1-10 TW. The best wave energy conditions according to IRENA (2014) lies in medium high latitudes and deep waters with a potential about 40-60 kW/m. In the case of these islands, the potential is about 20-30 kW/m with a high seasonal variation as seen in figure (4.9). This kind of potential is not viable and therefore will not be considered in our study.

4.4.8. Ocean Thermal Energy Conversion (OTEC)

For the sake of economic and practical viability, a minimum temperature gradient of 20°C is required. This can be translated roughly into a surface temperature of 26°C or more (Chalkiadakis, 2017). In the case of these islands the mean surface temperature for about 22 years is around 28.6°C, thereby making it an ideal site in these islands. The surface temperature trend map can be seen in figure (4.10).

The potential sites can be either identified as onshore or off-shore OTEC plants. Chalkiadakis (2017) mentions that if the plant is less than 9 Km away from the shore then it can be considered as onshore plant. However, as of now the technical potentials for on-shore is quite low as the geography is not favourable compared to off-shore. The thesis of Chalkiadakis (2017) has been

very helpful in identifying the temperature differences, theoretical potentials and practical potentials of this technology. In the case of these islands the mean temperature difference observed between 30 m depth and 1062 m depth is at about 22.6 K.

Appendix (A7) shows the model being used to calculate the net power output. Using this model, the power density is found out to be around 2.9 MW/km^2 . The total exclusive economic zone for these islands is about $660,000 \text{ km}^2$ and can be seen in figure (4.11) (Gopalakrishnan et.al, 2016). This makes the resource potential at about 1.9 TW. However, the entire potential cannot be used up. There must be some amount of spacing between two different OTEC plants to facilitate a proper cold-water flow without effecting the ecology. Based on Chalkiadakis (2017), most of the area belonging to these islands fall under the 0-50 km spacing category. Therefore, an average of 25 km will be used in this calculation. Assuming the OTEC plant requires 1 km^2 of area and is the only plant in a 25 km radius, a total of 336 plants can be feasible. This means a total installed capacity of 969 MW producing 31 PJ per annum at 100% capacity factor. However, in reality this value could be much lower owing to local geographical constraints. The potential for individual islands will be dealt by appropriating the number of plants based on the area of individual island and is shown in table (4.6).

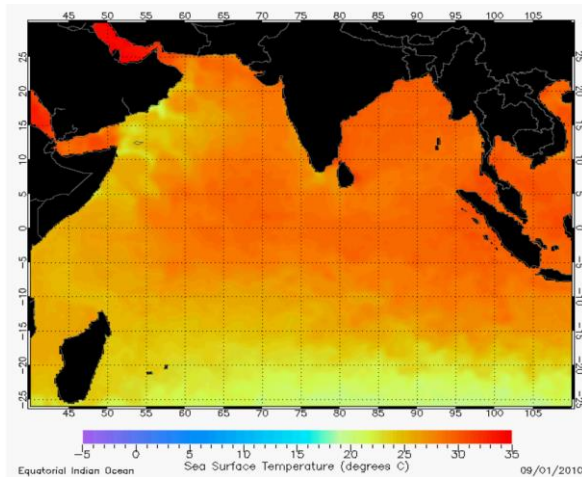


Figure (4.10): Sea Temperature Map of the Indian Ocean (Ocean Motion, N.d.)

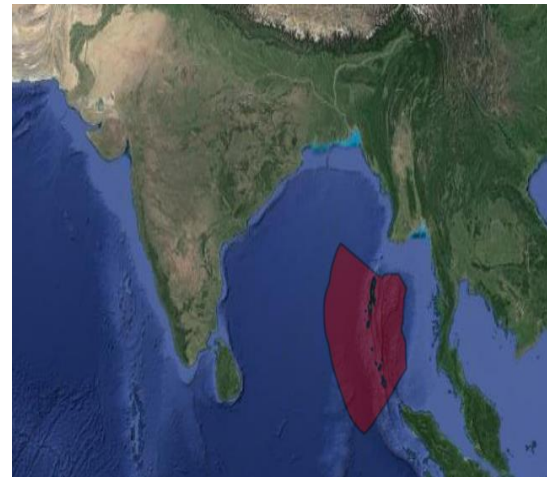


Figure (4.11): Exclusive Economic Zone of the Andaman Sea (Marine Regions, 2005)

4.4.9. Tidal Energy

In this assessment, only tidal turbines are considered and not tidal barrages due to their ecological impact and large land requirement. According to Mohammed et.al (2016), for a 500 kW tidal turbine, the minimum cut in speed for the turbine to run is about 0.4 m/s using a maximum power coefficient of 0.44. The Andaman Islands had a highest current speed of 0.34 m/s in the year 2014. In the Nicobar Islands, the current speeds are higher with a maximum speed of 0.49 m/s (oceanmotion, N.d.). On observing figure (4.12) even though the islands are not visible, the surface current speeds in the Bay of Bengal can be seen and is very low. Considering these wind speeds, it can be seen that there is no sizable potential for harnessing the kinetic energy using tidal turbines based on the technology available to date.

4.4.10. Storage Potential

In order to assess the different kinds of battery technologies figure (4.13) can be observed which compares the technologies at different levels of utilization. System power ratings and times of discharges were used as indices in the comparison in Hart (2016). In our scenario, bulk power, bridging power and load shifting levels are needed. This filters some of the available option. In addition, very low discharge times are not favorable as in the case of fly wheels. Options like pumped storage could be very beneficial but significant potentials in this region were not found. Considering the aspect of technological maturity and scalability, Lithium Ion (Li-ion) batteries have been the most widely used technology and show the most promise when grid level support or electric vehicles are considered. This can be supported by the fact that 95% of the existing grid tied storage is Li-ion technology (Hart, 2016). Three types of Li-ion batteries are available in commercial use. They are based on cobalt, manganese and phosphate elements addition to the Lithium ion composition. The potential or size of these battery options depends on the existing energy demand, the composition of energy mix and the meteorological conditions of this location.

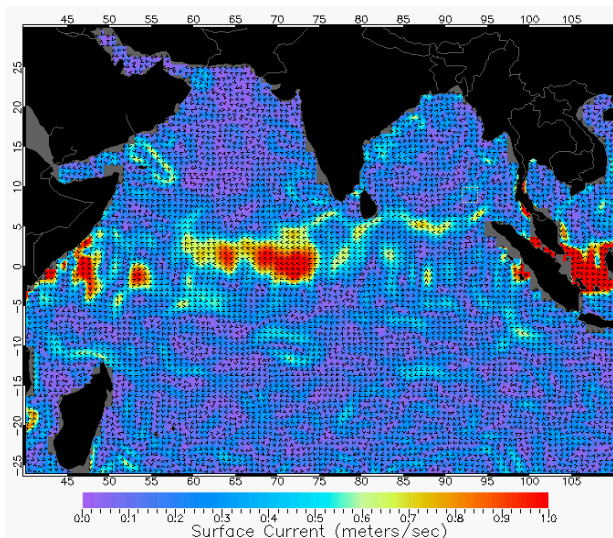


Figure (4.12): Surface Current Speed map of the Indian Ocean (Ocean motion, N.d.)

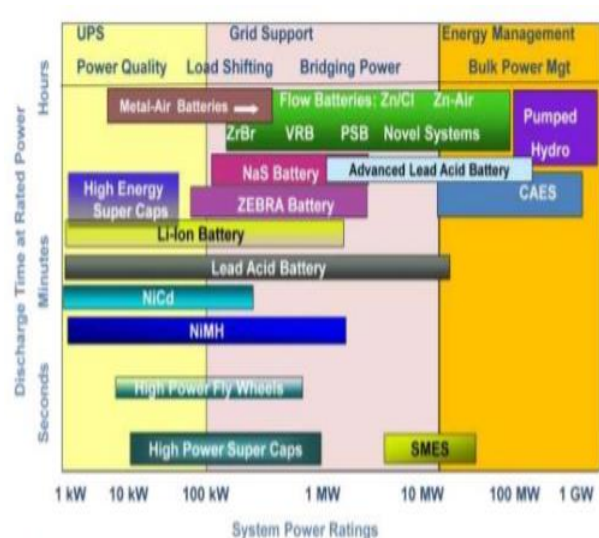


Figure (4.13): Comparison of different storage technologies (Hart, 2016)

There is some absorbing capacity in the batteries present in electric vehicles. As the number of electric vehicles are expected to rise, these batteries can be used efficiently to absorb some amount of fluctuations. The number of vehicles in the year 2016-2017 are used for this estimation and modifications were made based on the different classification of vehicles. Benchmark vehicles such as Vespa electric for two wheelers, tesla model 3 for cars, tesla semi-trucks and Tata electric busses are used for this estimation. The annual kilometers travelled by each vehicle are used from the estimations made in order to assess the energy demand in transportation. This can be used to establish the number of charging cycles for each vehicle. Using these estimations, the total absorption capacity is almost 1 PJ/year. In order to put this into perspective, this amount of absorption can be used to store almost the entire electricity demand for a year.

Table (4.6): Overview of Renewable Energy Potentials (PJ/yr)

Islands	Solar	CSP	Wind (onshore)	Wind (offshore)	Biomass	OTEC	Hydro
North Andaman	27.3	7.3	1.0	4.1	0.10	7.6	0.1
Middle Andaman	25.5	6.8	1.0	3.2	0.10	7.3	Nil
South Andaman	25.1	6.7	1.1	5.0	0.10	6.1	Nil
Baratang	1.5	0.4	0.1	1.4	0.01	0.4	Nil
Havelock	4.0	1.1	0.2	0.7	0.02	1.2	Nil
Little Andaman	10.6	2.8	0.5	0.6	0.05	3.4	Nil
Car Nicobar	1.3	0.3	0.1	0.6	0.07	0.4	Nil
Great Nicobar	12.5	3.3	0.4	1.6	0.06	4.2	Nil
Total	107.8	28.7	4.4	17.2	0.5	30.6	0.1

4.5. Assumptions and Constraints

Through this research, practical transitional pathways will be drawn to the extent possible. However, there are certain shortcomings due various reasons such as non-availability of data, geographical and technical constraints.

Geographical Constraints: In this study, a preliminary geographical boundary is setup by choosing this particular archipelago. Furthermore, all the islands in this archipelago are not taken into the analysis and a demographic filter has been established to choose the most important set of islands. This is due to military restriction on few of the islands, sparse populations, presence of hostile tribal groups and non-availability of data resources for a comprehensive study.

Non-availability of Data: The absence of data has affected this study in two ways. The first way is the issue relating to the absence of data regarding few of the smaller individual islands. This has been dealt with by applying a demographic filter and selecting the islands that comprises a little more than 95% of the population. The second issue is due to the absence of data regarding primary energy use, oil and fuel imports from the main land. Only data regarding electricity consumption is sufficiently available. This has been dealt with by making approximations for other sectors and end uses. The non-availability of data has also been a problem in assessing the potentials for renewable energy sources such as hydro energy, rooftop PV and geothermal energy.

Technical Constraints: There are several technical constraints and assumptions used in this analysis and are as follows.

1. Maritime and Air travel are not considered due to complexity in energy demand estimations and certain degree in establishing a system boundary for these large range travel demands.
2. The energy demand estimations for cooking and transport have been made on the basis of indicators used in several other international studies and have been appropriated for

the entire archipelago on the basis of population. However, in reality, this might not be the case and variations can be expected.

3. The estimates were made for the major consumers only and the overall consumption could be understated due to this.
4. The estimation of total final consumption only considers energy uses and non-energy uses. This understates the total final consumption estimates made.
5. While calculating the potential of OTEC, the entire exclusive economic zone has been considered. However, there are lots of regions in this economic zone that are unfit due to the presence of coral reefs, naval corridors and technical unfeasible areas that decrease the potential further.
6. The potentials are made by taking a specific technological model into consideration and any changes in the specifications of the model can affect the estimates of the potential.

Chapter 5: Future Visions and Scenario Development

In this chapter, the future visions and scenarios for the archipelago will be developed. This chapter comprises of the second step of the backcasting and provides with the main goal towards which the backcasting is intended to work.

5.1. Future Visions

A vision in this case represents the desired future. It will include an end point based on which the entire backcasting analysis will be done. Later on, the developed scenarios describe how the desired future can shape up in reality. In this case, the main desired future vision is to establish a 100% sustainable energy supply in these group of islands by the year 2040. When the term ‘energy supply’ is used, it encompasses all the electricity, heating, cooling and transport demands. It has been assumed that the heat demand and road transportation are electrified. This is done to reduce the usage of conventional fossil fuels in the energy system as much as possible and introduce electricity as the major energy carrier as it might function as a much more efficient energy carrier. The main desired future is supported by five objectives. Figure (5.1) describes the same. The five objectives are as follows:

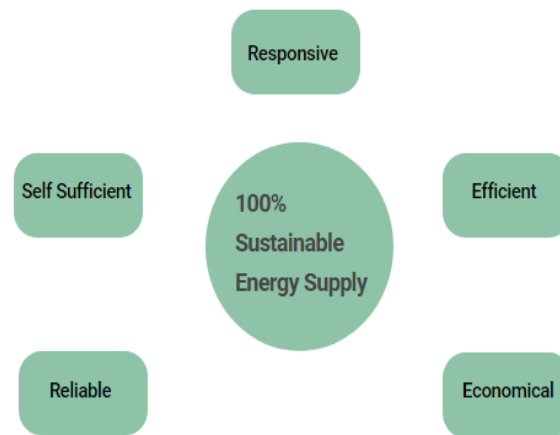


Figure (5.1): Key objectives of the Desired Vision.

- 1) **Self-Sufficient:** This objective has been chosen to minimize the dependence of the energy system on the fuel supplies from the Indian mainland and to utilize the local renewable energy potentials in the place of fuel supplies.
- 2) **Reliable:** Despite the claims of universal electrification of households and a 24 by 7 access to electricity, these islands suffer from frequent outages and power cuts on a daily basis for hours altogether. This lack of reliability is one of the reasons why rural consumer still use traditional cooking fuels like firewood. Therefore, establishing a reliable supply will be one of the main objectives.
- 3) **Responsive:** Currently the role of the consumer in the energy systems is very passive. They act as mere consumers or buyers of energy and the vision of this study with respect to the consumers is to involve them better into the energy system. This could be either in the form of better response to fluctuating supply or as a prosumer. This responsive consumer activity is a crucial aspect in a fluctuating energy system.
- 4) **Efficient:** The current energy system is largely inefficient due to kind of fuels used and the state of infrastructure. The objective is to improve the overall energy efficiency of

the entire system through technological interventions. The future energy demand growth is expected to be high making the need for energy efficiency even more important.

- 5) **Economical:** Currently, the electricity system is characterized by very high costs of generation and the electricity is heavily subsidized to make it affordable for everyone. The costs of fuels used for transportation are quite volatile in the international and domestic markets as well. Therefore, the objective would be to provide a truly economical supply of energy to the consumers.

As far as the end-point is considered, an electricity supply transition by 2040 can be an attainable target in these islands considering the size of the demands. However, the main issue would be due to the transition to the electric vehicles since there is near zero penetration as of now. The government of India has decided to ban diesel cars by the year 2030 and promote electric vehicles. This could be beneficial in our case. Therefore, a competitive end period of 2040 has been chosen for a complete energy transition.

5.2. Scenario Development

The scenarios are developed in this section essentially represent how the desired futures can be achieved. This is done using general morphological analysis. This analysis includes all the aspects of scenario generation, integration and consistency checking techniques. The scenario generation and integration will be done using a Zwicky morphological box. Populating the Zwicky box involves laying out the important parameters needed and assigning plausible values to them. Then, cross consistency analysis will be done to remove the inconsistencies. The important parameters chosen for scenario generation are as follows:

- 1) **Electricity Markets:** The nature of electricity market is an important parameter that can influence the nature of competitiveness and value for innovation.
- 2) **Energy Demand:** The demand growth and anticipated profiles are included into the scenario development process using this parameter.
- 3) **Energy Sources:** This parameter is majorly based on the assessment of renewable energy potentials and the plausible conventional energy sources. This parameter can be divided into three further categories.
 - a) **Conventional Energy Sources:** These sources are based on the existing energy sources that are being used commonly in island energy systems.
 - b) **Baseload Energy Sources:** These are the renewable energy sources that can provide a fairly constant energy output.
 - c) **Intermittent Energy Sources:** These energy sources represent the renewable energy sources that have a highly varying or fluctuating output that depends upon the meteorological conditions.
- 4) **Infrastructure Changes:** This parameter represents all the infrastructure changes that might be required to transform the existing energy systems.
- 5) **Energy Efficiency:** This parameter involves all the practices that can be used to improve the energy efficiency of the energy system. It also has its sphere of influence over the future demand.

- 6) **Storage:** This parameter shows all the possible storage options that can be integrated into the energy systems of islands
- 7) **Technological Maturity:** This parameter can be used to filter and chose the energy sources based on their technological maturity.
- 8) **Technological Costs:** This parameter represents the costs of various technologies. It can be used as a filter to make the choice of selecting various energy sources and storage options. It must not be confused with the cost of electricity generation.

The parameters and its range of values are presented in the Zwicky box in table (5.1). The total number of configurations that can be attained due to this analysis is 291,600. However, based on the visions developed and the cross-consistency analysis, three scenarios have been chosen. Some populated values will be removed to eliminate inconsistencies. Diesel, LPG and Natural Gas are included in the energy sources list as they are a representation of the Business as Usual (BAU) scenario in various island energy systems. However, they will not be considered in our scenarios as it is against our final vision. In each individual scenario developed, a modelling exercise based on Illoldi (2017) will be done to find out the cost optimal configuration of the energy mix at 100% renewable energy penetration.

Table (5.1): The Morphological Box for Scenario Development

Energy Markets	Energy Demand	Conventional Energy Sources	Baseload Energy Sources	Intermittent Energy Sources	Infrastructure	Energy Efficiency	Storage	Technological Maturity	Costs
Competitive Markets	Increase	LPG	Geothermal	Solar	Energy Monitoring Systems	Demand Side Management	Pumped Storage	High	High
Monopoly	Stable	Diesel	OTEC	CSP	Bi-directional Grid	Smart Metering	Electric Vehicles (V2G)	Medium	Medium
State Owned	Decrease	Natural Gas	OTEC-SWAC	Wind-onshore	Net Metering	Efficient Appliances	Batteries	Low	Low
			Biomass	Wind-Offshore	Distributed Generation		Hydrogen Fuels		
			Hydro		Centralized Generation				

5.3. Cross Consistency Analysis (CCA)

The cross-consistency analysis can be performed to eliminate logical and empirical inconsistencies that will help in filtering the large number of possible configurations. Together with the visions for the future, this analysis will be helpful in developing scenarios. The matrix in the table (5.2) has been developed to perform this analysis and shows the relation between various values of the parameters. The 'x' in the matrix represents the relation between the values. Energy demand and energy markets have not been shown in the cross-consistency analysis due to their independent relation with the other parameters. Only the parameters which show a higher degree of interdependent nature with other parameters have been considered. The parameter of conventional energy sources has not been considered in this analysis as it contradicts with the final vision. Based on the mapped relations, four major trends can be observed. The first trend is the relation between technological maturity and the generation technologies and storage technologies. The second trend relates the need for infrastructure changes with the introduction of each energy source. The third trend precisely indicates the need for storage in the intermittent sources. The fourth trend map indicates the comparison of costs versus the generation and storage technologies. In the technologies that were considered

here, the ones that had high maturity seemed to have lower costs. These trend maps can be helpful in pooling up similar values into scenarios. There will also be certain trade-offs between different parameters when the scenarios are being presented. These assumptions will be explicitly mentioned in the scenarios.

Table (5.2): Cross Consistency Analysis Matrix

		Maturity			Baseload					Intermittent				Infrastructure					Efficiency			Storage			
		High	Medium	Low	Geothermal	OTEC	OTEC-SWAC	Biomass	Hydro	Solar	CSP	Wind-onshore	Wind-Offshore	Energy Monitoring	Bidirectional grid	Net metering	Distributed Generation	Centralized Generation	DSM	Smart Meters	Efficient	Pumped Storage	EV (V2G)	Batteries	Hydrogen
Baseload	Geothermal	x																							
	OTEC			x																					
	SWAC			x																					
	Biomass	x																							
	Hydro	x																							
Intermittent	Solar	x																							
	CSP	x																							
	Wind-on-S	x																							
	Wind-off-S		x																						
Infrastructure	Monitoring	x					x			x	x	x	x												
	Net-meter		x							x		x													
	Bi-direction		x							x		x													
	Distributed		x			x	x	x	x	x		x													
	Centralized	x			x	x	x	x	x																
Efficiency	DSM		x							x	x	x	x				x								
	Smart Meter			x																					
	Appliances	x																							
Storage	Pumped			x						x	x	x	x	x											
	EV		x							x	x	x	x	x		x			x						
	Batteries	x								x	x	x	x	x											
	Hydrogen			x						x	x	x	x	x		x									
Costs	High					x	x						x									x			x
	Medium										x	x											x	x	
	Low							x	x	x															

5.4. Scenarios

5.4.1. Scenario 1: Solar-Wind-Hydro-Storage

This scenario takes the technological maturity into major consideration. As far as energy sources are considered, most of the intermittent energy sources have reasonable technological maturity and have been considered. In the base load category, geothermal energy has very low potential and other OTEC sources have very low maturity. The major potential for hydro energy has already been tapped and therefore will be considered in addition to the intermittent ones in the island of North Andaman. The intermittent sources require a few changes to infrastructure with most of them oriented towards distributed generation and better monitoring systems. The storage options available based on this criterion are batteries that show good technological maturity and have relatively lower costs compared to the other storage options. Even though features such as V2G and demand side management would be very ideal in this case, they have been opted out due to difficulties in implementation in the simulation model. This categorization based on technological maturity will also lead us to studying the impact of only intermittent sources in nexus with storage on the grid, energy security and cost of supply. It must be noted that the costs section in the table below, represents the costs of technologies considered but not the costs of the entire system.

Table (5.3): The Zwicky Box for Scenario 1.

Energy Markets	Energy Demand	Conventional Energy Sources	Baseload Energy Sources	Intermittent Energy Sources	Infrastructure	Energy Efficiency	Storage	Technological Maturity	Costs
Competitive Markets	Increase	LPG	Geothermal	Solar	Energy Monitoring Systems	Demand Side Management	Pumped Storage	High	High
Monopoly	Stable	Diesel	OTEC	CSP	Bi-directional Grid	Smart Metering	Electric Vehicles (V2G)	Medium	Medium
State Owned	Decrease	Natural Gas	OTEC-SWAC	Wind-onshore	Net Metering	Efficient Appliances	Batteries	Low	Low
			Biomass	Wind-Offshore	Distributed Generation		Hydrogen Fuels		
			Hydro		Centralized Generation				

5.4.2. Scenario 2: Solar-Wind-OTEC-Biomass-Hydro-Storage

This scenario is used to address the high need for storage in the first scenario. Therefore, baseload technologies such as OTEC and Biomass will be introduced to study their impact on the need for storage and supply costs despite the low technological maturity of OTEC and high costs. The inclusion of baseloads will decrease the need for storage. The rest of the parameters can be expected to be more or less the same. The values that are included in this scenario can be seen in table (5.4).

Table (5.4): The Zwicky Box for Scenario 2.

Energy Markets	Energy Demand	Conventional Energy Sources	Baseload Energy Sources	Intermittent Energy Sources	Infrastructure	Energy Efficiency	Storage	Technological Maturity	Costs
Competitive Markets	Increase	LPG	Geothermal	Solar	Energy Monitoring Systems	Demand Side Management	Pumped Storage	High	High
Monopoly	Stable	Diesel	OTEC	CSP	Bi-directional Grid	Smart Metering	Electric Vehicles (V2G)	Medium	Medium
State Owned	Decrease	Natural Gas	OTEC-SWAC	Wind-onshore	Net Metering	Efficient Appliances	Batteries	Low	Low
			Biomass	Wind-Offshore	Distributed Generation		Hydrogen Fuels		
			Hydro		Centralized Generation				

5.4.3. Scenario 3: Solar-Wind-OTEC-SWAC-Biomass-Hydro-Storage

This scenario is primarily derived from the second scenario. However, additionally energy demand has been explicitly considered in this case. Since the islands are tropical and as seen in earlier energy demand estimates, cooling demands play a significant role. Therefore, OTEC-SWAC is selected in order to directly satisfy the cooling demands without the need for electrical energy conversion. Even though it is assumed that all the heating and cooling demands are met by electricity, SWAC works as an efficient non-electrical and renewable alternative and therefore has been considered. The second scenario can be used as a reference case for this scenario and the results can be compared to find which alternative is more economically preferable. Rest of the parameters remain the same as in the case of the second scenario.

Table (5.5): The Zwicky Box for Scenario 3

Energy Markets	Energy Demand	Conventional Energy Sources	Baseload Energy Sources	Intermittent Energy Sources	Infrastructure	Energy Efficiency	Storage	Technological Maturity	Costs
Competitive Markets	Increase	LPG	Geothermal	Solar	Energy Monitoring Systems	Demand Side Management	Pumped Storage	High	High
Monopoly	Stable	Diesel	OTEC	CSP	Bi-directional Grid	Smart Metering	Electric Vehicles (V2G)	Medium	Medium
State Owned	Decrease	Natural Gas	OTEC-SWAC	Wind-onshore	Net Metering	Efficient Appliances	Batteries	Low	Low
			Biomass	Wind-Offshore	Distributed Generation		Hydrogen Fuels		
			Hydro		Centralized Generation				

5.5. Modelling

The main of the modelling exercise is to determine how the ideal desired future will look like. It will be used to find the hybrid renewable energy systems (HRES) for the future to give us

some insights into how the future energy mix can shape up. The model used here is adopted from the earlier work of Illoldi (2017) for various tropical islands. The model almost entirely runs on the software MATLAB and uses genetic algorithm to get suitable configurations for each individual island in all the three scenarios derived in the previous sub-section. In this section, a detailed introduction and description of the components of the model will be presented.

5.5.1. Model Novelty and Limitations

Most of the essential features of this model remain identical to the work of Illoldi (2017). However, to adapt the model to our backcasting study and our islands, a few additions have been made and will be discussed below.

- **Timeline:** Since the model is supposed to represent the energy mix at the end of the backcasting period, the time period of 2040 will be used. Therefore, a lot of estimations have to be made in order to estimate the future energy consumption patterns and the demand profiles.
- **Learning Rates:** In order to estimate the future costs of technologies, learning rates of technologies have been included into the model to see the changes in the energy configurations as a result of changes in future costs.
- **100% Renewable Energy:** The main vision of this study is to facilitate a 100% renewable energy transition in the Andaman and Nicobar Islands. For that reason, the conventional energy sources have not been considered in this model as opposed to the previous studies which included diesel in their energy mix.
- **Energy Sources:** In order to suit the model for this archipelago, the same energy sources used in Illoldi (2017) has not been used and the model has been modified to suit the local energy potentials.
- **EV Integration:** Since, electrification of all possible services is one of our visions, a 100% percent electric vehicle integration has been considered for both road freight and passenger transport. Due to the difficulties in data acquisition and for the sake of model simplicity, only road transport has been considered and not maritime or air transport.
- **Uncontrolled EV Charging:** The integration of electric vehicles into the demand schedule has been done based on a few research studies. These studies hint at the possibility of having an electric vehicle plugged in at a particular hour of the day. In an ideal case, controlled electric charging would be more preferable due to the flexibility from V2G technology. However, due to difficulties in integration into the model, uncontrolled charging has been considered and vehicles are just treated as a load and not a potential storage device.
- **Frequency Control:** Even though, Illoldi (2017) did employ spinning reserves to have an effective control strategy for frequency control, it has not been used in this model for the sake of model simplicity.
- **Hourly Variation:** In this model as well as in Illoldi (2017), an hourly energy system is considered and sub-hourly fluctuations are not considered. This is due to two reasons. Firstly, due to the absence of sub hourly meteorological data and secondly due to the requirement of very high computational time periods.

- **Estimation of Technological Advancements:** The technology considered for this model is based on the present-day technology and any advancements are not considered since they are complex to map. It is just assumed that the advancements have an effect on the price in the form of learning by doing and leaning by research.

5.5.2. Model Description

The figure (5.2) represents the entire structure of the model. The green blocks serve as the inputs to the model. The blue blocks represent the actual computational model and the output is represented by the yellow blocks. The various components of the model will be discussed in detail below.

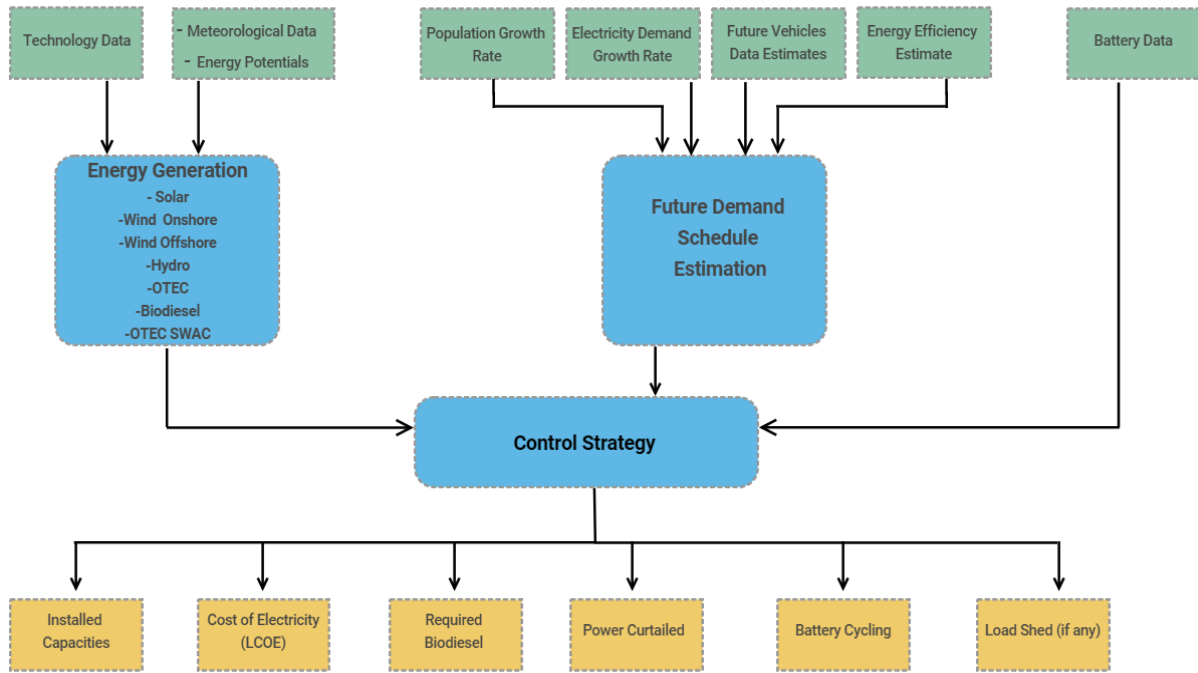


Figure (5.2): Model description diagram

5.5.2.1. Model Input

The main inputs required for the model are the meteorological data, the technology data and the future demand estimates. As far as the meteorological data is considered, the data that is used in order to calculate the energy potentials in the archipelago are used. They are shown in table (4.6).

In addition to the aforementioned inputs, the costs of technologies and their learning rates have to be sent as an input in order to estimate the future prices. The technologies selected are as follows:

- **PV:** Tata TP 260 W_p Solar Panels
- **Wind Onshore:** Vestas V110 2.0 MW
- **Wind Offshore:** Vestas V136 3.45 MW
- **OTEC:** 5 MW capacity plant
- **OTEC SWAC:** Sized based on the island demand
- **Biomass:** Sized based on the island potentials mapped

- **Hydro:** 5.25 MW plant in North Andaman
- **Battery:** Tesla utility scale ‘Powerpack’ battery (210 kW).

Costs of Technologies: The costs of technologies are very crucial as the cost of electricity will be one of the primary decision-making factor. However, since the model is set in the timeline of 2040, the costs must represent the future. Therefore, learning curves have been utilized to make approximations of the future costs of technologies. Table (5.6) summarizes the current costs of technologies, learning rates and the predicted costs. Most of the learning rates are derived from Rubin et al (2015). Based on the current prices, learning rates and the estimated cumulative installed capacities in the future, the future prices are calculated using the model in section (2.7).

Table (5.6): Costs of Technologies

Technology	Current costs (€/W)	Learning Rates	Installed Capacity by 2040 (GW)	Future Costs (€/W)
Solar	0.75	35% (Fraunhofer,2018)	2000 (IEA,2010)	0.24
Wind Onshore	1.23	21 % (Rubin et.al,2015)	1206 (IEA,2010)	0.88
Wind Offshore	3.78 (Wiser et.al,2016)	9%	366 (IEA,2010)	2.45
Hydro	1.26	1.96 %	3734	1.22
OTEC (Illoldi,2017) (Langer,2018)	12	• 6 % • 18% • 6 % • 18%	• 20% increase (p.a) = 0.66 • 30% increase (p.a) = 3.85	• 8.39 • 3.81 • 7.17 • 2.30
Bio Power	0.05	12%	158 (IEA,2012)	0.048
Biofuel	$1.2 \cdot 10^{-4}$	Null	Null	$6.72 \cdot 10^{-5}$ (€/Wh)
Battery	0.39 (€/Wh)	25% decrease in five years	Null	0.11 (€/Wh)

In the case of mature energy technologies, there were many studies such as Rubin et,al (2015) that predict the learning rates of these technologies. However, in the case of OTEC, only very few studies were found. Therefore, the thesis of Langer (2018) has been taken as a reference. This work hinted at two rates: 6% and 18%. In order to find out the future rates, the estimated cumulative installed capacity in the future has to be known. Therefore, two cases of 20% annual growth and 30% annual growth were considered based on Langer (2018) and the future costs were found out. These variable future rates will be used to find the influence of different rates of OTEC on the future energy mix and the cost of electricity generation. They will be referred to as learning cases A, B, C and D in the same order as in table (5.6). In the case of batteries, price decrease in the past years were used as a reference. IEA (2012) has hinted the potential price of biofuel production in 2040 at about 10 US dollar cents per gigajoule.

The development of demand schedule for the year 2040 is very tricky. Therefore, a lot of studies were considered and the estimations of future energy consumption and reliable demand schedule was established.

In the case of electricity, Power for all (2016) has provided with the demand growth rates for individual islands for the next few years. The growth rates varied from 3% per annum to about 15% per annum in the islands where high income growth and commercial activities are expected. These growth rates were discussed in detail towards the end of section (4.1.1). However, these projected growth rates are only until the next few years and therefore, it is assumed that the sudden spike in growth in few of the islands settles down around the year 2028 and all the islands will have more or less a standard rate of growth of about 5% per annum. 5% could be an ideal value with the assumption that the rural areas that currently have growth rates at around 3% per annum, start experiencing an economic growth much later than the urban regions and experience higher electricity demand growth rates from the year 2030. Since, energy efficiency is also one of our priority, it is assumed that the archipelago reached an annual efficiency rate 1.7% which is almost about the global average (IEA,2016). It is assumed that the archipelago attains and maintains this efficiency rate from 2022.

Taking all these factors in to consideration a final number can be established for the annual energy consumption. Since, the weather conditions are more or less same throughout the year with very few fluctuations, the daily demand for electricity can be expected to be more or less the same with small variations throughout the year. As far as daily variations are considered, the study by Chuneekar et.al (2016) has been used that puts the time varying usage of various appliance during the day for the residential sector in the South Indian state of Karnataka. Figure (5.3) indicates the same. If the cooking activity is completely electrified, the energy consumption for cooking comes down drastically due to a very high efficiency development. Indian studies that indicated the time of consumption of energy in this sector were not available and therefore a Japanese study by Yamaguchi and Shimoda (2014) that showed similar pattern has been used. For the other sectors such as commercial, agriculture, industry etc rough approximations have been made based on the usual hours of working or energy consumption.

As far as transport is considered, The current data puts the growth rate of vehicles at 8.99% per annum. In similar lines to the electricity case, this high growth rate is estimated to fizzle out by the year 2025 and reach an average rate of 4.7%. In order to calculate the final demand, the kilometres travelled per capita and the population are required. Reports hint at a population growth of 6.38% per annum in the archipelago. ADB (2007) puts the potential growth rate of passenger transport in terms of kilometres travelled per capita at about 4% per annum based on the data from Indian mainland. Based on the current energy intensity of various electric vehicles a final estimate of the passenger transport sector can be found out. In the case of freight, the growth rate is about 3% per annum compared to the 4% per annum in passenger transport (ADB, 2007). In order to convert this annual demand figure into a daily demand schedule for passenger transport, studies such as SmartGrid (2014), eARC (2016) have been helpful in identifying the probability of having an electric vehicle plugged into the grid at a particular hour of the day. Figure (5.4) shows that the probability of charging the electric vehicles can be the highest during midday and extends until evening. In the case of freight, no such data exists as electric vehicles have not yet diffused in this type of transport. However,

laws in India only permit large freight trucks to enter the city limits from 10PM to 7 AM or 8 PM to 7 AM depending on the city for traffic purposes. Therefore, it is assumed that they charge their trucks in the day time from 9AM to 5PM when they are not carrying out any other essentials.

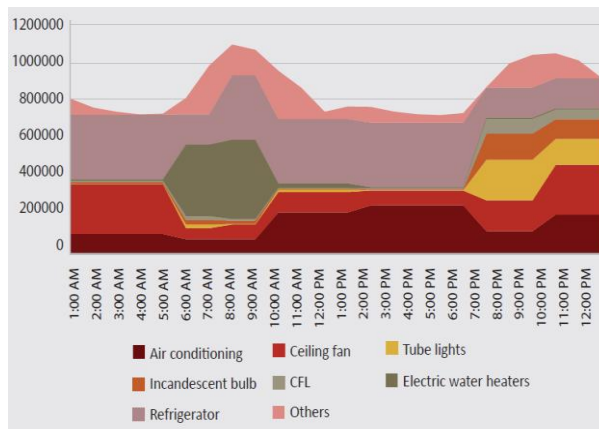


Figure (5.3): Time varying usage of appliances for the residential sector (Chunekar et.al,2016)

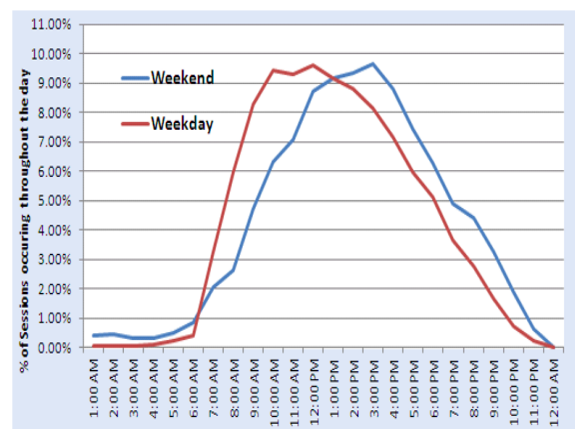


Figure (5.4): Electric Vehicle charging probability (SmartGrid,2014)

After incorporating the above-mentioned growth rates, proposed rate of energy efficiency and population increase, the final annual energy consumption by the year 2040 increased to 7 PJ from the current 4.4 PJ. The passenger and freight road transport electric vehicles together consume about 3 PJ annually. The main energy savings occurred due to the switch to electricity for cooking which brought down the annual consumption of this activity from 1.8 PJ to 0.1 PJ. Considering the aforementioned patterns of consumption, the final demand schedule for the island of Middle Andaman can be seen in figure (5.5). The demand variation for other islands can be seen in the figure (5.6).

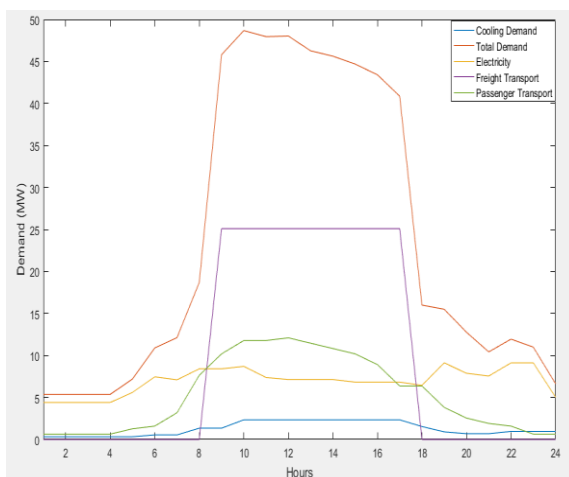


Figure (5.5): Demand Schedule for Middle Andaman

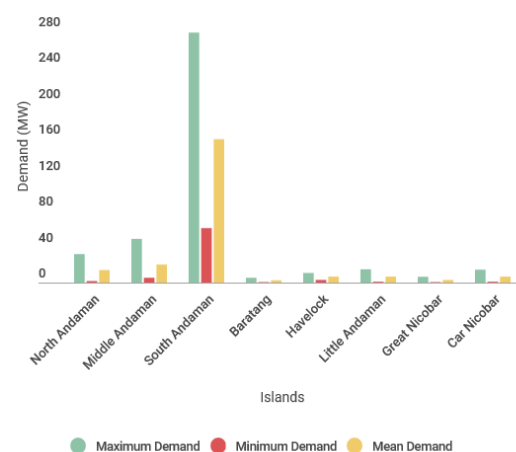


Figure (5.6): Demand Variations for the Islands

5.5.2.1. Control Strategy

The control strategy gets the data from the inputs mentioned above and it performs the computing operations that are needed to get the required results. Two control strategies have been used in this modelling exercise. One control strategy for the first scenario and the other for scenarios 2 and 3. This is due to the absence of some energy sources in scenario 1 from those of scenario 2 and 3. They are shown in figures (5.7) and (5.8).

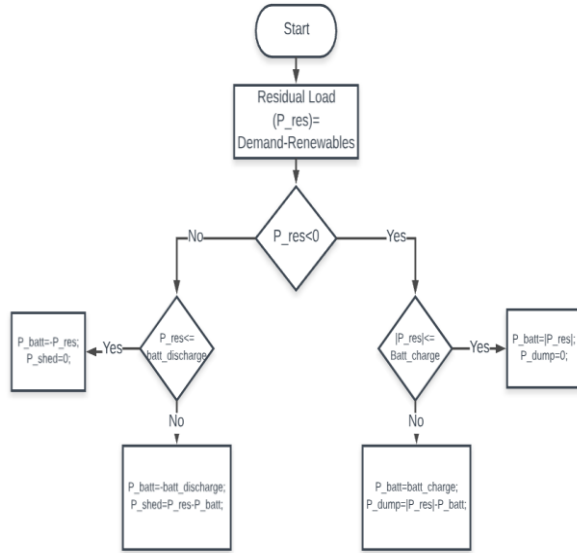


Figure (5.7): Control Strategy for Scenario 1

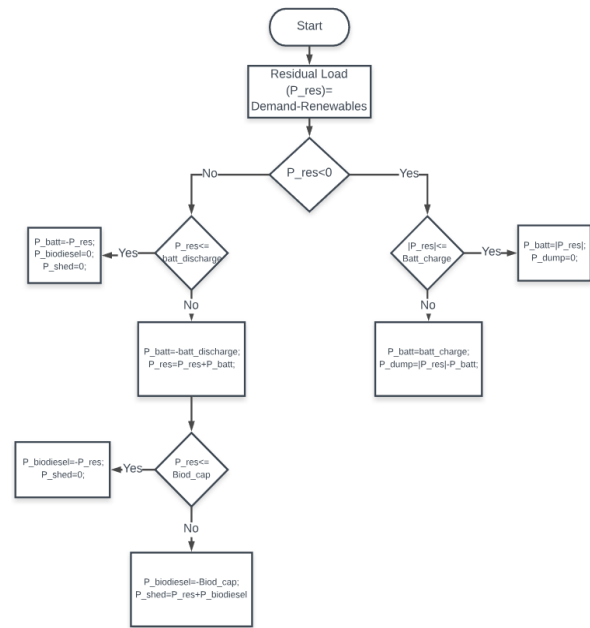


Figure (5.8): Control Strategy for Scenarios 2&3

5.6. Model Optimization

In order to derive the hybrid renewable energy mix configurations, an optimization model is needed that can optimize our results based on our requirements and preferences. One such optimizing technique is the Multiple-objective optimization method using genetic algorithm (GA) where the objective essentially represents our preferences.

5.6.1. Key Concepts and Optimization Methodology.

Multiple-Objective Optimization: Whenever multiple objectives are being used for the optimization process, they could be in conflict with each other, thereby making it impossible to optimize with respect to only a single objective. In such a case multiple objective optimization can be helpful as it tries to minimize the objectives to the extent possible and deliver non-dominated solutions that are said to be Pareto optimal. These solutions could be potentially infinite leading to a Pareto optimal set (Konak et.al, 2006).

Genetic Algorithm: Genetic algorithm is essentially inspired from the evolutionist theory explaining the origin of species. It works on the principle that the stronger and fitter species have greater opportunity to pass on their genes and in the long run with the correct combination can be the dominant species. In the same way, it is applied on multiple-objective problems in

order to find very diverse range of non-dominated solution set for difficult problems (Konak et.al, 2006).

Non-Dominated Sorting Algorithm 2 (NSGA 2): This is a kind of genetic algorithm that employs an elitist non-dominated sorting genetic algorithm. This algorithm was found to have a better spread of diverse solutions and better convergence compared to its counterparts (Debet.al, 2002). In this method, an initial creation function randomly creates a set of solutions within the specified bounds known as the population. Each solution essentially represents a chromosome. These populations are then subjected to crossover, that leads to newer populations. These are further subjected to a fitness test based on the objective functions and eventually lead to fitter populations (Konak et.al, 2006).The selection of the fittest chromosomes occurs based on the selection function. This process of crossover continues until the maximum number of generation or iterations specified is reached.

Considering the advantages, this algorithm has been employed in our case to perform the sorting approach to find an ideal energy mix based on our specified objective functions. This method has been applied using the gamultiobj solver in MATLAB. The same methods have been used in Illoldi (2017) and several other studies as well. Some of the parameters that have been used are specified below in table (5.7) in Appendix (A7).

5.6.2. Objective Functions

The objective functions will be used as a parameter to test the evolving population and create fitter population. In our model three optimization functions have been used. They are the cost of electricity, the amount of potential load shedding and the amount of power being dumped by the energy system. Using the minimization function of the genetic algorithm, the sorting process tries to keep these values as low as possible.

Cost of electricity generation: Levelized cost of electricity (LCOE) is usually used as the parameter that represents the cost of electricity generation. LCOE is the ratio of the total cost of installing and operating a power generating plant or system to the total power generated throughout the lifetime of the system. When the entire system is considered, levelized cost of system (LCOS) is used. This puts the units of LCOE at price per unit of power produced. The entire lifetime of the system is assumed to be 20 years and the batteries last 5 years each. The power generating plants are all assumed to be installed in the first year and the costs for the rest of the years would be only operational costs (except for batteries).

$$LCOS = \frac{\sum_{t=1}^{t_{LT}} \frac{\sum_{j=1}^{NT} I_{t,j} + O\&M_{t,j} + F_{t,j}}{(1+i)^t}}{\sum_{t=1}^{t_{LT}} \frac{E_d}{(1+i)^t}}$$

Where,

LCOS= Levelized cost of electricity (€/KWh)

$I_{t,j}$ = Investment of technology j in year t (€)

$O\&M_{t,j}$ = Operation and maintenance of technology j in year t (€)

$F_{t,j}$ = Fuel costs for technology j in year t (€)

i= discount rate

E_d = Energy Demand for year t

LT= lifetime

NT=number of technologies

Load shedding: This objective function is a measure of the amount of load that had to be shed as a result of a perfect match between demand and supply. Even though the mismatch between demand and supply is considered as load shed, in the real world it would mean that this gap would be filled up by the use of traditional fuels such as diesel. Since, diesel is not considered at all in our study, it is assumed that the mismatched demand is shed. Energy security is one of the main visions of this study. Therefore, this objective will be given the highest priority.

Power Curtailed: This function represents the amount of energy generated that could not be both utilized or stored. This function is used to minimize this curtailment and to keep the system sizing as optimum as possible without oversizing it.

Table (5.7): Variables and objective functions used for different scenarios

Rounds	Scenario 1	Scenario 2	Scenario 3
Round 1	- Number of Variables = 5 - Maximum Generations = 150 - Objective Functions = Load Shed, Power dumped	- Number of Variables = 7 - Maximum Generations = 150 - Objective Functions = Load Shed, Power dumped	- Number of Variable = 8 - Maximum Generations =150 - Objective Functions = Load Shed, Power dumped
Round 2	- Number of Variable = 5 - Maximum Generations =100 - Objective Functions = Cost, Load Shed	- Number of Variable = 7 - Maximum Generations =100 - Objective Functions = Cost, Load Shed	- Number of Variable = 8 - Maximum Generations =100 - Objective Functions = Cost, Power dumped
Round 3	Null	Null	- Number of Variable = 8 - Maximum Generations =100 - Objective Functions = Cost, Load Shed

Table (5.7) represents the variables and objective functions used in the three scenarios. The rounds in the table represent the number of times the solver was run in MATLAB. Multiple rounds were used since all three objective functions are used to optimize the model. However, they are done differently in each scenario. Table (5.8) represents the summary of all the cases used in the modelling.

Table (5.8): Summary of cases used for modelling

Cases	Energy Source	OTEC learning
Case 1	Solar-Wind Onshore-Wind Offshore-Hydro-Battery	Null
Case 2 A	Solar-Wind Onshore-Wind Offshore-Hydro-OTEC-Biomass-Battery	20% growth, 6% learning
Case 2 B	Solar-Wind Onshore-Wind Offshore-Hydro-OTEC-Biomass-Battery	20% growth, 18% learning
Case 2 C	Solar-Wind Onshore-Wind Offshore-Hydro-OTEC-Biomass-Battery	30% growth, 6% learning
Case 2 D	Solar-Wind Onshore-Wind Offshore-Hydro-OTEC-Biomass-Battery	30% growth, 18% learning
Case 3 A	Solar-Wind Onshore-Wind Offshore-Hydro-OTEC-OTEC-SWAC-Biomass-Battery	20% growth, 6% learning
Case 3 B	Solar-Wind Onshore-Wind Offshore-Hydro-OTEC-OTEC SWAC-Biomass-Battery	20% growth, 18% learning
Case 3 C	Solar-Wind Onshore-Wind Offshore-Hydro-OTEC-OTEC SWAC-Biomass-Battery	30% growth, 6% learning
Case 3 D	Solar-Wind Onshore-Wind Offshore-Hydro-OTEC-OTEC SWAC-Biomass-Battery	30% growth, 18% learning

5.7. Model Results and Discussion

In this section, the results of the modelling exercise for the cases seen in table (5.8) will be presented. Later on, a brief discussion follows that compares the results of all the cases.

5.7.1. Scenario 1: Solar-Wind Onshore-Wind Offshore-Hydro-Battery

In this scenario, all the islands use intermittent energy sources only with the exception of the island of North Andaman, which has an existing small hydro power plant. This plant is used as a controllable source that runs whenever required. This exception provides with the opportunity to compare costs and storage required for an intermittent energy system and an energy system with some form of base load technology. Figure (5.9) shows the graph indicating the relative installed capacities of power generating sources for all the islands developed based on the modelling results.

The dominant source used is solar energy. Onshore wind also had significant shares in all the islands except for North Andaman where it's share is replaced by hydro power. Offshore wind had very small capacities in a few islands only. This is due to it's high investment costs. In all the cases the installed capacities and annual yields are well under the assessed potential for those islands with the exception of South Andaman. The high demand in this island requires large amounts of wind energy and the onshore wind capacity comes alarmingly close to it's maximum potential.

Due to the high amount of intermittent energy sources, large batteries are necessary. In order to put the sizing of the battery into perspective, days of autonomy is used. Days of autonomy essentially represents the number of days the battery can power these islands by itself. The days of autonomy ranged from a maximum of about two and half days to a minimum of half a day. The average days of autonomy for all the islands is slightly lesser than two days. The minimum

has been observed in the case of North Andaman, where a small base load already exists thereby decreasing the need for a large battery pack.

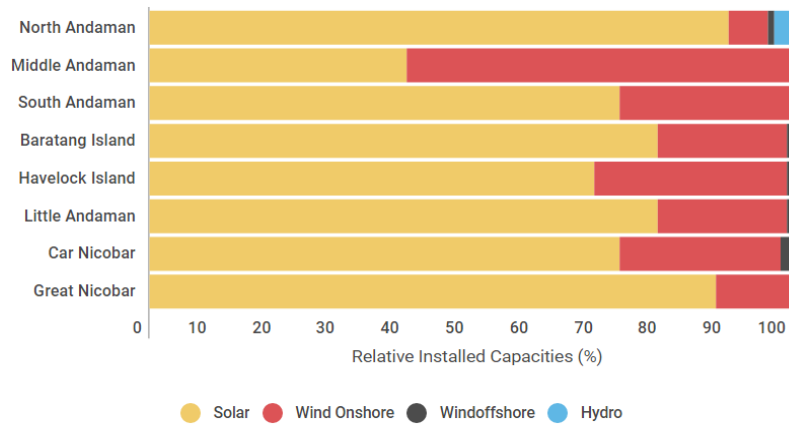


Figure (5.8): Relative Installed Capacities for Scenario 1

Even though in all the islands load shedding is not observed, large amounts of power curtailment were present. In order to put the amount of power curtailed into perspective, it is compared with the annual demand of that individual island. The curtailed power ranged from a minimum of about 45% of annual demand to a maximum of 150% of the annual demand.

The islands show a huge variation in their daily demand variation as well. For example, the island of North Andaman almost shows a factor of thirty difference in the maximum and minimum demand. Therefore, in order to deal with these fluctuations and to have zero load shedding, large overcapacities of energy sources were needed. The average overcapacities needed were almost 5 times the maximum demand of the concerned islands. When large scale intermittent sources are deployed onto highly fluctuating demands high power curtailment is inevitable. It is interesting to note that the maximum power dumping is seen in the island of North Andaman where a small baseload technology exists. The inclusion of hydro power for the island of North Andaman resulted in a decrease of the battery capacity required thereby further increasing the power dumped.

The main cost influencing factor in this case is the size of the battery. The islands that had higher days of autonomy such as Havelock Island and Middle Andaman show a higher cost of electricity generation and can be seen in figure (5.10). The island of North Andaman has the smallest days of autonomy and also the lowest cost of electricity generation. Even though the cost of electricity generation in this scenario is quite high, they are still cheaper than the current price of electricity generation which is about 32 Euro cents per kWh making these systems financially feasible. The total investment cost required in the year 2040 would be around 2.2 billion euros (2040 Euro). However, high further investments must be made multiple times to replace the battery packs which usually last for a few years only. The capital cost of infrastructure changes needed for this scenario is not included in the costs estimated here.

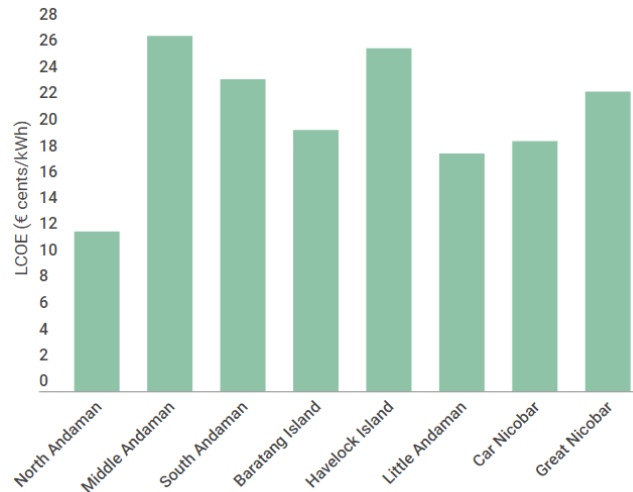


Figure (5.10): LCOE for islands in Scenario 1

5.7.2. Scenario 2: Solar-Wind Onshore-Wind Offshore-Hydro-Biomass-OTEC-Battery

In this scenario, base load technologies are added to the existing intermittent sources and the resulting energy mix is found out. The biomass potential assessed in the previous chapter has been used as an upper limit in the model. The scenario is further classified into four cases (A, B, C, D) based on the different market growth and learning rates of OTEC as seen in table (5.6). Case A represents the most expensive case, case D represents the most economical case and case C is slightly more expensive than case B. The Case D has costs slightly lower than that of off-shore wind power as well (can vary based on the learning rates and cumulative installed capacities in the future of both the technologies). In the following figures, the energy mix found out for each case in all the islands is presented.

On comparison with scenario 1, if the energy mix is considered, the share of solar and wind energy decreases on a large scale due to the diffusion of OTEC and biomass. Large decrease in the overcapacities were observed. Even in the most expensive scenario A, the base loads accounted to almost 50% of the installed capacity in most of the islands with the exception of Little Andaman and Baratang. The share of baseloads is much higher in the other cases. The installed capacities of baseloads were usually slightly higher than the mean demand for the island and the intermittent sources together with the battery were used to supply the spikes during the day. This trend also depended on the biomass potential for the individual islands.

The influence of biomass potentials on the energy mix can be seen in the islands of Car Nicobar and Great Nicobar. These islands have low demands and high biomass potential, thereby needing lesser amount of OTEC. Therefore, the influence of future costs of OTEC in all the cases had only a small influence on the resultant energy mix of these two islands. The island of Baratang has a low demand and a low biomass potential as well. Therefore, it has shown a more stronger reaction to the future costs, as OTEC is the only base load technology feasible there. In the cases B and D, where the learning rates were higher, the entire energy mix of this island was shared by biomass and OTEC along with some battery storage. The influence of biomass potential on the bigger islands such as North Andaman, Middle Andaman and South Andaman was limited due to their relatively larger energy demands.

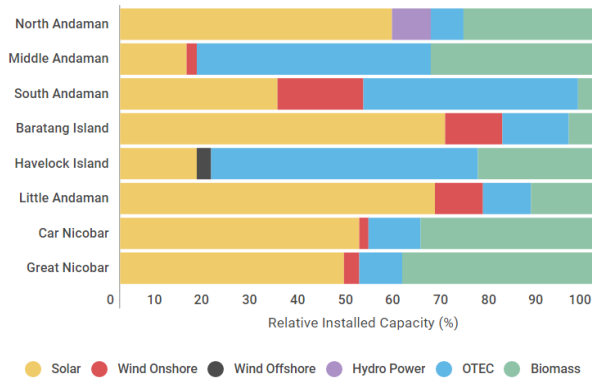


Figure (5.11): Relative Installed Capacities for Case A

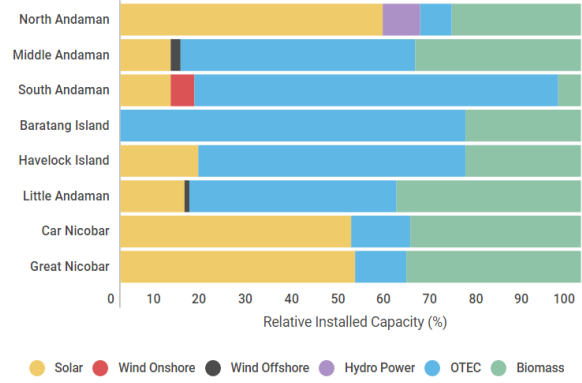


Figure (5.12): Relative Installed Capacities for Case B

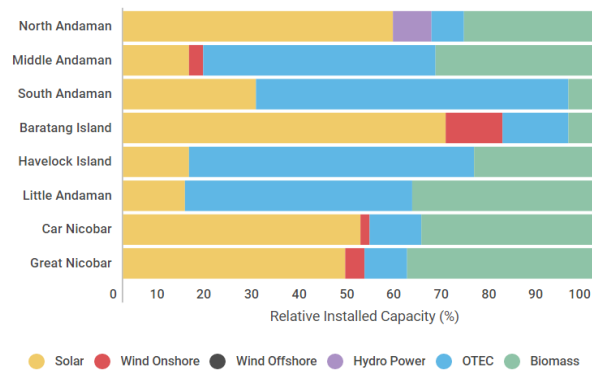


Figure (5.13): Relative Installed Capacities for Case C

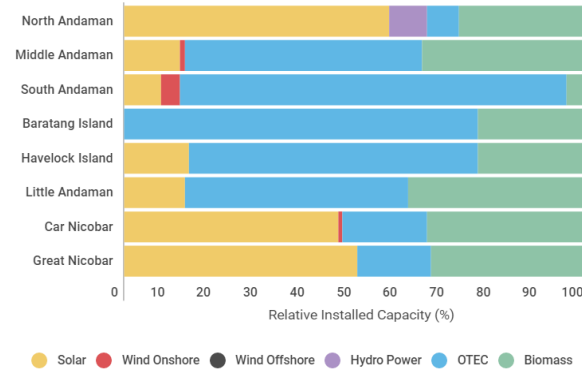


Figure (5.14): Relative Installed Capacities for Case D

In the case of North Andaman, the presence of hydro power reduced the dependence on the amount of OTEC needed. Therefore, these islands did not show a large variation in energy mix due to OTEC price changes. The hydro power was used as a controllable source in the model and the capacity factor of hydro power ranged in between 25-30%. In the case of South Andaman which has the highest energy demand, the requirement for OTEC was quite high. This is due to the insufficient potential of biomass and to eliminate the need for larger batteries. This can be seen in the comparison of energy mix for cases A and C where even a small change in the future price of OTEC triggered a large change in the energy mix. In the economical cases of B and D, OTEC completely dominates the energy mix in this island.

The battery storage required in these islands was much lesser than in the intermittent scenario. The maximum days of autonomy observed in this scenario was about half a day as opposed to two days in the previous scenario. From the relative installed capacities, it can be seen that the amount of OTEC used increased with the decrease in future costs. But a strong co-relation between the increasing OTEC capacity and the amount of storage cannot be drawn. This could be because the battery storage has been optimized to reduce the load shed and also the power curtailed, making it complex to predict the amount of storage required. The power dumped was also relatively quite low when compared to the previous case. In most cases, the power dumped was under 10% of the annual demand of the respective islands. Figure (5.14) represents the resultant levelized costs of electricity for all the islands in each of the cases. These costs are lesser than in the previous scenario due to the absence of large batteries. The main cost deciding factor is the amount of OTEC used. The relatively lower amounts of OTEC

used in North Andaman, Car Nicobar and Great Nicobar has made the cost of electricity generation in these islands lower and also had a lower response to the changes in the future costs of OTEC. The total cost of investment for the entire archipelago ranges between a maximum of 2 billion euros in the most expensive case to a minimum of 760 million euros in case D. It must be noted that the investment costs estimated are based on the estimated costs of these technologies in the year 2040.

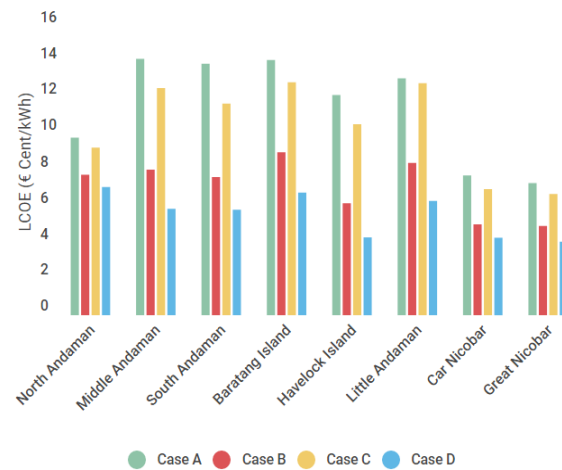


Figure (5.15): Resultant LCOE for all the cases

5.7.3. Scenario 3: Solar-Wind Onshore-Wind Offshore-Hydro-Biomass-OTEC-SWAC-Battery

In this scenario, the specific cooling demands in the islands have been considered. The energy sources used will remain the same as in the case of scenario 2 with the addition of sea water air conditioning (SWAC) configuration for OTEC plants. These SWAC systems can work in parallel with an OTEC plant to satisfy the cooling demands. SWAC can more efficiently deal with the cooling demands. Therefore, in this scenario, the electrified demand would be slightly lower than in the other scenarios. The main aim of this scenario is to check the influence of SWAC on the energy mix (especially OTEC), battery and the final sizing. The following figures represent the resultant energy mix configuration for all the islands and cases.

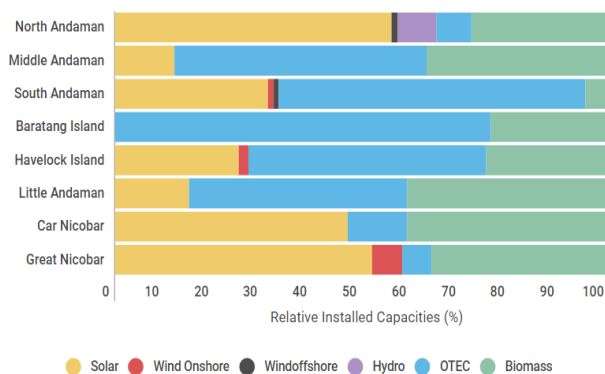


Figure (5.16): Relative Installed Capacities for Case A

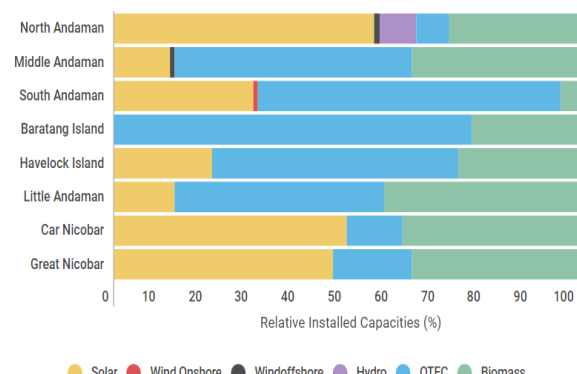


Figure (5.17): Relative Installed Capacities for Case B

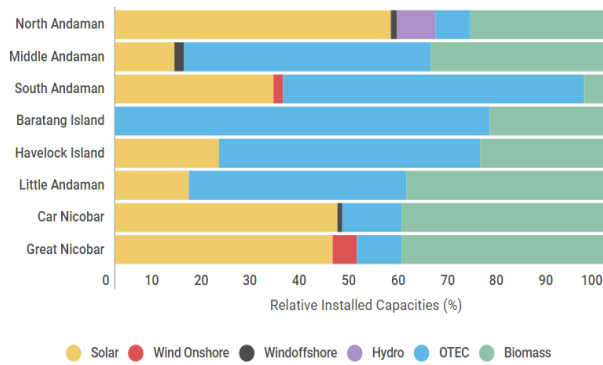


Figure (5.18): Relative Installed Capacities for Case C

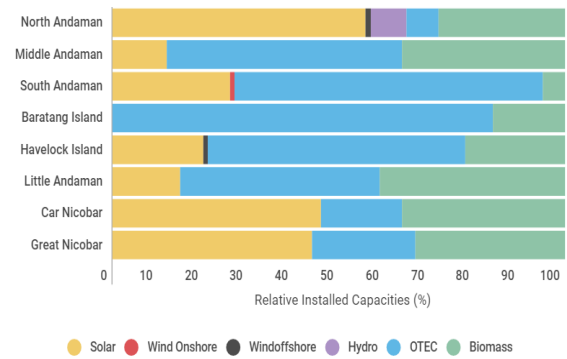


Figure (5.19): Relative Installed Capacities for Case D

The installed capacities of OTEC for all the cases were similar to the ones in scenario 2 except in the case of Baratang island. The usage of SWAC had a positive effect on the overall installed capacity of OTEC. There seemed to be a slight economic profitability in this case which overcame the need for solar energy even in the most expensive case. The reduced demands due to SWAC had a positive effect on the installation of OTEC and higher amounts of OTEC were installed even in the expensive cases. The positive effect of having SWAC was seen in the installed capacities of the batteries. The battery storage required was slightly lower than scenario 2. The days of autonomy for all the islands were more or less the same as in scenario 2. This addition reduced the amount of power being curtailed. It was observed that the amount of biomass being used in this scenario was higher than the usage in scenario 2. The cost of electricity generation was also lower in scenario 3 than in the previous scenario. This small change in the costs could be due to the decrease in energy demand and decrease in the amount of battery storage needed. Figure (5.19) shows the cost of electricity generation in all the cases for this scenario. The installation costs for the year 2040 ranges between a minimum of 700 million euros and a maximum cost that is slightly lower than 2 billion euros.

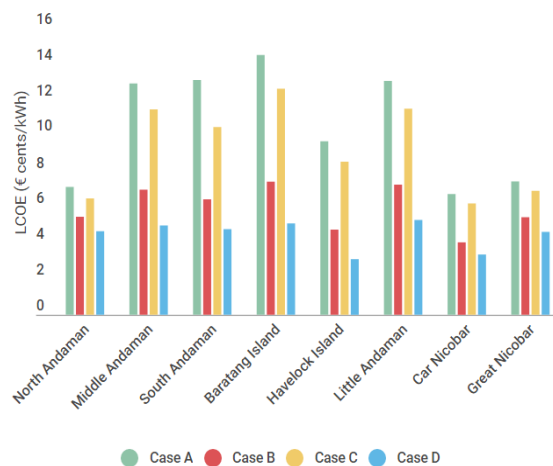


Figure (5.20): Resultant LCOE for all the cases

5.7.4. Comparison of Scenarios and Discussion

In the first scenario, high amounts of battery storage and large overcapacities were necessary to have zero load shedding. This resulted in very high amount of power curtailment that was in the range of 45-150% of the annual demand of the respective islands. Earlier studies such as Illoldi (2017) or Gioutsos et.al (2018) had similar overcapacities in such an intermittent system. Despite the power curtailment being high in our scenario, they are still lesser than in the previous studies. This could be because the batteries in the future would be much cheaper than the current prices making it feasible to have much larger batteries which leads to higher contribution of batteries in the energy system and can reduce the curtailment to an extent. Additionally, since most of the islands are solar dominated, the production of solar energy coincided with the high demand during the day time due to EV integration reducing the power curtailed. However, the effect of solar production and demand coincidence on power dump might be limited due to large overcapacities. On a cost front, for the first scenario, subsidies might still be needed since these costs do not come close to the cost of electricity supply even though they are lesser than the cost of electricity generation (except North Andaman).

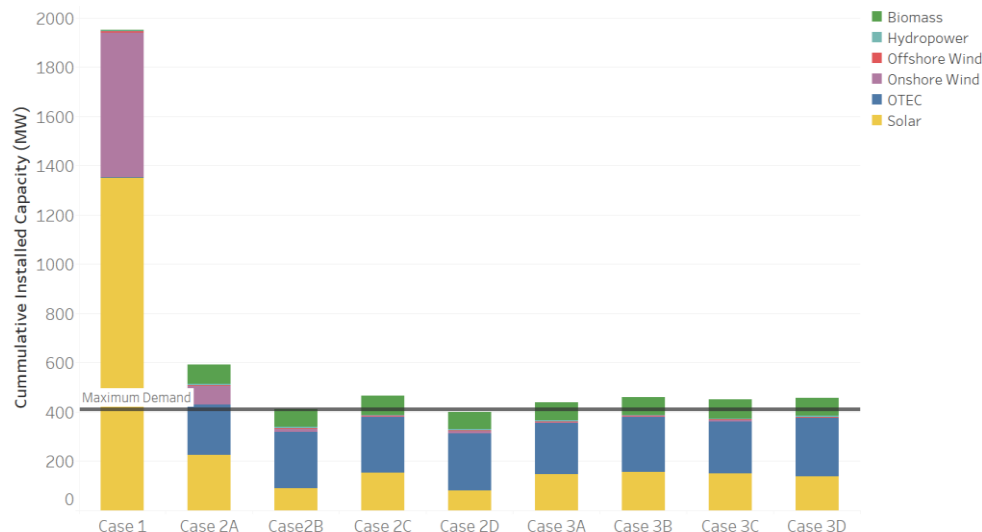


Figure (5.21): Cumulative Installed Capacities in all the cases (own illustration)

The addition of baseloads largely reduced the overcapacities and power curtailment as seen in figure (5.21). The power dumped is lesser than 10% in most cases. The islands that had relatively lower bioenergy potential had a higher dependence on OTEC and showed high fluctuations with change in learning rates. In both scenario 2 and 3, in cases where the learning rate of OTEC was 18%, the cost of generation was near the current subsidized cost of electricity supply thereby eliminating the need for any subsidy. In the cases where the learning rates were 6% for OTEC, the costs were lesser but still slightly more expensive than the cost of electricity supply. The costs in scenario 3 were slightly lower than in scenario 2 due to reduced demand and increased bioenergy utilization. The islands that had high bioenergy potential and low demands such as Car Nicobar and Great Nicobar had much lower costs of electricity generation irrespective of OTEC learning rates.

Chapter 6: Backcasting Analysis

In this chapter, the steps 3,4,5 of backcasting analysis are presented. As discussed in the methodological framework, the backcasting steps 4,5 have been merged.. Essentially, the step 3 represents the identification of changes and defining the necessary interventions required using the What-Who-How analysis mentioned in Quist (2016). The unified step deals with the identification of possible transitional pathways and an implementation timeline. The step 3 is performed for each of the scenarios. Based on the results found in chapter 5 and the identified interventions, specific scenarios will be developed for every individual island. Later, transition pathways and implementation timeline will be devised for the entire archipelago considering the scenarios selected.

6.1. Backcasting for Intermittent Scenario (Scenario 1)

In this analysis, interventions and necessary changes required in the technological, cultural-behaviour, organizational, institutional and structural aspects of the current energy landscape in the archipelago will be discussed. ‘What-How-Who’ analysis will be used to as a tool to identify these changes.

Technological Change:

What: In order to attain the futures derived in chapter 5, there needs to be numerous disruptive technological changes. Large scale changes can be seen across the entire energy system in terms of energy sources, infrastructure and the kind of fuels used. The cumulative installed capacity in 2040 for this scenario is expected to be almost 18 times the present capacity of 109 MW. Almost 12 GWh of battery storage capacity is required. A total of 471,000 electric vehicles are expected to replace the current internal combustion engines. The entire archipelago reduces their energy consumption for cooking by a factor of 15 by switching to electricity as their source for cooking. Overall, the entire energy system will be largely based upon electricity.

How: This subsection deals with the necessary changes and interventions. Eight major technological interventions that are deemed necessary for the transition have been identified.

Diesel Phaseout: A majority of the diesel generators have outlived their lifetime of 20 years, after which they have frequent breakdowns and have higher specific diesel consumption making the generation costs even more expensive. The data from Power for all (2016) shows that the entire diesel capacity in Havelock Island, Great Nicobar, Little Andaman and Baratang Island have outlived their lifetimes. In the rest of the islands, around half of the current generation capacity is quite old. Therefore, these aged generators have to be completely phased out or can be used as reserve capacity based on their fitness. In the four islands that need immediate action, high scale deployment of solar and onshore wind is necessary in the initial stages itself. This deployment can be in the tune of 60% of the peak demands to replace the obsolete generation. At this level of penetration, the required amount of storage will also be much lesser. Since the government is currently developing LPG terminals, LPG based systems can supplement these renewable energy systems by providing some stability and reducing the need for large scale storage in the initial stages itself.

Monitoring Systems: The islands currently lack proper energy and power monitoring system leading to frequent voltage fluctuations and power outages. These monitoring systems are much more crucial with the integration of fluctuating generation to perform balancing activities, manage peak demands, maximize efficiency and increase system reliability. These systems are essential in managing storage systems and discharging them immediately whenever necessary.

Forecasting: Better weather forecasting and yield prediction systems are necessary in this scenario due to the high fluctuations in the power system. These improved forecasting systems can help in managing the demands and generations better. They are crucial in planning proper reserve capacity without which either under or over investments can occur.

Distribution Losses: The current rate of transmission losses must be reduced to the optimum rate of 5% on par with global standards by making infrastructure changes at the distribution level, correcting the large power factor losses and replacing defective meters. The current high losses result in overinvestment of generation capacity and overloads the power lines which ultimately leads to failures and power cuts.

Bidirectional Flows: The current distribution systems have to be upgraded to facilitate both import and export of energy and export energy meters have to be provided to every household. This is essential in developing distributed generation systems and is necessary to increase the prosumer activity.

Grid Integration: The standalone systems in the islands of North Andaman, Middle Andaman, Baratang Island and South Andaman can be integrated to provide more resilience to fluctuations in the system since these fluctuations are spread out over a larger region. This kind of integration is not possible in the rest of the islands since they are spread out and far from each other.

EV Charging Infrastructure: Even though the majority of the electric vehicles anticipated in the future are two wheelers which can be plugged into regular power sockets, charging station are required for road freight (trucks etc) which have a much higher power rating. Large number of charging stations are not necessary as the typical distances covered are usually small and range anxiety might not be a huge issue. Therefore, optimum sites on the main freight and long-range passenger routes can be identified to set up few charging stations.

Efficient Cooktops: In other underdeveloped regions in India, where traditional fuels are common for cooking, electric cooktops even though provided for free were not adopted by the local people since most of the cooktops have a rating of about 1 kW which is quite high for the kind of power supply available in these rural areas. Additionally, lack of reliable power supply has also been a deterrent for a wider adoption. Therefore, to completely electrify cooking, a reliable electricity supply along with efficient electric cooktops that require low wattage are required. Such low wattage cooktops can also work in tandem with a nominal solar panel making it more feasible in the rural areas.

Who: The main responsibility of planning the implementation of these changes would lie with the Ministry of Power (MoP). MoP will have to develop targets for the replacement of old

diesel generators and replacement with renewable and LPG generation. This will occur in tandem with Ministry of New and Renewable Energy (MNRE) for renewables and National Thermal Power Corporation Limited (NTPC) for LPG based generation. MoP in consultation with Power Grid Corporation India Limited (PGCIL) would be responsible for the development of Monitoring Systems and the upgradation of the current grid. The main implementing agency for all these agencies is the electricity department of Andaman and Nicobar Islands (EDA&N). This agency will also co-ordinate with the private sector to facilitate investments in generation. Energy Efficiency Services Limited (EESL) is the primary implementation agency for activities related to steering the cooking practices towards electricity and promoting integration of EVs.

Consumer-Behavior Changes:

What: This sub-section represents the consumer behaviour changes that are required to adopt to this transition. Currently, the consumers are not completely involved in the energy landscape. The consumers will witness a wide range of changes in the electricity markets, consumption patterns and energy sources. They are expected to be active in the energy system and adopt efficient technologies and practices.

How: The three main interventions in the consumer behaviour are as follows

Energy Efficiency: Most of the present energy efficiency measures are focussed on lighting. However, to reach the target of efficiency rate of 1.7% per annum from the year 2022, this has to spread to other appliances as well. The aim is to push for the desired efficiency through policy by raising building standards and appliances ratings. They need to comply with these new standards and must be encouraged to invest in these efficient appliances.

Adapting to the Transition: Both EVs and electric cooktops are usually characterized by high upfront costs and relatively lower maintenance. The high upfront costs are often a deterrent for the adaptation. Therefore, there is a need for better financial models and incentives. The role of the consumers would be to take advantage of these benefits offered and facilitate higher integration of EVs and cleaner cooking rather than sticking to the conventional practices. Additionally, taking up the role of prosumers will also be beneficial for both the consumer and the overall transition.

Freeriding and Theft: Often malpractices such as theft of electricity from the distribution lines are noticed leading to high losses. This also causes an overload on the distribution lines leading to failures and power cuts in a few instances. Therefore, consumers must not be involved in such activities.

Who: Energy Efficiency Services Limited (EESL) is responsible for revising the building standards and appliance standards. Through EESL, MoP will provide the required financial assistance to support these programs. NGOs, educational institutes and civil societies are essential in encouraging the consumers to adopt to the changes.

Institutional Changes:

What: This subsection represents the changes required from the institutional side primarily with respect to regulation and policies that aid this transition. A concrete policy framework and financial incentives have to be developed to speed up the flow of investments into the energy

system of the archipelago. The sources of investments can range from large corporations to households living with very low incomes that adopt newer technologies.

How: Seven major institutional interventions have been identified.

Efficient Land Use: According to the estimates made, the required land area for energy generation is quite high but well under the available land area. However, this land demand is in direct competition with land required for other economic development activities. Since, most of the islands are solar energy dominated, alternatives such as rooftop and floating solar can be explored. In the case of rooftop, leasing models can be adopted to have a bigger reach.

Rural Integration: As mentioned earlier, large scale diffusion of renewables is anticipated in the initial stages itself. In this period, it would be ideal to push for higher renewable energy integration in the rural areas also. This can solve the issue of unreliable supply of electricity in these regions. Investments in energy generation from the local rural communities can be encouraged using financial models such as joint liability group micro finance schemes that offer loans at low interest rates and no collateral. These schemes can stimulate economic growth in the rural regions that are otherwise largely dependent on agriculture or fishing. This can also eventually lead to a positive snowball effect on the adoption of EVs and clean cooking.

Green Tourism: Tourism is expected to grow at a high pace and will be one of the major sources of economic growth in the islands. Popular destinations such as Havelock Island and few other places in South Andaman can be developed as green tourism zones. This could attract more tourist influx, economic growth and also provide with incentives to have higher local investments in energy technologies from businesses. This will also reduce the influence of economic activities on the local ecology.

Feed in Tariff (FiT): The proper implementation of feed in tariff schemes can result in a higher investor safety and confidence. Different tariffs can be used for various sources of generation and the size of capacity of the plant. This latter will reduce the effect of economics of scale and make small scale generation such as rooftop solar economically attractive. The digression of tariffs has to be predetermined for a few years in order to reduce the perceived investor risk. In order to fix the tariffs at optimum levels, the current competitive bidding method can be used.

Storage Subsidy: The main cost influencing factor will be storage and most of the storage installation will be expected to be in the latter stage of the implementation period. The capital subsidies provided for generation sources will have to be reduced as they become cost effective and can be shifted to the storage devices to get in investments into storage. Regulatory committees have to be established for storage as in the case of electricity to develop optimum tariffs for energy capacity. Alternatively, investments in generation and storage hybrid plants have to be encouraged with high combined tariffs.

EV Incentives: If the current electric two wheelers available are considered, most of them are cost competitive with combustion engine vehicles but have much lesser performance. Economic incentives can be used as a tool to have high uptake of electric two wheelers until they catch up technologically. The main incentives used in countries like Norway are VAT exemption, annual tax exemptions and other benefits such as free parking and access to bus lanes (Kempton, 2014). In this case, VAT exemption and annual tax exemptions could be the most crucial incentives. In the case of LMVs and trucks, purchase cost subsidy must also be

provided in addition to the other incentives since they are quite expensive and not very cost effective yet.

Financial Models for Cooking: In rural areas and low-income regions, switching to electric in the initial stages itself would be difficult due to reasons mentioned in the technological changes. Therefore, LPG has to be used as a transitional fuel. In the low-income households, the investment costs for the purchase costs of LPG cylinders could be quite high making the shift to modern fuels difficult. Therefore, newer financial models such as ‘pay per use’ can be used for LPG in order to amortize the high initial costs over a period of time making it affordable for everyone. Later subsidized and technically viable electric cooktops can be provided.

Who: The administration of the Andaman and Nicobar Islands has to develop green tourism zones. MoP will work with supporting agencies to provide the required financial assistance and policy development. In the case of rural electrification, the supporting agencies would be Rural Electrification Corporation (REC) and MNRE. Joint Electricity Regulatory Commission (JERC) would be responsible for setting the optimum FiT through competitive bidding. As mentioned earlier EESL will be the main organization responsible for the promotion of EVs and clean cooking.

Structural Changes:

What: This subsection deals with the changes required in the current energy system. Major upgradation is required in the structure of the energy markets in the archipelago. They are currently run almost entirely by public monopolies. Restructuring of electricity markets must occur to promote economic efficiency in the market.

How: The major change required here is to shift to a price-signal based system rather than a volume-based system. This would make the market more responsive to the fluctuations in the energy system. Competition (especially in generation) has to be introduced through liberalization of the markets in order to promote economic efficiency and the incumbent public monopoly has to recede slowly by giving priority to the private sector. Public monopoly will continue to exist in the transmission and distribution activities.

Who: The major stakeholder for market restructuring is the MoP and Central Electricity Regulatory Commission (CERC).

Organizational Changes:

What: This section essentially represents the governmental changes necessary to improve the free flow of investments from the private sector into the energy system. Presently, there are a few roadblocks that are hindering such a flow and need to be addressed.

How: Two major interventions are needed in order to have a better flow of investments

Single Window Clearances: Currently, there exist a large amount of bureaucratic procedures that are a huge hassle and lead to a long lead times in private investments. All those procedures can be replaced by single window clearances to make the investment procedure easier for the private sector.

Delayed Payments: There have been issues regarding delays in payments for power purchase agreements making the investors skeptical in investing. Similar issues have been observed across the country and has a direct effect on investor safety.

Who: The main implementational organization would be the local administration of EDA&N to undertake these changes.

6.2. Backcasting for Base-load Scenario (Scenario 2)

As seen in the modelling results in the previous section, the addition of baseload technology had a positive effect on the cumulative installed capacities and the battery sizing. Most of the interventions identified for the previous scenario stands valid here as well. Although, the degree of some of the changes needed might vary. The common changes in both the scenarios are the development of monitoring systems, bi-directional flows, energy efficiency, feed in tariffs and the incentives for the growth of EVs. The interventions such as storage subsidy and financial models for LPG based cooking are not necessary in this scenario. The main kind of additional changes necessary are technological changes, institutional changes and consumer-behavior changes. The organizational and structural changes are the same for both the cases.

Technological Changes

What: There is a lot of variation in both the scenarios technologically. The fluctuations are largely eased in this scenario due to OTEC and Biodiesel. There is no need for overcapacities and the required battery capacity falls by a factor of 10. Nevertheless, this scenario depends largely on the development of OTEC. The interventions in transport sector remain the same from the previous scenario. The inclusion of bioenergy helps in directly leapfrogging to electricity as a cooking option and skipping LPG altogether.

How: Six major technological changes are necessary in addition to the ones mentioned in the previous scenario.

OTEC Zones: Within the exclusive economic zones available, offshore and onshore sites that show maximum potential for OTEC have to be identified. While identifying the sites, legal aspects, environmental safety, shipping routes and naval activity have to be considered. Higher preference must be given to onshore sites since they are usually less expensive.

Pilot Projects: Small scale pilot projects have to be developed. These projects will be crucial in assessing the technical feasibility of having OTEC plants in energy generation and will also serve as demonstration projects that can be used to attract further private investments. Both onshore and offshore projects have to be developed for this purpose due to a difference in the costs between onshore and offshore.

Grid Integration: Although this change has been mentioned in the previous scenario, it serves an important role in this scenario. The integration of the grids of North Andaman, Middle Andaman, South Andaman and Baratang Island can help in the development of OTEC plants that are larger than 100 MW and have better economic profitability. This advantage will be largely seen in the case of Baratang which only needs an OTEC plant in a few megawatt range.

By-product Utilization: Even though in this study, only the potential from bioenergy from coconuts and nuts have been considered, it can be extended to other agricultural residues as

well. The entire supply chain of the agri-based industries can be tapped to have a higher potential for bioenergy.

Efficient Generators: Most of the islands show a high utilization of bioenergy in their energy mix. Therefore, it is necessary to increase the efficiency of the electricity generators so as to have lower consumptions and emissions.

Efficient Biomass Cooktops: In the rural areas, the economically backward population need not switch to LPG as a transitional fuel. Instead, traditional solid biomass can be used in improved forced draft or natural draft cookers that have much lesser emissions and losses.

Who: Site identification assessments for OTEC will be done with the help of research institutes. Institutes such as Indian Institute of Technology in Chennai have performed such assessments throughout the country and also in the archipelago. MNRE will have to facilitate the implementation of OTEC pilot projects and higher utilization of bioenergy. MoP on consultation with PGCIL and EDA&N will have to undertake the integration of the grid. EESL will have to provide the new improved cookstoves for the rural areas.

Consumer-Behavior Changes

What: Most of the essential changes have been dealt with in the previous scenario. The additional changes in cultural-behavior patterns would be seen in adapting their practices for the development of bioenergy development.

How: The major change required is in the form of active participation in the rural areas, farming community and the agricultural industry community in order to collect the by-products throughout the supply chain of the agricultural sector and provide the feedstock for bioenergy generation.

Who: The main responsibility here lies with civil societies, public administration and Non-government organizations in creating awareness and knowledge among consumers.

Institutional Changes

What: The main institutional changes necessary in this case is to create a platform for the growth of OTEC and Bioenergy technologies in the archipelago. This requires improvement in technology, implementation of supportive policies and the development of investor confidence.

How: Five major interventions have been identified in addition to the ones developed in scenario 1 and are as follows

Framework for OTEC: A detailed legal, regulatory and policy framework has to be established for OTEC across the country to send a clear signal to the market. Currently, there has been some discussion regarding financial help to ocean energies but, no concrete framework has been laid out.

Research and Development: The implementation of this scenario largely depends upon the development of OTEC globally. A funding program has to be established to empower research institutes such as IIT for the research on technology, cost cuttings and development of OTEC pilot projects.

Feed-in Premiums: In the case of OTEC, designing a high feed in premium could attract a larger amount of private investments due to a higher rate of return. Large capital subsidies for this technology could be difficult considering the high upfront costs of OTEC and therefore, the benefits can be amortized in the form of premiums. These premiums can be classified on the basis of the size of the plant since larger plants show better economic viability.

Feedstock Procurement: In the agriculture sector and related industries, payment systems have to be developed to incentivize the collection of different kind of by-products by the farming community. This could incentivize the farmers and industries to provide the feedstock and develop an additional revenue stream.

Leapfrogging in Cooking: In the previous scenario, LPG had to be used as a transitional fuel for cooking in the eventual universal shift to electricity. However, in this scenario, traditional biomass can be used in tandem with improved forced draft cookers without making a switch to LPG in the case of rural and economically backward areas. LPG will still continue to exist in the urban areas that can afford them. The new cooktops can be provided at subsidized rates and would be more economical in the rural areas. Later, a direct leapfrog to electric cooktops can be done using incentives as in the first scenario.

Who: The most influential body in implementing these changes would be MNRE (except for changes in cooking). The local EDA&N will act as an implementing body as mentioned earlier. EESL will be responsible in dealing with the interventions required in the cooking practices

6.3. Backcasting for Base-load and Cooling Scenario (Scenario 3)

The modelling results do not show a large variation between the scenarios 2 and 3 since the only difference is the usage of SWAC. The addition of SWAC to the system shows a slight economic dominance over the second scenario due to higher efficiency in dealing with the cooling demands of the Islands. Since SWAC can work in parallel with OTEC and the majority of the generation sources are the same, only the changes that are not discussed in scenario 2 are discussed here. The necessary changes for this scenario are mostly technical. Therefore, all the changes are presented together.

What: The SWAC technology provides the required cooling at almost 10-20% of the conventional cooling load. This increase in efficiency consequently decreases the total energy demand and has a positive effect on the cost of electricity generation and the overall installed capacities. The implementation of SWAC needs dramatic changes in infrastructure and the way in which the current cooling systems work.

How: Six major changes are necessary for the implementation of SWAC and are as follows

Distribution Systems: Cold deep-sea water is drawn using OTEC-SWAC plants and used to chill fresh water. This fresh water is used as the cooling agent in the buildings and need to be distributed to the buildings which requires district cooling systems. These systems are not used in the archipelago and therefore large investments are required in the archipelago for the development of such infrastructure. Technical codes and standards for such cooling systems also have to be developed.

Updating Current Buildings: The current buildings only use conventional cooling systems and need to update themselves to the district cooling systems based on the standards and codes developed. The new developers must adopt these practices in their future projects.

Load Planning: The cooling loads in various urban regions throughout the archipelago must be studied and the future growth should also be factored in. These estimates decide the size of the SWAC plant, the amount of cold water needed and the electricity output from the hybrid plant.

Urban Planners: Urban or City planners need to design the distribution systems based on the cooling loads and population densities. These systems can be economically viable in places with high density population due to economies of scale. Zones that show profitability for the development of such systems must be identified.

Demo-projects: As in the case of OTEC, demo projects with SWAC configuration as well must be developed. Wherever SWAC generation is involved, it would be ideal to develop onshore plants since the cold water only has to be transported for short distances and is less expensive.

Tariffs: An optimum tariff structure has to be developed for the cooling services. Two kinds of tariff schemes can be developed. One tariff for metered usage of cooling services and the other will be an amortized payment for development of SWAC capacity.

Who: The responsibility of implementation and development of SWAC and district cooling systems lie on a range of actors. There are no clear agencies across the country that has been dealing with district cooling directly. EESL had shown some interest in developing such pilot projects. MNRE will be responsible for the implementation of OTEC-SWAC plants. The role of local municipalities is quite high in identifying viable zones and the designing of the district cooling system. As far as cooling tariffs are concerned, no relevant actor has been found. Regulatory commission on the lines on JERC that decides the electricity tariffs have to be developed for cooling.

6.4. Scenario Selection

In the previous sections, the necessary changes and interventions for each of the scenarios have been identified. In this section, the most practical scenarios for individual islands will be chosen.

Although scenario 1 uses mature technologies, the presence of high amounts of intermittency needs large generation capacity and large amounts of investments in infrastructure upgradation. Due to the presence of large amounts of overcapacities and the need for large amounts of storage, the costs of electricity generation in islands such as Middle Andaman and Havelock Island are quite close to the current costs of electricity generation. These costs will be much higher if the investments in infrastructure development are factored in. Additionally, in case the present costs of electricity supply falls to the levels of the year 2013, then the first scenario becomes totally unviable. These electricity costs need to be subsidized further to make it affordable to the consumers. Therefore, the high costs involved make it undesirable for any of the islands.

Compared to scenario 1, scenario 2 can offer a relatively stabilized electricity system and lower costs. The inclusion of bioenergy had a high impact on the final energy mix configurations and costs especially in the Nicobar Islands. The final cost of electricity generation largely depends upon the learning rate and global uptake of OTEC. Even in most expensive case, the costs are lower than scenario 1. The infrastructure changes needed are also relatively lower. Overall, these additions make this scenario a very favorable choice.

Scenario 3 has a small addition to scenario 2 in terms of technologies considered. The addition of SWAC increases efficiency and decreases the costs further. However, these cost cuttings come at the expense of higher requirement for infrastructure development (cold water distribution systems). The technical feasibility of universal usage of SWAC is doubtful. This makes the application of SWAC constricted although it has lower costs of generation. Table (6.1) shows the scenarios selected for each of the islands.

The majority of the islands can adopt scenario 2 while few of the locations identified in the islands of Middle Andaman, South Andaman and Havelock can adopt scenario 3. North Andaman displays some chances of employing scenario 1 due to its low costs, but the inevitable high amount of power curtailment makes it undesirable. The scenarios chosen here for the islands will be used to develop an implementation timeline for the whole transition.

Table (6.1): Scenario Selection for Islands.

Islands	Scenario 1	Scenario 2	Scenario 3
North Andaman	✗	✓	✗
Middle Andaman	✗	✗	✓
South Andaman	✗	✗	✓
Baratang Island	✗	✓	✗
Havelock Island	✗	✗	✓
Little Andaman	✗	✓	✗
Car Nicobar	✗	✓	✗
Great Nicobar	✗	✓	✗

6.5. Creation of Implementation Timelines (Step 4)

In this section, transition pathways and an implantation timeline will be developed for the entire archipelago based on the scenarios chosen for individual islands in table (6.1). A timeline of activities will be presented based on the changes identified using the ‘What-Who-How’ analysis in the previous sections. The implementation strategy is planned until the year 2040 and can be agglomerated into three phases.

The first phase lasts from the current year of 2018 until 2025. This phase is easily the most important phase in the transition. A wide range of activities like development of a strong policy framework, infrastructure upgradation and a high renewable energy diffusion will be witnessed in this phase. This phase will mark the initial integration of EVs into the grid. Universal clean cooking can be achieved during this phase.

The second phase lasts from the year of 2025 until 2032. During this phase a steady growth of investments, especially in medium sized OTEC plants will be seen. The global learning rates of OTEC start getting clearer. Utility scale battery storage projects will be developed during this period. Complete diffusion of electric two wheelers and decent progress in light motor vehicle segment can be anticipated in this phase. It has been envisioned that by the end of this phase, electricity becomes the preferred cooking option throughout the archipelago.

The third phase lasts from 2032 until the end point 2040. This phase will observe the growth a large sized OTEC plants and the cost decrease in OTEC until this period will have a huge influence on this development. A full scale integration of electric LMVs and trucks will be observed.

An undercurrent research and revision step will always exist to create improved targets based on technological advancements or cost changes. A further detailed discussion on each of the stages are as follows.

Phase one (2018-2025): The first steps in this stage will have to be oriented towards establishing a concrete energy policy for the archipelago. Supporting schemes such as feed in tariffs, tax incentives, single window clearances, EV incentives and microfinance options for rural areas must be implemented immediately. Simultaneously, infrastructure changes such as bi-directional flows and monitoring systems must be done. The distribution losses have to be dealt with by revamping the electricity meters and distribution equipment wherever needed. It must be made sure that the losses fall to the desire level of 5% by the end of this phase. Similarly, through the upgradation of appliance ratings, the desired rate of 1.7% annual efficiency increase can be achieved by the year 2022. It might be necessary for the archipelago to have its own appliance standards and regulations as implementing such changes for the whole country in a short span of time would be difficult.

For the development of OTEC, sites that show high potential and feasibility must be identified. The legal and policy framework necessary for OTEC must be established. Since SWAC can be developed parallelly with OTEC, the locations in the islands of Middle Andaman, South Andaman and Havelock Islands are both economically and technically viable for the implementation of district cooling systems must be identified by the local municipalities. The cooling loads and consumption patterns have to be studied in these locations and a detailed roadmap for district cooling systems has to be developed. The current building codes and regulations must be updated to suit the new cooling systems and the new constructions must comply these codes. A regulatory commission must be formed to oversee the cooling tariffs. For the development of bioenergy, the incentives supporting feedstock procurement must be declared immediately. The population in the rural areas must be educated about the new microfinance schemes to get them interested in investing in biofuel production and bioenergy generation systems.

In order to establish clear a timeline of activities for individual islands, the islands can be divided into two clusters. The first cluster represents the scattered islands namely Havelock Islands, Little Andaman, Car Nicobar and Great Nicobar. The second cluster represents the rest of the islands that are quite close to each other and can have a unified grid.

In the case of the scattered islands, with the exception of Car Nicobar, all of the islands need replacement of the entire capacity. Biomass based generation can be developed in all of the

four islands with immediate effect. These islands have high biomass potential and therefore such a generation can be ramped up at a rapid pace. Additionally for the development of OTEC, pilot demonstration projects have to be established. These pilots (both onshore and offshore) can be used to persuade private companies and investors to invest in OTEC by providing them with some insights about the economic and technical feasibility. These small scale OTEC pilots can be developed for these small islands since their maximum amount of OTEC required is in the range of a few megawatts itself. The presence of resorts and tourist activity in Havelock islands makes it an ideal place to implement OTEC-SWAC hybrid pilot projects. The implementation of SWAC pilot can be initially done to satisfy the cooling demands of a few resorts initially which can be spread to the rest of the locations in the subsequent phases. Using these OTEC plants and biomass based energy generation, the current old diesel based generation can be replaced. These diesel generators can be used as reserve capacity based on their fitness. Overall, in these scattered islands, a renewable energy coverage of about 75% can be attained by the end of this phase. Diesel generators are expected to power the remaining 25% and it might be necessary to invest in some diesel generation for this purpose. It must be noted that the coverage levels mentioned here correspond to the kind of demands anticipated during this phase and not the final demand.

In the rest of the islands, a similar strategy can be applied for the diffusion of bioenergy. Large scale solar energy and bioenergy will be added to the energy mix of these islands. However, in the case of Baratang Island, investments in diesel generation must also be made since the entire present diesel generation is quite old and the future energy largely depends upon OTEC due to low potential for biomass. In rest of the islands, around 50% of the diesel capacity is functional. Almost zero OTEC diffusion can be expected for these four islands during this phase since most of the OTEC investments in this phase are concentrated in the scattered islands. Overall, using solar and bioenergy, 40% renewable energy coverage can be attained in these islands with the exception of South Andaman. It is difficult to attain this in South Andaman due to the large demand in this island and the heavy dependence on OTEC. Considering this implementation timeline, it would be ideal for the government to scrap its idea of developing LPG terminals.

In the early periods of this phase, pilot projects on electric buses can be developed in the urban regions as in the case of other Indian cities and then a full scale diffusion of electric buses into the public transport systems can be expected by the end of this phase. In the case of electric two-wheelers, they still underperform in both cost and performance when compared to internal combustion engines. Therefore, EV incentives that were discussed in the interventions must be setup to make these vehicles attractive. Together with the technological advancements that can be expected, by the year 2025, 20% diffusion of electric two wheelers in sales can be expected. The diffusion of electric LMVs will be low in the range of 5% due to their relatively high costs. No diffusion of electric trucks can be expected. This puts the overall diffusion level at around 15% in this phase.

In the case of cooking, awareness has to be created in the rural areas regarding the ill-effects of the usage of traditional fuels in the current state for cooking. Therefore, subsidized improved cooktops must be provided to all the houses using firewood as a source and can attain universal access to clean cooking can be attained by the end of this phase. The term 'clean cooking' here is used in terms of health effects and not in terms of energy source used.

Overall, this period is a capital intensive period with a decent flow of investments into the archipelago and witnesses a large number of changes in a short span itself.

Phase two (2025-2032): The infrastructure and policy developments in the first phase continue reaping benefits in this stage. During this period, the learning rates of OTEC start getting clear and can be predicted. Based on these predicted learning rates and their corresponding final energy mix, the required improvements for distributional capacity can be made (if high amounts of solar is anticipated).

This phase will witness the development of medium sized OTEC plants (in the range of 25 MW). The power grids of North Andaman, Middle Andaman, Baratang Island and South Andaman will be integrated by the year 2027. This is done to with the aim of agglomerating the small OTEC capacities needed for North Andaman and Baratang Islands with the large capacities needed for South Andaman and Middle Andaman. This is advantageous economically since the larger plants have the advantage of economies of scale. Therefore, the OTEC installation in Middle Andaman and South Andaman will also serve North Andaman and Baratang. Storage and solar energy can be ramped up to match the demand growth as a result of higher EV diffusion. In these islands that are a part of the unified grid, the renewable energy coverage can grow upto 60% of peak demand. Diesel capacity has to be managed to supply the remaining 40%.

In the case of the scattered islands, the coverage levels remain at 75% since no further investments in OTEC have been made in these islands and the increasing demands are counterbalanced by the increase in solar, wind and storage. Based on the experience gained in SWAC in the pilot project in Havelock, cold water distribution systems will have to be developed for the urban areas in the island and SWAC plant can then scaled up to satisfy the cooling demands of the entire island. In order to embrace these changes, the local households and businesses in the island will have to update their buildings to suit the new cooling systems. The developments in this phase will help in attaining a 24 by 7 reliable access to energy supply throughout the archipelago. The usage of microfinance schemes in the rural areas can help in ensuring a reliable energy supply in the rural areas.

In the case of transport, by the end of this period a 100% diffusion of electric two wheelers can be anticipated. The incentives for two wheelers can be reduced in the initial stages of this study itself as they become cost-effective. This can be diverted towards LMVs. 3 out of every 4 cars can be electric cars by the end of this phase due to the incentives offered and possibility of development of economic cars. The decision to ban the sales of diesel cars by the year 2030 will be a helpful factor as well. In the case of trucks, conventional fuels will continue to be the norm despite small scale diffusion. This puts the overall EV diffusion rate at about 80%.

In the case of cooking, the availability of reliable energy supply can be a benefit. The development of economical and efficient electric cooktops can facilitate a leapfrog from biomass based cookstoves to electrified cooktops in the rural areas and achieve universal electrified cooking.

Phase Three (2032-2040): By this phase, the learning rates, market growth and future prices of OTEC will become clear. Large scale OTEC plant must be developed for the unified grid (especially for the island of South Andaman). This plant will be in the order of 100MW. The decrease in OTEC costs as a result of learning will make the plants of this size viable. Similarly

small sized OTEC plants will be developed in the scattered islands to match the increased demands in these islands as a result of higher EV diffusion.

In the islands of South and Middle Andaman, the existing buildings will be updated to match the new cooling systems. SWAC plants will be developed along with the large OTEC plants. Cold water distribution systems will be developed in the urban areas of these two islands such as Port-Blair and Ferrargunj. In all the islands, the diesel generation present will be used as reserve capacity only.

The full-scale diffusion of electric LMVs is expected to finish by the year 2035. In the initial stage of this phase, the supporting infrastructure needed for road freight will be developed. The diffusion of electric trucks is expected to peak in the last five years eventually leading to a universal diffusion by the year 2040. The schematic representation of the implementation timeline can be seen in figure (6.1). This figure highlights the key activities and the targets during the entire transition.

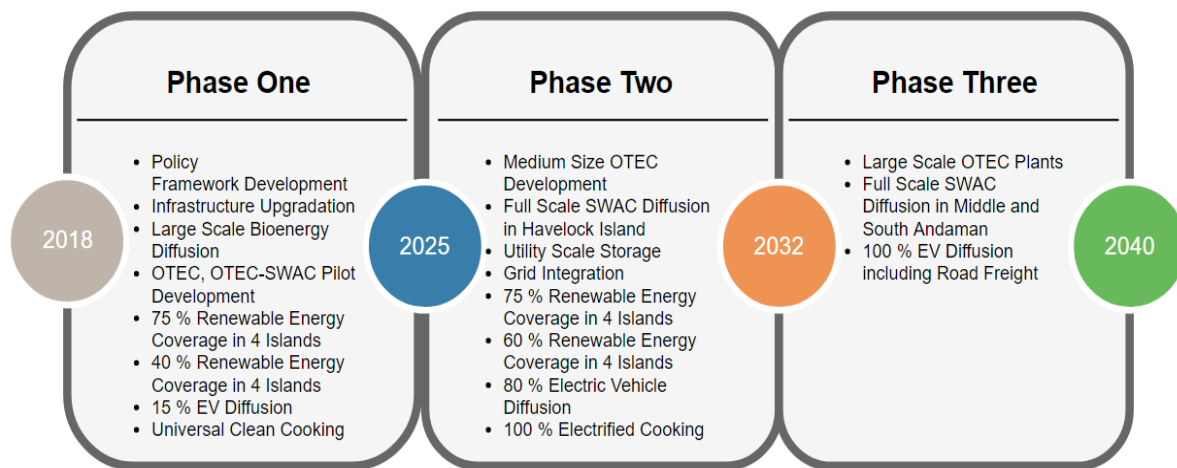


Figure (6.1): Implementation Timeline of the transition (Own illustration)

Chapter 7: Discussion and Reflections

In this chapter, reflections on the entire research work will be presented. The main themes of the discussion on the research will be oriented towards addressing the limitations of the study, review the validity of the results and evaluate the methodological framework.

7.1. Limitations

In this thesis, a backcasting analysis on the Andaman and Nicobar Islands has been performed and detailed transitional pathways have been drawn for the islands. A unique combination of topics has been explored in order to develop concrete pathways.

Nevertheless, this thesis has its own share of shortcomings. The main shortcoming can be the usage of a non-participatory backcasting methodology. Despite, the Quist framework being a participative backcasting methodology, it has been not performed due to technical limitations and the difficulties in identifying and accessing different range of stakeholders within the archipelago. Therefore, stakeholder perspectives and opinions have not been considered and a top-down approach has been used in drafting the visions, scenarios and transitional pathways. If participative methods have been used, perhaps much more relevant and suitable pathways could have been developed.

The second shortcoming is the presence of large data voids. Large number of estimates have been done in order to fill these voids and it can be said that this thesis partially fills these voids. However, the presence of accurate data could have made the analysis much more precise. This issue is strongly observed in the case of non-electricity energy demands. In this thesis, only the main sectors and activities have been considered to make an estimate on the final energy consumption. These estimates only represent a subset of a larger consumption. Overall, it can be said that lack of concrete and reliable data has made this analysis slightly vague.

The third shortcoming comes in regarding the scenarios developed and the optimization model used. As seen in the results, it can be seen that the intermittent scenario (scenario 1) developed is not preferable for any of the islands. However, if elements such as controlled charging for EV have been integrated into the model, the results of this optimization model could have been much better. This has not been added to the model due to the issue regarding large computational time period requirement. Even though the presence of a small baseload in nexus with intermittent sources has been tested out in the island of North Andaman, testing out small baseloads such as biomass together with intermittent sources could have possibly led to interesting results.

The forth shortcoming of the study is using an hourly timescale for the model. Even though the model tries to present with accurate sizing, these might be different in reality when a sub-hourly basis is used and can potentially also change the entire optimization system.

7.2. Validity of Results

The results from the model have led to some interesting outcomes. These results can be compared to the results from past studies such as Illoldi (2017) and Gioutsos (2018). In these studies, it was observed that most of the optimal configurations have been observed in the 30%-

70% renewable energy integration range and a strong cost increase has not be observed until 50% integration.

However, in the case of this study, the whole model is set up in a different timeframe distorting the costs of technologies and optimal configurations. Due to the accounted cost decrease in technologies, the cost optimal configurations observed in the past studies have been pushed further. In the intermittent scenario, until the 85-90% renewable energy integration range, the cost were relatively low. The need for overcapacities and large batteries increases in this range making the whole systems highly expensive in this range. The observed power curtailment at 100% integration was also much lesser due to the availability of cheaper batteries.

In the case of the other two scenarios, the end configurations are largely dependent upon the global development of OTEC. There were similarities from Illoldi (2017) in terms of OTEC . However, the usage of multiple OTEC leaning rates and market growth rates has took these results further and the differential uptake of OTEC has been analyzed with respect to it's global trajectory. All of the islands employed sizable amounts of OTEC in their energy mix even in the most expensive case. But, there is a lot of ambiguity over the global development of OTEC. The transitional pathways developed in this study will become invalid if OTEC does not have at least 6% learning rate and an annual market growth rate of 20%.

This brings up the question of 'what if OTEC does not show the kind of growth that has been expected in this study?'. As seen in the results, some kind of sizable baseload technology is absolutely necessary. In the smaller islands, biomass functions as a strong baseload technology. The OTEC capacity needed can be filled with additional solar, onshore wind and storage capacity. Moreover, there is always the possibility of increasing the biomass capacity by procuring a wider range of feedstocks and the treatment of domestic wastes for biofuel production. Furthermore, mini and small hydro plants can also be developed for small streams in the islands.

The main issue arises in the case of the bigger islands such as South Andaman and Middle Andaman which have higher demands and a strong dependence on OTEC. OTEC plant in the range of 100-150 MW is required for the island of South Andaman. These capacities cannot be replaced by biomass plants or mini hydro plants. In case OTEC growth is not as expected, then the other option would be to go for the intermittent sources together with biomass and storage. For the intermittent scenario, during optimization, it has been observed that the need for large overcapacities and storage starts from around 85-90% renewable energy coverage. Therefore, intermittent sources can be used to achieve around 85% of coverage together with storage and the remaining 15% has to be covered by some form of baseload. Newer technologies such as hydrogen fuels can also be explored in the future based on the global development of these technologies.

Based on the results produced in this study and the identified shortcomings, the following recommendations can be made for further studies.

- It can be challenging to integrate both the participative methods of backcasting and the optimization model used in a single study considering a the time limitations. But, if an approach can be developed to fit both these aspects, it could lead to more holistic transitional pathways.

- On the other hand, the integration of vehicle to grid technology, optimization model based on Illoldi (2017) and learning rates in a single model can lead to better results as well.
- During the identification of interventions, few financial incentives and models have been briefly mentioned. A participative study that can combine backcasting with a detailed evaluation of such financial models can also lead to better pathways. Such an evaluation on financial incentives is even more crucial in the developing world.
- Additionally, it would be ideal to use this kind of methodology on locations that have good amount of data available in order to make the analysis holistic and get a clear understanding of the current energy situation.

7.3. Reflections on Methodology

Firstly, the setting of this study itself is unique and brings in value to the study. The Andaman and Nicobar archipelago represents the developing world with large infrastructure backwardness and an underdeveloped rural economy. Therefore, in order for a complete transition to occur in such a place, first the technology and infrastructure of the islands has to catch up with that of the developed world. This process of catching up can be seen clearly in the transitional pathways developed. Furthermore, these kind of studies on the developing world can be of great value and can potentially aid them in leapfrogging towards sustainability. This has been one of the motivation for choosing this particular archipelago. Nevertheless, a downside observed with these place is the lack of large amounts of data which constraints the overall study. The usage of this methodology on an entire archipelago has also been interesting. In this thesis, even though the socio-political aspects of the individual islands are the same, the identity of individual islands has not been lost as their technological and geographical conditions have been taken into consideration and pathways have been drafted accordingly.

Secondly, the lack of proper data brought up the need to work on a detailed consumption mapping analysis. This has done by observing the major activities in the islands and make estimations regarding their consumption patterns based on various suitable international and domestic indicators. It would be ideal to have concrete data sources for this kind of a methodology as it paints a better picture of the current energy situation and reduces the amount of speculation.

Thirdly, the quick scan backcasting study from Agarwala (2017) has been used as a basis for this study and this thesis succeeds in advancing the quick scan backcast. This advancement can be in divided into two stages. The first addition would be the integration of the optimization model based on Illoldi (2017) into this framework to give more developed and detailed future scenarios. The second stage of addition would be the usage of such an optimization model in the future timeline. This presents with an opportunity to develop demand schedules that can possibly mimic the future demands and also brings in the concept of future costs of technologies. The inclusion of these topics into the model, gives us an opportunity to analyze how the futures will shape up based on the potential trajectories of various technologies. The usage of learning curves had it's downsides as well. The usage of multiple learning rates for OTEC developed multiple future for those scenarios, thereby making the transitional pathways more generalized to an extent.

Overall, the unique nexus of these wide range of concepts on such an archipelago has led to the development of robust transitional pathways. The methodology used in this study in it's own way is open-ended and can be revised in the future to fit in the latest technological developments that can make the envisioned futures and the transitional pathways much better.

Chapter 8: Conclusions

In this chapter, the entire research is concluded by answering the sub-research questions and the main research question. In the second half of this chapter, concrete recommendations will be given to the main actor in the energy systems.

8.1. Conclusions

Based on the research done throughout the thesis, the sub-research question and the main research questions have been answered as follows.

Sub-Research Questions:

How does the present energy landscape of the Andaman and Nicobar Islands look like?

Based on the available data and the estimates made, three major categories of energy carriers used were identified. They are electricity, liquid fuels and firewood. The liquid fuels are primarily used for transportation, but small fractions of it are used for cooking too. Due to the underdeveloped rural economy, firewood used for cooking is the major energy carrier. Consumption levels of liquid fuels such as petrol, diesel and LPG are similar to that of firewood although used in a larger number of services. The usage of electricity is relatively lower due to the absence of major industries.

Overall, the energy landscape in the archipelago is largely characterized by the lack of both technical and economic efficiency. The consumption patterns are quite basic due to the small size of the local economy. But the inefficient usage of conventional fuels causes the energy requirement to be much higher. Large amounts of losses are observed in generation, transmission and consumption. These kinds of losses are commonly seen throughout the entire spectrum of energy services provided and carriers used. The end consumers are largely inactive in the energy system and unaware of the adverse effects of their unsustainable practices. The presence of a dominant public monopoly and the lack of competition can be one of the reasons for the lack of economic efficiency. The high dependence on expensive imported conventional fuels has been acknowledged but very little action has been taken to alleviate these burdens. The public monopoly has been stuck in a cyclic loop of making investments in diesel generation, replacing old generation and trying to provide a constant supply of electricity. Strong interventions are necessary to come out of the loop and shift to a sustainable energy supply.

Who are the most prominent actors in the energy landscape of the archipelago?

The key actors in the energy landscape of the archipelago are the government bodies and agencies. Apart from their roles in policy making, they have a strong position in fuel supply, energy generation and energy supply. The absence of a strong private sector and the passive nature of users make the governmental bodies the single most prominent actor. Within the governmental bodies, it can be said that the central governmental bodies such as MoP, NTPC, EESL and MNRE play the most vital roles. They design plans and policies and provide funds to the state body of EDA&N for implementation. The state body does not seem to be very

active in the planning or decision-making phase. Even though many other relevant actors have been identified, they play a very passive role and lack significant influence as of now.

What does the desired future of the energy system of the archipelago look like and to what extent do learning rates of technologies influence the desired energy configurations?

In the future, it has been envisioned that electricity becomes the dominant energy carrier in the system and largely eliminates the usage of other energy carriers such as firewood and other liquid fuels. This is done with the aim of promoting efficiency in the energy sector. Based on the current demands and growth rate trends, the final consumption in the year 2040 is estimated to be around 7 PJ.

The future energy configurations have been optimized using the three parameters of load shedding, power curtailment and costs of electricity. These optimizations have been done for each of the scenarios and the detailed results have been discussed in chapter 5. The learning rates of technologies like solar and onshore wind makes them very economical thereby permitting the large-scale over-capacity installation in scenario 1. The main cost deciding factor in this scenario turns out to be the storage and despite the heavy cost reductions makes the entire system very expensive. Scenario 2 seemed to be the most reasonable and suitable choice for the archipelago. Even though scenario 3 produced better results, it cannot be applied for all the islands due to the lack of economic viability. The dominant energy sources in these scenarios are solar energy, OTEC and bioenergy. The presence of two baseload technologies relaxes the need for large amounts of storage. But the relative amounts of solar energy and OTEC needed largely depends upon the learning rates of OTEC and the market uptake of OTEC. The installed capacities of bioenergy seemed to be fairly constant irrespective of the learning rates of OTEC due to its low costs and constant output. A higher usage of OTEC has been observed in the case of 18% learning rates in both 20% and 30% annual market growth rate cases. Overall, the presence of baseload technologies brought down the need for large scale storage and the cost of electricity. The addition of SWAC systems to OTEC, reduced the cost of generation further. But, the implementation of SWAC systems need large scale infrastructure investments in cold water distribution systems which makes its viability constricted to densely populated areas.

What are the drivers and barriers of the energy transition in Andaman and Nicobar Islands?

Three factors contribute as the drivers to an energy transition of the islands. The first factor would be the heavy dependence on fuel imports from Indian mainland and on international trade. The effects of fluctuations of fuel price in the international market are directly seen in the archipelago as fuel procurement is the most cost intensive factor. A 60% price increase has been observed in between the years 2013-2016 due to the fluctuations of the prices of crude oil in the international market. Moreover, the high costs of electricity generation also serve as a motivation to move on to more economically efficient system. The second factor would be the aging generator systems in the archipelago. The replacement of these systems needs investments of significant size. This serves as a motivation to move on onto investing in

renewable energy technologies. The third motivation is the access to major companies in the Indian main land who are interested in developing large scale renewable energy projects in the archipelago.

Three major barriers to the energy transition in archipelago have been identified. The first barrier would be the lack of seriousness in the policy makers. Targets are often developed but very little action is taken to reach those targets. Initial plans have been made to shift towards renewable energy in the islands and this attracted private companies to plan investments in such projects. Later, these proposed projects have been scrapped and the focus currently lies on using LPG for generation. Such lack of serious targets and roadmaps are affecting the investor confidence. The second barrier would be the lack of infrastructure. As seen in transitional pathways that have been developed in chapter 6, large scale infrastructure changes are essential to facilitate a proper transition and these changes require high amounts of investments. The third barrier is the size of the economy and the lack of awareness in the people of the archipelago. Considering both the drivers and the barriers, it can be said that the barriers outweigh the drivers.

What are the imperative changes needed to materialize the visions?

Based on the interventions identified in chapter 6, the main kinds of changes can be broadly classified into two categories. The first kind of change would be the policy initiatives that are required for both developing the sustainable technologies and aiding the people in adopting them. This policy changes range from the development of capital subsidies and feed in tariffs to attract investments in energy technologies to policies such as purchase subsidies and tax rebates for the higher adoption of electric vehicles and cleaner cooking systems. The second kind of changes required are technological changes that are mostly related to the development of the current infrastructure to facilitate the transition. Apart from these two major clusters of changes, there exist some that focus on the changes from the consumer end.

Main Research Question:

‘What are the possible pathways that can be followed by various actors in order to attain a 100% sustainable energy transition in Andaman and Nicobar Islands?’

The necessary transitional pathways have been discussed in detail in Chapter 6. Therefore, only the most important points are highlighted here. The crucial pathways primarily involve two ranges of actors. The first ones are the policy makers and public administration while the second range of actors are the end consumers.

The policy makers and public administration jointly are crucial in initiating a strong transition in the archipelago. The first steps would be to develop a tangible policy framework to develop an investment friendly situation in the islands. This can be supported by the implementation of required infrastructure changes needed for a successful transition. These actions can help in regaining the investor confidence that has been previously marred by a lack of seriousness and the presence of a large amount of red tape. Appropriate allocation of funds has to be done by both the state and central governments to fulfill these wide range of incentives and policies. The oncoming investments must be initially prioritized to the islands of Car Nicobar, Great

Nicobar, Little Andaman and Havelock Island due to the need for immediate action. The future energy configurations largely depend upon OTEC. Therefore, the development of pilot projects of OTEC can become very crucial and assistance from both domestic and international research institutes must be taken. Despite these concrete initial actions, the trajectory of this transition largely depends upon the learning rates and the global market uptake of OTEC.

One of the barriers to the transition is the underdeveloped nature of the local economy. The consumers, especially in the rural communities must make use of the financial models developed in order to invest in biofuel production and bioenergy generation. Such investments can boost the local economy and spur major growth in the rural areas. However, the feasibility of such a development occurring depends upon the access to capital provided by the banking sector.

Other important changes will also have to be observed from the end consumers. They have to be aware of the issues with the current energy systems and consumption practices. They have to educate themselves about the various incentives and schemes which can help in them in fully joining the transition be it in switching to electric vehicles, steering away from traditional fuels for cooking or the adoption of energy efficient appliances and practices.

8.2. Recommendations

Earlier, many changes and specific interventions have been developed for each of the scenarios. This sub-section highlights the major recommendations to individual or a group of actors in the archipelago. Five major recommendations have been developed with most of them being directed towards the public administration. These recommendations are as follows.

Target-oriented Approach: The electricity department of the archipelago (EDA&N) and the overseeing Ministry of Power must develop practical targets and roadmaps for both long term and short term. There is a certain degree of lack of direction in the current targets being developed. Together with strong policy developments and infrastructure upgradation, large amount of private investments can be attracted which drives the transition forward and helps achieve the targets developed. This can be very helpful in the case of electric vehicle diffusion. The main responsible agency of EESL can specifically focus on the incentives and development of specific categories of vehicles. Such initial actions for one category can help achieve the desired levels of diffusion which can speed up the diffusion in other kinds of vehicles.

Development of Local Solutions: If the energy related activities or developments are observed, it can be seen that in most situations the local electricity department only acts as an implementational body. It would be ideal for this body to develop local solutions using a bottom-up approach to solve the main issues rather than largely relying on the central governmental Ministry of Power of the development of projects. This involvement in decision making process should not just be limited to the case of electricity but should also be present for the diffusion of electric vehicles and cooktops. Currently, there exist no local bodies that aim at the diffusion of electric vehicles and push for clean cooking. The central government agency of EESL works on this and it would be better if there are separate local agencies that can tailor policies according to the archipelago and achieve the desired results.

Rural Energy Policies: It can be seen in the implementation timeline that most of the necessary changes are slightly delayed in the rural areas due to the backward economy. Therefore, these regions have to be targeted and separate policies and assistance must be provided in such regions to facilitate a transition. Schemes such as joint liability microfinance could be useful and many other financial models have to be explored to achieve the desired results in these regions. The implementation of such schemes or policies in turn depends upon the active participation of local bodies as mentioned in the earlier recommendation.

OTEC Development: As mentioned earlier, the success of this transition heavily relies on the global growth of OTEC. Therefore, research institutes across the country have to be empowered in terms of research grants and funding. Additionally, global co-operation over the development of OTEC must be taken especially for the development of pilot projects. A strong policy and legal framework must be developed for OTEC to stimulate growth in this sector. These activities should be performed by the central government authorities as the local island authorities have only limited power.

Market Restructuring: This will be a key development in the growth of economic efficiency in the energy system. A shift towards price based mechanism is necessary. Such a shift, facilitates the market to steer away from inefficient and expensive diesel generators towards economical renewable energy sources. This also helps improve economic efficiency within the public monopoly as well since they will be in direct competition with efficient private sector.

Appendix (A1): Power Houses in the Archipelago

The power houses present in each of the islands and the cumulative installed capacities in the islands are presented in table (A1.1). The highest number of power houses and the installed capacities are seen in the island of South Andaman. It must be noted that the power houses essentially represent diesel generators.

Table (A1.1): Installed Capacities in selected islands for the study (Power For all, 2016)

Islands	Number of Power Houses	Installed Capacities (MW)
North Andaman	10	3.598
Middle Andaman	20	10.08
South Andaman	37	68.8
Little Andaman	7	5.65
Car Nicobar	12	5.636
Great Nicobar	10	2.836
Baratang Island	2	0.512
Havelock Island	7	1.33
Total	105	98.442

Appendix (A2): Future Electricity Demand Projections

In this appendix, the data regarding electricity consumption growth rate projections have been presented. This is seen in tables (A2.1, A2.2). This data has been used for developing future annual consumption estimates. In the second table, detailed data for every individual island has been presented. This data is procure from Power for all (2016).

Table (A2.1): Projected Electricity Demand Growth (Power for all, 2016)

Indicators	Units	FY 15	FY 16	FY17	FY 18	FY 19
Energy Sales Requirements	GWh	229	249	271	297	330
AT&C Losses (Target)	%	23.96	20	19	17.50	16
Distribution Losses	%	19.96	17.53	16.49	14.95	13.40
Energy Input Requirements	GWh	287	302	324	349	381
Peak Demand	MW	58	60	62	65	68

Table (A2.2): Projected Electricity Demand Growth (Power for all, 2016)

Indicators	FY 15	FY 16	FY 17	FY 18	FY 19
<i>South Andaman (including Rutland)</i>					
<i>Total Sales (GWh)</i>	168.16	185.73	204.89	228.53	259.3
<i>T&D Loss (%)</i>	19.44	16.87	15.63	13.74	11.91
<i>Electricity Demand (GWh)</i>	205.45	218.71	238.33	260.62	290.26
<i>Peak Demand (MW)</i>	41.57	43.46	45.77	48.42	52.22
<i>Havelock Island</i>					
<i>Total Sales (GWh)</i>	4.96	5.42	5.93	6.48	7.09
<i>T&D Loss (%)</i>	23.83	23.33	22.83	22.33	21.83
<i>Electricity Demand (GWh)</i>	6.51	7.07	7.68	8.35	9.07
<i>Peak Demand (MW)</i>	1.70	1.90	2.10	2.50	3.00
<i>Little Andaman (including Creek and Straight)</i>					
<i>Total Sales (GWh)</i>	7.45	7.67	7.90	8.14	8.39
<i>T&D Loss (%)</i>	30.09	29.59	29.09	28.59	28.09
<i>Electricity Demand (GWh)</i>	10.66	10.90	11.15	11.40	11.66

<i>Peak Demand (MW)</i>	2.07	2.12	2.17	2.21	2.27
<i>Baratang & Middle Island</i>					
<i>Total Sales (GWh)</i>	18.36	18.91	19.48	20.06	20.66
<i>T&D Loss (%)</i>	24.13	23.63	23.13	22.63	22.13
<i>Electricity Demand (GWh)</i>	24.20	24.76	25.34	25.93	26.54
<i>Peak Demand (MW)</i>	5.70	5.83	5.97	6.11	6.25
<i>North Andaman</i>					
<i>Total Sales (GWh)</i>	11.40	11.74	12.09	12.46	12.83
<i>T&D Loss (%)</i>	26.00	25.00	24.0	23.00	22.00
<i>Electricity Demand (GWh)</i>	15.41	15.66	15.91	16.18	16.45
<i>Peak Demand (MW)</i>	3.97	4.23	4.28	4.33	4.39
<i>Car Nicobar</i>					
<i>Total Sales (GWh)</i>	8.84	9.11	9.38	9.66	9.95
<i>T&D Loss (%)</i>	21.34	20.84	20.34	19.84	19.34
<i>Electricity Demand (GWh)</i>	11.24	11.50	11.77	12.05	12.34
<i>Peak Demand (MW)</i>	1.97	2.02	2.06	2.11	2.16
<i>Great Nicobar and Panja</i>					
<i>Total Sales (GWh)</i>	4.10	4.22	4.35	4.48	4.62
<i>T&D Loss (%)</i>	25.71	25.21	24.71	24.21	23.71
<i>Electricity Demand (GWh)</i>	5.52	5.65	5.78	5.91	6.05
<i>Peak Demand (MW)</i>	1.12	1.10	1.09	1.08	1.07

Appendix (A3): Energy Consumption for Cooking

In this appendix, the annual consumption for cooking activities are estimated for each kind of fuel used. This is later appropriated on a population basis for each of the islands in the study.

Firewood:

Annual Consumption per capita = 876 kg/person

Number of Households = 31,561

Average Number of People in a Household = 4 people/household

Total Annual Consumption = 110,589,744 kg

Calorific Value = 15.5MJ/kg

Total Energy Demand = $110,589,744 \times 15.5 = 1,714,141,032$ MJ

= 1,714,141.032 GJ

= 1.714 PJ or 476.15 GWh

LPG:

Daily Consumption per Household = 7 MJ/day

Annual Consumption per Household = 2555MJ/year

Number of Households = 41,552

Total Energy Demand = 106,166,177.6 MJ

= 106,166.1776 GJ

= 0.1 PJ or 39.491 GWh

Kerosene:

Daily Consumption per Capita = 11.5 L/person

Average Number of People in a Household = 4 people/household

Number of Households = 18,489

Calorific Value = 43.1 MJ/kg

Density = 0.8201 g/cm³

11.5 L of Kerosene = 9.43115 kg of Kerosene

Total Energy Demand = $9.43115 \times 4 \times 18,489 \times 43.1 = 30,061,824.58$ MJ

= 30,061.82458 GJ

= 0.03 PJ or 8.351 GWh

Total Cooking Consumption = 1.850 PJ or 523.992 GWh

Appendix (A4): Transport Sector Consumption Estimates

In this appendix, the data regarding the number of vehicles in the archipelago have been presented in table (A4.1). The figures for multiple years have been used to establish the growth rates of vehicles. This is further used to establish an estimation on the number of vehicles that can be anticipated in the year 2040 which is crucial for estimating the final energy consumption of transport sector. The process of estimation is shown in the chapter 4. The final estimates have been appropriated for the islands on a population basis and can be seen in table (A4.2).

Table (A4.1): Number of Vehicles in the Archipelago (National Informatics Centre, 2017)

Type of Vehicle	2014-15	2015-16	2016-17
Two Wheelers	72,800	72,098	86,402
Lorry/Truck	2,638	2,730	2,829
Bus	1,039	1,074	1,088
Light Motor Vehicles	21,439	23,334	26,097
Auto	3,826	4,072	4,304
Others	559	821	839
Total	102,301	111,129	121,558

Table (A4.2): Calculation of Energy Demand for the Transport

Islands	Population (2011)	Energy Demand for Freight Transport (TJ)	Energy Demand for Passenger Transport (TJ)
North Andaman	42,541	49.641	133.649
Middle Andaman	55,632	64.917	174.776
South Andaman	209,602	244.586	658.495
Little Andaman	18,823	21.965	59.135
Car Nicobar	17,841	20.819	56.050
Great Nicobar	8,067	9.413	25.344
Baratang Island	6,351	7.411	19.952
Havelock Island	5,691	6.641	17.879
Total	364,548	425.393	1,145.28

Appendix (A5): Energy Technology Models

In this appendix, the models used for estimating the potentials of various technologies are presented here.

Solar Photovoltaic Technologies

The photovoltaic technologies harness the energy from the oncoming solar irradiation on to the surface of the earth using semiconductor devices called solar cells. These cells build up in number to form solar modules and consequently solar arrays and power plants. The main dominant technologies used are crystalline silicon (C-Si), hydrogenated amorphous silicon (a-Si), cadmium telluride (CdTe), copper diselenide (gallium) and indium based (CIS and CIGS). The dominant technologies out of the aforementioned ones is the crystalline silicon (Ferreira et.al, 2018). The solar arrays produce a direct current power output and is later on converted into alternating current using inverters. There are several other components that are used to maximize the yield of the system and are all collectively called the balance of system. The yield of a PV plant can be calculated as follows.

$$P_{pv} = A_{mod} * \int \eta_{(T_m, G_m)}(t) * \eta_{BOS} * G_m(t)$$

$$\eta_{(25^\circ C, G_m)} = \frac{P_{mpp}}{G_m * A_{mod}}$$

$$\eta_{(T_m, G_m)} = \eta_{(25^\circ C, G_m)} * (1 + k(T_m - 25^\circ C))$$

$$T_m = T_{amb} + \frac{G_m}{G_{NOCT}} * (NOCT - 20^\circ C)$$

Where,

- A_{mod} = Area of modules in total (m^2)
- $\eta_{(T_m, G_m)}(t)$ = Efficiency at Temperature (T_m) and irradiation (G_m)
- η_{BOS} = Efficiency of balance of system
- $\eta_{(25^\circ C, G_m)}$ = Efficiency at Temperature ($25^\circ C$) and irradiation (G_m)
- P_{mpp} = Power at maximum power point = 187.2 W
- G_m = Irradiation (W/m^2)
- k = temperature coefficient = -0.06
- T_{amb} = Ambient Temperature ($^\circ C$)
- G_{NOCT} = Irradiation at NOCT conditions ($800 \text{ w}/m^2$)
- $NOCT$ = NOCT temperature = $47^\circ C$

Concentrated Solar Power (CSP)

Concentrated solar power harnesses energy from the solar radiation incident on the earth's surface. However, power is not produced in the traditional way of solar power plants using semiconductors. In this technology, mirrors are used to focus sunlight and convert the incident radiation into heat energy by heating up diathermic oils or molten salts. This heat energy will be then later on converted into electricity using Rankine cycle (Iaquaniello, 2017). The fluid is

contained in a tower on to which radiation is focussed. The yield of a CSP plant can be calculated as follows

$$P_{CSP} = DNI * A_m * \eta_{el}$$

(or)

$$P_{CSP} = DNI * A_{site} * \eta_{landuse} * \eta_{el}$$

Where,

- DNI = Direct Normal Irradiance (KWh/m²/year)
- A_m = Area of reflective mirrors or parabolic reflectors (m²)
- A_{site} = Area of total land available (m²)
- $\eta_{landuse}$ = Percentage land used by reflectors in the total land available
- η_{el} = Efficiency of conversion of incident irradiation to electricity

Wind Power

Wind energy is harnessed with the use of wind turbines to extract the kinetic energy in the wind. The kinetic energy in the wind is converted into mechanical energy through the turbines and is later converted into electrical energy through the generators. The power output of a single turbine is modelled as follows.

$$P = \frac{1}{2} * C_p * \rho * A * u^3$$

Where,

- P = Power output (W)
- C_p = Power coefficient of the wind turbine (Assumed to be 40% based on (26))
- ρ = Density of air (1.225 Kg/m³)
- u = Wind Velocity (m/s)
- A = Area swept by the rotor.

The model for calculating wind speeds at hub height is as follows

$$\text{- Logarithmic law: } u(h) = u(h_{ref}) * \frac{\ln(\frac{h}{z_0})}{\ln(\frac{h_{ref}}{z_0})}$$

-

$$\text{- Power Law: } u(h) = u(h_{ref}) * (\frac{h}{h_{ref}})^\alpha$$

- Where,
- $u(h)$ = Wind speed at altitude h
- $u(h_{ref})$ = Wind speed at altitude $u(h_{ref})$
- z_0 = Roughness length (0.03 m for land)
- α = Power law coefficient = 0.143

Ocean Thermal Energy Conversion (OTEC)

OTEC is an energy conversion system that can harness energy based on the temperature difference between the surface and at a depth of about 1000 m in the ocean. It is essentially a

power cycle that uses a heat engine to rotate a low-pressure turbine that in turn produces electricity. A working fluid such as Ammonia is used where it boils at the surface temperature and cold water from about 1000m depth is used to condense it later on (Engels et.al, 2014). The plant can run in different combinations like open cycle, closed cycle or hybrid cycle where it can be combined with additional features such as desalinisation plant or sea-water cooling systems (Andrawina et.al, 2017). The power density can be modelled as follows

$$P_{net} = W_{cw} * \rho * \varepsilon_{tg} * C_p * \left(\frac{\Delta T^2}{8 * T_{surf}} - \frac{1}{20} \right)$$

Where,

- P_{net} = Net power output density (W/Sq.km)
- W_{cw} = Cold Water Volume Flowrate (m^3/s)
- ρ = Sea water density ($1022 \text{ Kg}/m^3$)
- ε_{tg} = Efficiency of the turbine generator (87%) (20)
- C_p = Specific heat capacity ($J/Kg*K$)
- ΔT = Difference of Temperature at 30m and 1062 m depth = 22.5756 K
- T_{surf} = Surface Temperature = 301.6 K

Wave Energy

The rise and fall of tides occurs due to the influence of the gravitational forces of astronomical bodies on the gravitational forces governing our seas. Tidal energy is harnessed using the energy dissipated by the tidal movements (Araquistain, N.d.). The harnessed energy could be either due to the potential energy in a rising tide or the kinetic energy due to flood and ebb movements in the currents. The yield can be modelled as follows

$$P_T = \frac{1}{2} * \rho * A * v^3 * C_p$$

Where,

- ρ = Sea water density ($1022 \text{ Kg}/m^3$)
- A = Area of the turbine (m^2)
- v = Current speed (m/s)
- C_p = Power Coefficient of the turbine

Appendix (A6): Land Availability Data

In this section, the land available for energy related projects is calculated for each island based on various reports. The common factor for all of these islands is that a major share of the land is covered by evergreen forests, semi evergreen forests, mangroves and plantations. The presence of these limits the available land. There are also reserved forests and protected forests present in a large scale and is illegal to use any of those lands. Most of the land that is available apart from the ones that are not already used up for settlements or agriculture is form mud lands, degrading mangroves, sandy land, fragmented patches and small patches of barren land. On average each of the island had about 5% land that can be utilized for energy except for Car Nicobar which has only 3.25 %. In the case of islands like South Andaman, where information was not clear enough, approximations were made based on the general data for the archipelago.

The table (A6.1) represents the amount of land that can be used and the major contributors for that land.

Table (A6.1): Land Availability Data

Islands	Total Area (Sq.Km)	Percentage Available Area (%)	Available Area (Sq.Km)	Contributors
North Andaman	1,317	6%	79.02	Mud lands, sandy regions, degrading mangroves (Prasad et.al., 2010)
Middle Andaman	1,523	5%	76.15	Non forest areas, sandy regions. (Department of environment and forest, N.d)
South Andaman	1,262	6%	75.72	Barren uncultivable land, mud lands, sandy regions (Reddy at.al, 2016)
Little Andaman	707	5%	35.35	Sparse and damaged forests, sandy regions (Narayanan, 2012)
Baratang Island	92.2	5%	4.61	Highly fragmented lands, recovered land from deforestation (Nagabhatla et.al, 2007)
Havelock Island	242.6	5%	12.13	Small Grasslands, sandy regions (Reddy et.al, 2016)
Car Nicobar	126.9	3.25 %	4.12	Small Grasslands, sandy regions, scrubs (Gupta et.al, 2004)
Great Nicobar	921	4.7 %	43.287	Small Grasslands, sandy regions, scrubs (Gupta et.al, 2004)

Appendix (A7): Optimization Variables

The optimization parameters have been used to perform the modelling for the scenarios in developing the future visions.

Table (A7.1): Optimization parameters used in modelling

Parameters	Values
Population Size	500
Pareto Fraction	0.6
Creation Function	gacreationlinearfeasible
Selection Function	Selectiontournament, 3players
Crossover Function	Crossoverintermediate; ratio=1.4
Crossover Fraction	0.8

Appendix (A8): Model Results (installed Capacities)

Chapter (5.7) discusses the results of the modelling done for all the scenarios and the results were presented in the form of percentages of installed capacity for each energy source in order to analyze the results better. In this appendix, the installed capacities for each island for scenarios will be presented in a tabular form.

Table (A8.1): Installed Capacities for Scenario 1

Island	Solar (MW)	Onshore Wind (MW)	Offshore Wind (MW)	Hydro (MW)	Battery (MWh)
North Andaman	162	12	1	5.25	160
Middle Andaman	122	185	0	0	1040
South Andaman	900	330	0	0	9370
Baratang	20	5	0	0	115
Havelock	37	16	0	0	430
Little Andaman	47	12	0	0	266
Car Nicobar	41	14	1	0	280
Great Nicobar	105	14	0	0	130

Table (A8.2): Installed Capacities for all the cases in scenario 2 (MW)

	Case A							Case B						
Islands	Solar	Wind Onshore	Wind Offshore	Hydro	OTEC	Biomass	Battery (MWh)	Solar	Wind Onshore	Wind Offshore	Hydro	OTEC	Biomass	Battery (MWh)
North Andaman	39	0	1	5	5	19	158	39	0	1	5	5	19	158
Middle Andaman	7	1	0	0	25	18	198	5	0	1	0	26	18	181
South Andaman	119	66	1	0	157	15	1392	24	11	0	0	175	13	1144
Baratang	10	2	0	0	2	1	27	0	0	0	0	3	1	27
Havelock	2	0	0	0	7	3	21	2	0	0	0	7	3	21
Little Andaman	30	4	0	0	5	6	74	2	0	0	0	7	6	59
Car Nicobar	13	1	0	0	3	10	8	13	0	0	0	3	10	6
Great Nicobar	6	0	0	0	1	5	2	6	0	0	0	1	5	1
	Case C							Case D						
Islands	Solar	Wind Onshore	Wind Offshore	Hydro	OTEC	Biomass	Battery (MWh)	Solar	Wind Onshore	Wind Offshore	Hydro	OTEC	Biomass	Battery (MWh)
North Andaman	39	0	1	5	5	19	158	39	0	1	5	5	19	158
Middle Andaman	7	1	1	0	25	18	198	6	0	0	0	26	18	181
South Andaman	73	0	0	0	176	15	879	16	9	0	0	177	10	1267
Baratang	10	2	0	0	2	1	27	0	0	0	0	3	1	27
Havelock	2	0	0	0	7	3	27	2	0	0	0	7	3	20
Little Andaman	2	0	0	0	7	6	59	2	0	0	0	7	6	59
Car Nicobar	13	1	0	0	3	10	8	12	0	0	0	5	9	3
Great Nicobar	6	0	0	0	1	5	2	6	0	0	0	2	4	1

Table (A8.3): Installed Capacities for all the cases in scenario 3 (MW)

	Case A							Case B						
Islands	Solar	Wind Onshore	Wind Offshore	Hydro	OTEC+ SWAC	Biomass	Battery (MWh)	Solar	Wind Onshore	Wind Offshore	Hydro	OTEC+ SWAC	Biomass	Battery (MWh)
North Andaman	39	0	1	5	5	19	158	39	0	1	5	5	19	158
Middle Andaman	6	0	0	0	25	18	177	6	0	0	0	25	18	176
South Andaman	79	4	1	0	158	12	1102	79	3	1	0	171	10	885
Baratang	0	0	0	0	3	1	18	0	0	0	0	3	1	18
Havelock	3	0	0	0	6	3	7	2	0	0	0	6	3	5
Little Andaman	2	0	0	0	7	6	52	2	0	0	0	7	6	52
Car Nicobar	12	0	0	0	3	10	4	13	0	0	0	3	10	6
Great Nicobar	7	1	0	0	1	5	23	5	0	0	0	2	4	19
	Case C							Case D						
Islands	Solar	Wind Onshore	Wind Offshore	Hydro	OTEC +SWAC	Biomass	Battery (MWh)	Solar	Wind Onshore	Wind Offshore	Hydro	OTEC + SWAC	Biomass	Battery (MWh)
North Andaman	39	0	1	5	5	19	158	39	0	1	5	5	19	155
Middle Andaman	6	0	1	0	25	18	178	6	0	0	0	25	18	175
South Andaman	83	5	0	0	161	13	932	72	2	0	0	185	14	940
Baratang	0	0	0	0	3	1	18	0	0	0	0	3	1	18
Havelock	2	0	0	0	6	3	11	2	0	0	0	7	3	4
Little Andaman	2	0	0	0	7	6	52	2	0	0	0	7	6	50
Car Nicobar	11	0	0	0	3	10	6	11	0	0	0	4	9	2
Great Nicobar	5	0	0	0	1	5	13	5	0	0	0	2	2	22

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