How to reduce carbon emission in an electric utility?

Feasibility of solar cells in the Maldives

By

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List of Abbreviations

BMBF	Ministry of Education and Research
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CMM	Capability Maturity Model
EEG	Renewable Energy Sources Act
EU	European Union
GDP	Gross domestic product
ICT	Information and Communication Technology
IDC	Island Development Communities
IEA	International Energy Agency
JICA	Japanese International Cooperation Agency
JPY/kWh	Japanese Yen / kilo Watt Hour
METI	Ministry of Economy, Trade and Industry
MW	Mega Watt
NEDO	New Energy and Industrial Technology Development Organization
NIES	National Institute for Environmental Studies
PtJ	Project Management Organisation
R&D	Research and Development
RDD	Research, Development and Demonstration
RETDAP	Renewable Energy Technology Development and Application Project
SCADA	Supervisory Control And Data Acquisition
SEI	Software Engineering Institute

SGMM	Smart Grid Maturity Model
SLMM	Solar cell Low carbon Maturity Model
STECLO	State Electric Company Limited
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme
US	United States
USD	US Dollar

Certification

I hereby declare that this thesis is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they have been acknowledged.

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Abstract

Climate change is the major overriding environmental issue that the world is faced with. Climate change caused by green house gases such as carbon dioxide is causing global warming which is threatening the existence of countries like the Maldives. The Maldives has set a goal of becoming carbon neutral by the year 2020.Fossil fuel combustion for electricity is the main contributor to carbon emission in the Maldives. The Maldives is blessed with renewable energy resources such as solar radiation; hence replacing a substantial amount of fossil fuel generators by solar cells will help the Maldives in achieving its low carbon goals. Solar cells are financially feasible in the Maldives but technological, socio-economic and political factors are hindering the dissemination of solar cells. Hence this paper originally creates a new maturity model based on the framework of the Smart Grid Maturity Model to analyze the solar cell technological system in the Maldives as well as propose measures to strengthen the technological system to help the Maldives achieve its low carbon goals. The new maturity model which is named as the Solar cell Low carbon Maturity Model was applied to the Maldives and it was found that the maturity ranking of the Maldives is at level 0 (default level) for the domains industrial organization, institutional infrastructure, government policy and technological infrastructure. Based on this result the following recommendations are proposed. A solid action plan on how to reduce carbon emission using renewable energy sources needs to be formulated. This action plan should address countrywide feasibility studies of grid-connected solar cells and solar cell education training needs. Decentralized solar cell projects need to be successfully conducted. These projects should focus on developing standards as well as financing and application knowledge. The utilities need to implement a smart grid vision. Awareness programs for global warming and solar cells need to be conducted. The electricity market in the Maldives needs to be liberalized. The study also proposed two hypotheses which proved that a higher awareness of global warming is associated with a higher willingness to pay a premium for renewable energy as well as a higher willingness to adopt a solar cell system.

1) Introduction

Economic development has been blamed for the deterioration of the environment. The effect of industrialization and globalization has had a major impact on every aspect of human daily life. The benefits that economic development brought about came at a price which was the deterioration of the environment. The problems that arose due to the deterioration of the environment include air pollution, deforestation, water shortage and waste disposal (Tominaga, 2001).World population growth and its strain on the natural resources (De Souza, Williams, & Meyerson, 2003), nuclear contamination and its long term effects (Cropper, 1980) as well as climate change have also been identified as global environmental challenges that the world is faced with. The problems mentioned above are linked to each other with climate change being the major overriding environmental issue of our time (United Nations Environment Programme).Climate change is mainly caused by the effect of increased greenhouse gas concentrations in the earth atmosphere which is warming the earth (global warming) causing melting of ice and increasing the sea level as well as ocean acidification and posing risks to the global agriculture and water supply (United Nations Environment Programme, 2010).The major green house gas contributing to global warming has been identified as carbon dioxide which is produced from the combustion of fossil fuels (Lashof & Ahuja, 1990).

In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) was adopted to provide a framework for policy making to deal with climate change which was followed by the Kyoto Protocol in 1997 which commits developed countries to reduce their green house gas emission to a certain level as well as all countries in general to decrease their green house gas emissions (Faure, Gupta, & Nentjes, 2003).Due to the Kyoto Protocols commitments and the need to reduce and maintain greenhouse gas concentrations at a safe level, visions of low carbon societies have been created globally with countries like Japan and the UK initiating the transition to low carbon societies (Skea & Nishioka, 2008).

Recently developing countries such as the Maldives have jumped on the low carbon bandwagon in order to reap the benefits that a low carbon society proposes. In 2009 the Maldives set a goal of becoming carbon neutral by the year 2020 (Ministry of Foreign Affairs, 2010).The Maldives is a country heavily dependent of fossil fuels for its energy production though it is blessed with renewable energy resources (Weisser, 2004a).In a U.S Department of Energy study on the solar resource assessment of the Maldives, it was found that there is a high level of solar resources throughout the entire country making it well suited for solar cell applications which could substitute fossil fuel based generators (Renne, George, Marion, Heimiller, & Gueymard, 2003). The first ever carbon audit of the Maldives show that for the year 2009 Maldives emitted 1.3 million tons of CO_2 of which 50% was due to combustion of diesel fuel for the generation of electricity(Bernard et al,2010). Hence benefits of a low carbon society will rid Maldives of the economical and financial vulnerability it faces due to high dependency on fossil fuels (Weisser, 2004b), especially when the annual energy demand is increasing at an annual rate of 11 percent (United Nations Development Programme, 2007).

The single largest electric utility of the Maldives is the State Electric Company Limited(STELCO) which supplies power to the capital Male' which accounts for 72 percent of all generated power for inhabited islands (Government of Maldives, 2009).Studies have shown that 20% of the total electricity demand in the capital Male' could be supplied by solar cell systems connected to the STELCO electric grid by the year 2020 (Japan International Cooperation Agency, 2009).This estimation is done based on the current capabilities of the electric grid which if improved could accommodate more solar cell systems. Apart from the technological barriers posed by the electric grid, socio-economic and political factors hindered the dissemination of renewable energy technologies throughout the world (International Energy Agency, 2001).Though solar cell power generation is financially feasible in the Maldives (van Alphen, van Sark, & Hekkert, 2007) the above mentioned factors are expected to hinder the dissemination of solar cells in the Maldives.

How to reduce carbon emission in an electric utility? And how can it be done using solar cells? Acknowledging the fact that many factors contribute to the dissemination of solar cells, a system view of technological change is used with the creation of a new maturity model to address these issues. This new maturity model named as the Solar cell Low carbon Maturity Model (SLMM) will show the current situation of the solar cell diffusion in the Maldives as well as a pathway that the Maldives can take in order to increase the diffusion of solar cell to help its low carbon goals. The SLMM consists of four domains which are government policy, industrial organization, technological infrastructure and institutional infrastructure. The SLMM has six maturity levels which are default, initiating, enabling, integrating, optimizing and pioneering. Anything below the initiation stage is considered as default stage. The maturity model proposed in this paper can be applied to countries trying to increase their dissemination of solar cells and achieve a low carbon society.

2) Literature Review

2.1) Defining Low Carbon Society

National Institute for Environmental Studies(NIES)defines low carbon society as; (1)takes actions that are compatible with the principle of sustainable development, ensuring that the development needs of all groups within society are met; (2) makes an equitable contribution toward the global efforts to stabilize atmospheric concentrations of carbon dioxide and other green house gases at a level that will avoid dangerous climate change through deep cuts in global emissions; (3) demonstrates high levels of energy efficiency and uses low carbon energy sources and production technologies; and (4) adopts patterns of consumption and behavior that are consistent with low levels of greenhouse gas emissions (National Institute for Environmental Studies, 2006).The idea of a low carbon society came to life due to the challenges brought about by global warming to the survival of the planet and humanity.

2.2) Solar Cells and Low Carbon Society

Solar power is the energy which comes from the sun. Solar cells also known as photovoltaic cells convert the sun's energy to electricity. Solar cells provide environmental and socio-economic advantages in comparison to conventional energy sources such as reduced green house gas emissions, absence of any air emission or waste product during their operation, reduction of transmission lines, increased national energy independency, security of energy supply and also rural area electrification in developing countries (Tsoutso, Frantzeskaki, & Gekas, 2005).Solar cells have become a popular sustainable energy source with governments implementing policies to enhance their use.

2.3) Maturity Models

2.3.1) Capability Maturity Model

Maturity models were first used in the 1970's in the areas of information systems but the popularity of maturity models increased with the introduction of the Capability Maturity Model in the early 1990's (Mettler,2009).The technical report of the Capability Maturity Model(CMM) states that the CMM was created by the Software Engineering Institute (SEI) of Carnegie Mellon University as a tool for the United States federal government to assess the capabilities of its software contractors (Paulk, Curtis, Chrissis, & Weber, 1993). The CMM proposes a step by step approach to improving the software development process. The CMM has five maturity levels where the maturity is defined as the potential for the development of capabilities. These levels indicate the strength and efficiency of an organizations software process and how well the organization can apply these capabilities to develop software.

The success of the CMM for organizations in developing their software process led to the development of maturity models for different areas by SEI such as Capability Maturity Model Integration for process improvement to increase an organizations performance and Smart Grid Maturity Model (SGMM) to modernize the power grid.

2.3.2) Smart Grid Maturity Model

The smart grid uses digital technology that allows two-way communication between a utility and a customer and all points in between them to automate monitor and control power grid activities (U.S Department of Energy, 2011).One of the main characteristics of a smart grid is the accommodation of renewable energy sources and decentralized energy sources. A solar cell is a renewable energy source that is best utilized within a smart grid as the power generated by solar cells depends on weather conditions. Hence communication with the solar cell energy source and the power grid helps to maximize the utilization of the energy produced while minimizing imbalances in the power system. The two-way communication within the power grid enables achievement of higher efficiencies in power production as demand and supply is better matched in a smart grid than a grid that does not employ smart grid technologies.

In the technical report of the Smart Grid Maturity Model (SGMM), the SGMM Team (2010) describes the SGMM as a model developed by electric power utilities for electric power utilities which is now under the stewardship of SEI. The SGMM provides a framework to show the current status of smart grid deployment activities and capabilities of a utility and future strategies needed to improve on the current status in order to achieve a smart grid.

2.3.3) Creating a Maturity Model

De Bruin, Freeze, Kulkarni, & Rosemann (2005) proposes a framework for creating a maturity model which involves the study of existing literature of the field that the maturity model is to be made to identify what represents maturity. Once a literature study has been done, the maturity level can be defined using a top-down approach where the definitions for each level of maturity are developed followed by an assessment criterion for each level. The definitions of each maturity level provide a summary of the major requirements at each level and the assessment criteria used to measure that level. In the case where very few literature is available on the subject or if the field is a new or emerging field, a bottom-up approach is recommended where the assessment criteria is created first followed by a definition for each maturity level.

The innovation system approach is used to study innovation, industrial transformation and economic growth (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008) using time as a dimension to analyze the system as the systems are dynamic in nature (Carlsson, Jacobsson, Holmén, & Rickne, 2002).As an innovation system evolves with time, its evolution can be categorized into maturity levels and used to compare different innovation systems of the same field. Due to the diversity of innovation, innovation systems can be aggregated at different levels such as at a national level or a regional level. Since nations differ in their economic structure as well as their institutional setup, Johnson (2010) defines a National System of Innovation as all interrelated institutional and structural factors that generate, select and diffuse innovation within a country. Different innovation systems have emerged in recent times such as national systems of innovation, regional innovation systems, sectoral systems of innovation and production, technological innovation systems and technological systems (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008).A technological system is defined by Carlsson & Stankiewics (1991) as: “a network of agents interacting within a technology area under a particular institutional infrastructure to generate, diffuse and utilize a technology”.

When the system of analysis of a technological system is a product, four major components of the technological system are identified as industrial organization, technological infrastructure, institutional infrastructure and the government policies (Sung & Carlsson, 2003). Industrial organization is the relation and interaction within actors that take place for the production and consumption of the product (Sung & Carlsson, 2003).In the case of solar cells, the actors within the industry are the suppliers of solar cell systems, green power marketers who are producers of electricity using solar cells and users who consume the electricity. Users consume the electricity produced by the green power marketers via the electric grid as well as electricity produced by their own solar cell system. The suppliers of solar cell systems are firms that supply the equipment used to generate electricity using solar cells. The technological infrastructure consists of technologies needed to support the use of the product. In the case of solar cells, the technological infrastructure consists of the electric grid which facilitates the transfer of electricity from the producer to the users. The industrial organization and the technological infrastructure are interdependent on each other (Sung & Carlsson, 2003).Institutional infrastructure is the institutional setup that supports and regulates the process of innovation and diffusion of a product (Sung & Carlsson, 2003).The institutional infrastructure consist of the educational system, the financial system and the regulatory system. The government and the institutional infrastructure are different components as the government has the ability to influence the industrial organization, technological infrastructure and the institutional infrastructure through its specific policies (Sung & Carlsson, 2003).Hence the government is considered a separate component of a technological system which has the capacity to guide the direction and growth of the whole technological system. Functions are used to diagnose the present state of a system or the performance of a system where a function is defined as a contribution to achieving the goal of the system (Johnson, 1998).Hence the more functions present in a system, the higher the performance of the system is.

To create the Solar cell Low carbon Maturity Model (SLMM) the four major components of the technological system are used as domains in the SLMM model. As the aim of the new maturity model is to increase the dissemination of solar cells within a technological system, the technological infrastructure domain is replaced by the SGMM and expanded while preserving the form and structure of the SGMM to accommodate the institutional infrastructure, industrial organization and government policy. The contents of the institutional infrastructure, industrial organization and government policy domain are developed using the maturity model framework created by De Bruin, Freeze, Kulkarni, & Rosemann (2005).

3) Methodology

The methodology for this study is split into two parts. The first part is the creation of the SLMM using case studies. The second part is the analysis of the solar cell technological system in the Maldives by applying the model to the Maldives using a questionnaire survey, interviews and national studies and reports. Figure 1 below shows the overall methodology of the paper.

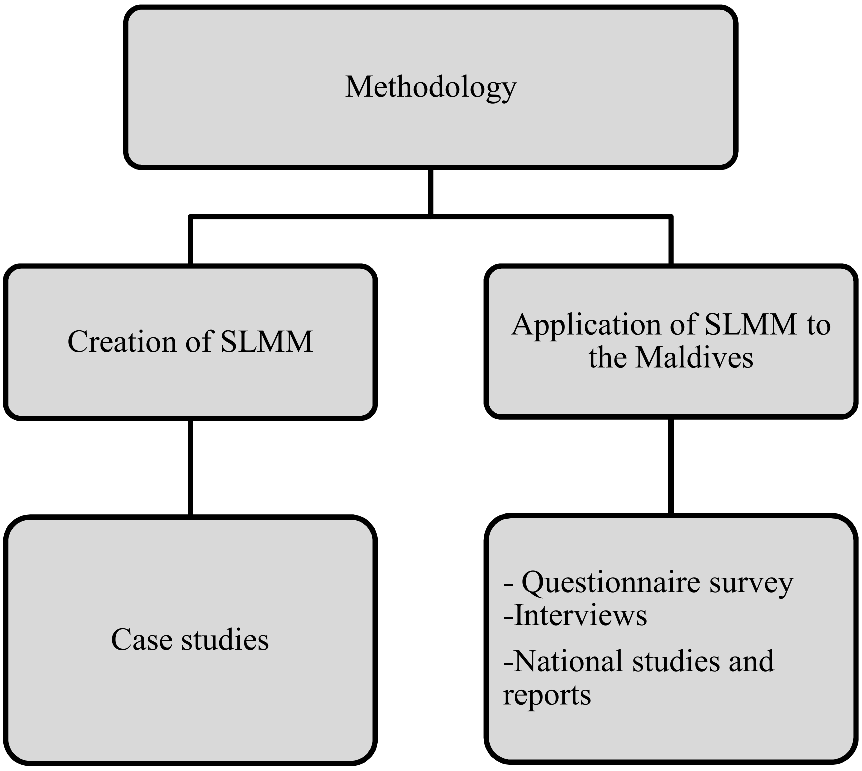

Figure 1 Methodology

3.1) Creation of SLMM

The domains of the SLMM model are identified through the works of (Sung & Carlsson, 2003) which are industrial organization, technological infrastructure, institutional infrastructure and the government policies. The domains are categorized into six maturity levels which are consistent with the maturity levels of the SGMM. The maturity levels are defined with a bottom-up approach proposed by De Bruin, Freeze, Kulkarni, & Rosemann (2005) which calls for the use of existing literature to identify maturity levels at each domain.

The International Energy Agency report on renewable energy (International Energy Agency, 2010b) shows that the largest producers of electricity by solar cell power in 2009 were Germany, 6200GWh, Spain, 6103GWh and Japan, 2251GWh. Germany's electricity production by solar cells increased at an annual rate of 67% from 2000 to 2009 while in Spain the annual increase in production was 91% while in Japan it was 23% for the same time period (International Energy Agency, 2010b).A case study of literature on Germany and Japan is conducted to analyze what represent maturity with respect to the domains which will allow for the categorization of each domain into different levels. The reason only the case of Germany and Japan was taken in the study is due to the availability of literature on solar cells with respect to these two countries as well as their long history in the development and use of solar cells. This long history enables the identification of specific functions that were crucial in the dissemination of solar cells within these countries.

Literature studies that use the systems approach to analyze the development of solar cells within Germany and Japan will be mostly used. As the systems approach does not emphasize much on the behavior and attributes of the users who consume the electricity generated by solar cells, general literature on the subject will be referred to understand and develop the maturity levels pertaining to the users. In order to gain more insights about users, two hypotheses will also be proposed.

The literature studies of Germany and Japan will only be used for the government policy, institutional infrastructure and the industrial organization. The part pertaining to users in the industrial organization will be developed using general literature on the subject of the users of the renewable energy. The technological infrastructure will be developed by analyzing the SGMM, specifically the SGMM Compass Assessment Survey and SGMM Definition. Figure 2 below shows the methodological approach of creating the SLMM.

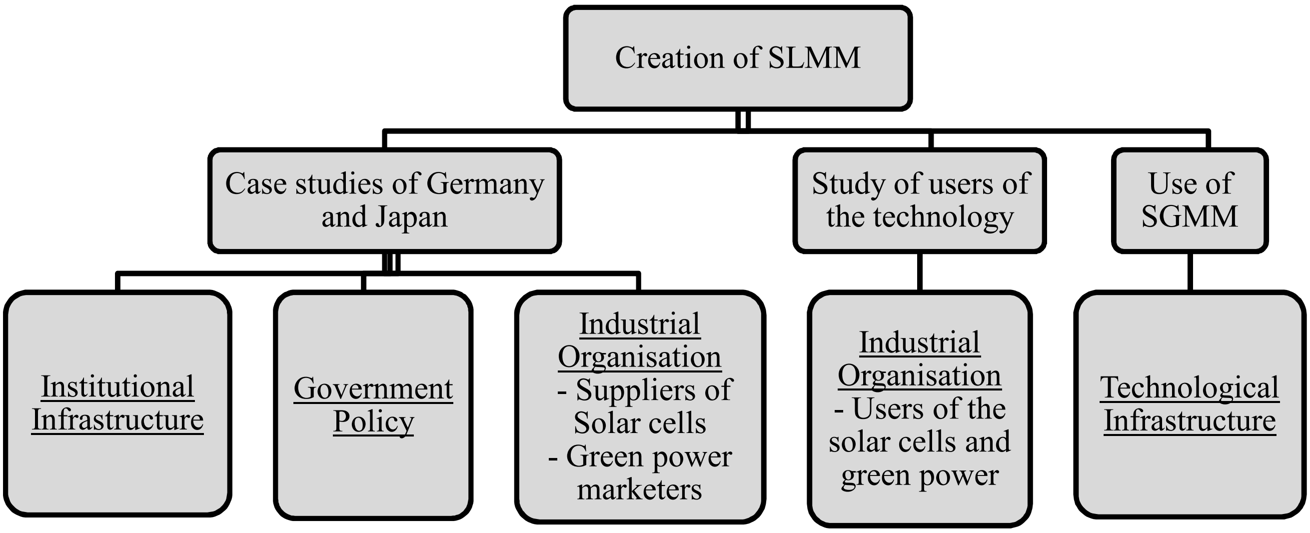

Figure 2 Methodology for creating the SLMM

3.2) Application of SLMM to the Maldives

Once the SLMM has been created each domain will have six maturity levels. Each maturity level will have an assessment criterion that needs to be met for the technological system to be recognized at that level. The assessment criteria should be completed by a person well versed in that specific domain. In the case of CMM and SGMM which are created specifically for organizations, the person who completes the assessment criteria may be a senior executive or a department head. In the case of SLMM which is focused on a technological system which has different domains which are not under one umbrella such as in the case of an organization, multiple people who are knowledgeable in these areas should be use to complete the assessment criteria. In the case of application of the SLMM to the Maldives, interviews with relevant key stakeholders of the technological system, a review of national studies and reports as well as a questionnaire survey will be used.

The industrial organization domain assessment will be done using a questionnaire survey administered to citizens of Maldives and the use of national studies and reports. The results of the questionnaire survey will also be used to verify the hypotheses proposed in the paper.

The institutional infrastructure domain assessment will be completed with the use of national studies and reports. The government policy domain assessment will be completed with the use of interviews with Ministry of Housing and Environment's senior executive's as well national studies and reports. The technological infrastructure domain assessment will be completed with the use of interviews with senior executives of STELCO. Even though other utilities exist within the country, STELCO is specifically chosen because STELCO is the leading utility in Maldives in terms of human resource, finance, generation capacity and technical infrastructure. In terms of achieving a smart grid, STELCO is the most likely candidate as STELCO operates in the capital Male', which is the main political and economic centre of the Maldives hence making STELCO the best candidate for assessing the technological infrastructure. Figure 3 below shows the methodology of applying the SLMM to the Maldives.

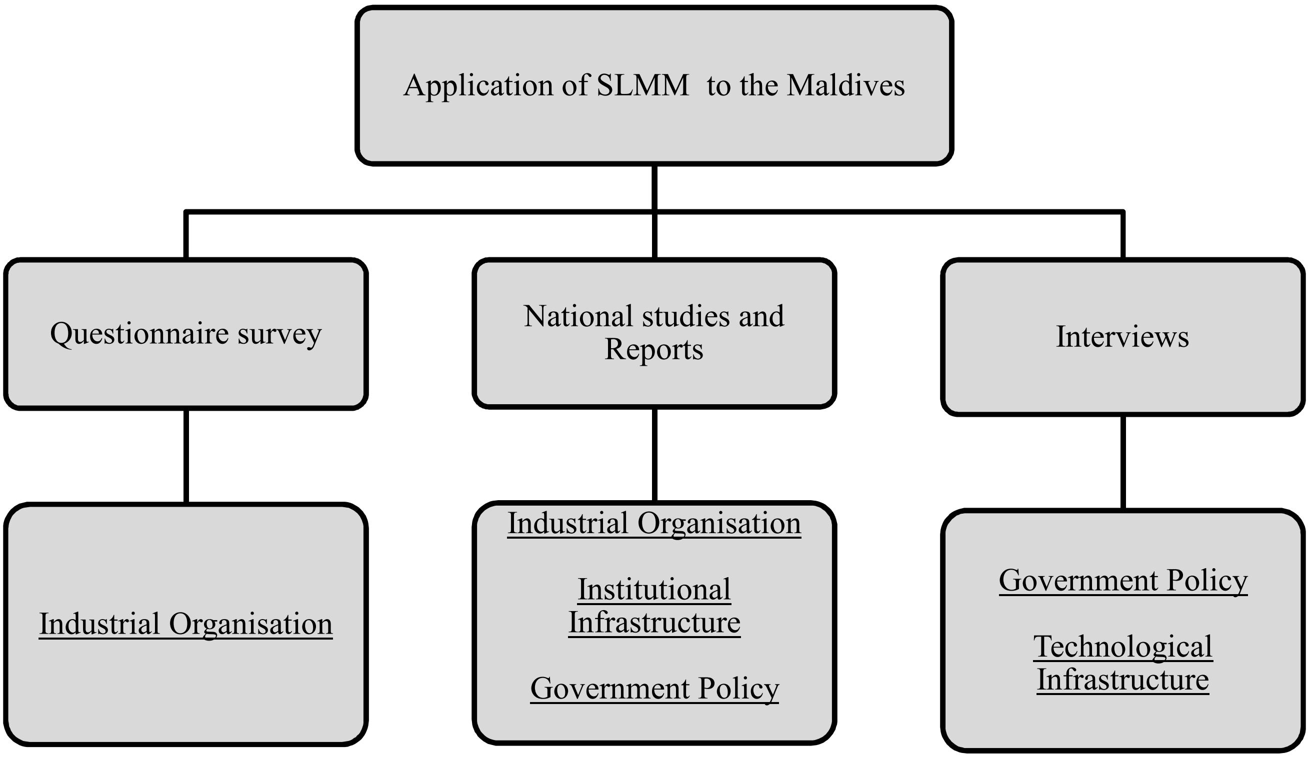

Figure 3 Methodology of application of SLMM to the Maldives

Once the SLMM model is applied to the Maldives, an analysis of the current situation of the solar cell technological system in the Maldives as well as recommendations on how to improve the solar cell technological system will be proposed.

4) Research Concern and Originality

My employment in STELCO as a power grid distribution engineer from 2006 to 2009 inspired me with the idea for this thesis. The STELCO power grid is over utilized as demand is increasing at a higher rate than the rate at which new capacity can be accommodated into the system. Hence system failures are becoming a norm. Major constraints for increasing new capacity within the power system are the unavailability of space, finance and the centralized nature of the system. When a power system is centralized power loss increases as the power has to travel a longer distance to reach the consumers and also the system becomes more vulnerable as a high load is put on the transmission network. Decentralized power generation is the solution to these problems as the system load is more distributed though out the system meaning consumption takes place closer to the production point. The other advantage of decentralized power generation is that it solves the issue of space constraints as many small spaces are needed rather than one large space to produce power. And finally the ultimate advantage is the sustainable nature of the generation systems when the generation source is a renewable energy source. Hence based on these experiences, my aim was to do a study on the dissemination of decentralized energy systems within a power system. Solar cells were chosen due to the easy integration of the system into domestic households as well as due to the high availability of solar resource within Maldives.

The originality of this paper is that the SGMM is taken as the technological infrastructure and is expanded to accommodate the industrial organization, government policy and the institutional infrastructure to create the SLMM. The structure of the SGMM was maintained throughout the SLMM. The purpose that the SLMM achieves is different from the SGMM, where the SLMM aims to foster the diffusion of solar cell technology within a country to achieve a low carbon society while the SGMM aims to realize a smart grid at a utility level. Maturity models have been created to achieve certain goals of an organization such as the use of SGMM to achieve a smart grid by a utility. To my knowledge this is the first time a maturity model has been created to improve a technological system at a country level.

Systems literature states that is it easier to borrow from a technological system that is identical or closely related. Hence in the case of the Maldives it is better to replicate functions of a technological system closer to their system such as Malaysia rather than to replicate functions from developed countries like Germany and Japan. Germany and Japan has a long history of solar cell development as well as solar cell use spanning more than 30 years and the evolution of their technological system have been well documented in literature. In the case of Malaysia, solar cell technological system is just five years old with total installed capacity as of 2009 being a mere

11MW of which 90% are not connected to the electric grid. In Japan the solar cell installed capacity is 2627MW as of 2009 of which 96% is connected to the grid (International Energy Agency, 2010a).Hence the solar cell technological system of Malaysia is not mature enough to be used in the development of SLMM.

It is expected that papers like this will contribute to the existing knowledge in this area which eventually will lead to a solution to achieving a low carbon society and their economic and environmental benefits.

5) Solar cell technological system

5.1) Leading solar cell countries

5.1.1) Case of Germany

a) Industry

The solar cell industry in Germany was initiated in the seventies by the federal government's RDD Programme (Research, Development and Demonstration Programme) which helped universities, research institutes and firms in the development of solar cell technologies (Jacobsson, Andersson, & Bångens, 2002).The funding provided by the government induced knowledge creation within the newly formed solar cell technological system and guided the search process of firms towards solar cell development (Jacobsson, Andersson, & Bångens, 2002).The research direction is set by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) which announces guidelines and research priorities which will be funded by them each year. Currently R&D in solar cells is conducted under the 5th Programme of Energy Research which is administered by the Project Management Organisation (PtJ).Apart from BMU Ministry of Education and Research (BMBF) also supports the R&D projects.

The demonstration projects backed by federal funding saw the construction of large solar cell plants as well as domestic roof mounted installation projects which had the effect of creating application knowledge ,installation know how and also standards for installing systems (Jacobsson, Andersson, & Bångens, 2002).The German universities and research institutes had a strong research base and became attractive partners for firms in the solar cell industry and the government helped in fostering this partnership (Jacobsson, Andersson, & Bångens, 2002).The existing strong manufacturing industry of Germany contributed to the success of the solar cell industry through reductions in the manufacturing costs of the solar cells (Marinova & Balaguer, 2009).Manufacturing a product locally can only be justified if a demand is available for the product. German manufacturers were reluctant to invest in local production until policy makers gave assurances that demand creation for the solar cells produced will take place (Jacobsson, Andersson, & Bångens, 2002).

Hence in 1990 a market formation program called 1000 Roofs Programme was started which resulted in 2250 grid-connected systems being installed on German roof tops (Berger, 2001).Under the program on average 70% of the initial investment cost was subsidized (Berger, 2001).The implementation of the 1000 Roofs Programme was well monitored and based on the success of the programme, the 100,000 Roofs Programme was implemented (Berger, 2001). Fraunhofer states that the 1000 Roofs Programmes main objective was to develop standards for installing the solar cell systems as well as to increase system installation knowledge (cited in Jacobsson, Andersson, & Bångens, 2002).After the commencement of the 1000 Roofs Programme, the rate-based incentive programme was introdcued in 1993 where a fixed tariff rate was set for a solar cell system that feeds into the grid for a time period of 10-20 years (Berger, 2001). This meant that the utilities were obliged to buy the electricty produced by solar cell systems. Due to awarness of solar cells within the german public,utilities began to conduct their own solar cell support programmes due to the increasing public demand as well as increasing awarness of the utilities towards solar cell (Berger, 2001).

Due to the governments initiatives as well as the utilities, the solar cell market within germany began to expand.This growing market attracted various entrants into the solar cell market which saw the emergence of spacialized suppliers and new markets (Jacobsson, Andersson, & Bångens, 2002).One of these specialized markets is the building integrated solar cell facades.The first building integrated solar cell facade project was done in 1991 on a building in Aachen,Germany which attracted the attention of architechts and engineers from around the globe (Perlin, 1999).Since then building integrated solar cell systems have been increasing within Germany.

Due to the resources that the German government was inputing to develop solar cells, more firms started devloping solar cells and due to the growing market, more firms started entering the business of solar cells.Hence the number of actors within the solar cell technological system in Germany increased and strengthend the advocay coalitions that supported solar cells (Jacobsson, Andersson, & Bångens, 2002).Various organizations were created to support the dissemination of solar cells within germany such as the German Society For Solar Energy, Förderverein Solarenergie(created the concept behind the feef-in laws), German Professional Association of Solar Energy, German Solar Energy Industries Association and Eurosolar.The membership of these organizations include people from the political arena,industry and acadamia. These organizations were involved in the creation of polices,technical standards and conducting of public awarness programmes.The networks these organizations created influenced the technical as well as political, industrial and public arena which was crucial in changing the institutional setup in favor of dissemination of solar cells (Jacobsson, Andersson, & Bångens, 2002).During early stages of development of a technology, the institutional setup is more favourable to the incumbents technologies hence advocates of emerging technologies such as solar cells have to make broad coalitions with other reenwable energy interest groups to form a critical mass to tackle the well organized opposition from the incumbents.The collaboration of German wind and small hydro operators in 1990 is an example of this (Wustenhagen & Bilharz, 2006).

Compared to the German governmnets efforts to develop solar cell technologies in response to the oil crisis, the efforts put into nuclear energy as well as coal was much higher (Lauber & Mez, 2004).With the Chernobyl accident in 1986 public opinion against nuclear energy was more than 70% and environmental awarness started increasing in Germany.This maybe one of the reasons why the German Green Party came to power and they gave special attention to climate change policies with an aim of making the energy sector an example in their environmental efforts (Lauber & Mez, 2004).

In 1998 the green power market was opened to all customers with the liberalization of the electricty markets (Bird, Wustenhagen, & Aabakken, 2002).But it took one year for competetive green power offerings to be available to residential customers (Bird, Wustenhagen, & Aabakken, 2002).Prior to the liberlization of the electricty sector, the utilities had green power offerings for customers but with the liberalization came the emergence of green power marketers with competetive product offerings (Bird, Wustenhagen, & Aabakken, 2002).This changed the power structure of the electricity industry which was previouly monopolized by utilities.This stimulated aggressive green power marketing activities by utilities as well as green power marketers.

In terms of renewable energy capacity increases, the government subsidies have been more effective than green power marketing.Between 1991 and 2003, in the german wind industry 13,000MW of new capacity was installed due to government subsidies while between 1999 and 2003 the amount of new wind capacity due to green power marketing was 127MW (Wustenhagen & Bilharz, 2006).

Due to the liberalization of the electricty markets the monopoly states of the utilities were lost, hence the obligation to purchase power that was set on the utilities was trasnferred to the local grid companies which were regulated monopolies (Wustenhagen & Bilharz, 2006).A nation wide settlement system was developed where the cost of purchasing the grid-fed electricty is tranferred to the high voltage transmisson which is controlled by the governmnet,and this cost is evenly distributed through out Germany (Wustenhagen & Bilharz, 2006).Out of the 900 municipal utilities in germany, 95 utilities offer green power products (Bird, Wustenhagen, & Aabakken, 2002).German green power products are catagorized into three areas which are 100% hydro power,a mixture of renewables with cogeneration and 100% renewables which includes new renewable energy sources such as solar cell power mixed with hydropower (Bird, Wustenhagen, & Aabakken, 2002).The market for power produced by solar cells is still low in Germany , mainly due to the high cost of solar cells and also due to the dominace of hydropower within the green power market. The green power market in germany is moderately developed and there is potential for solar cells to play a key role in the market as the prices of solar cell systems decrease.

In green power markets, the product differentiation is difficult as the electricty produced from a renewable energy socurce is the same as the electricty produced from a fossil fuel energy source.Hence in Germany eco-labelling schemes have been created to differentiate the attributes of green power (Wustenhagen & Bilharz, 2006). These differentiations include wheather the generated electricty is subsidized or subsidy free (Wustenhagen & Bilharz, 2006). Eco-Labelling schemes in germany include ok-power,GSL and TUV.In order to foster the addition of new capacity by green power marketers, these labelling schemes require new addional capacity to be installed by the green power marketers for their prodcuts to be certified (OK-Power, 2011).

By the end of 2009, the Installed capacity of grid-connected solar cells was 9800 MW with 3840MW being installed in 2009 alone (International Energy Agency, 2010a). The high increase in 2009 is due to a decrease in system prices of 30% compared to 2008 (International Energy Agency, 2010a).The figure 4 below shows the cumulative installed capacity of solar cell power in Germany. As can be seen in figure 4, the liberalization of markets in 1999 and the revision of the existing feed-in law helped increase the dissemination of solar cell in Germany.

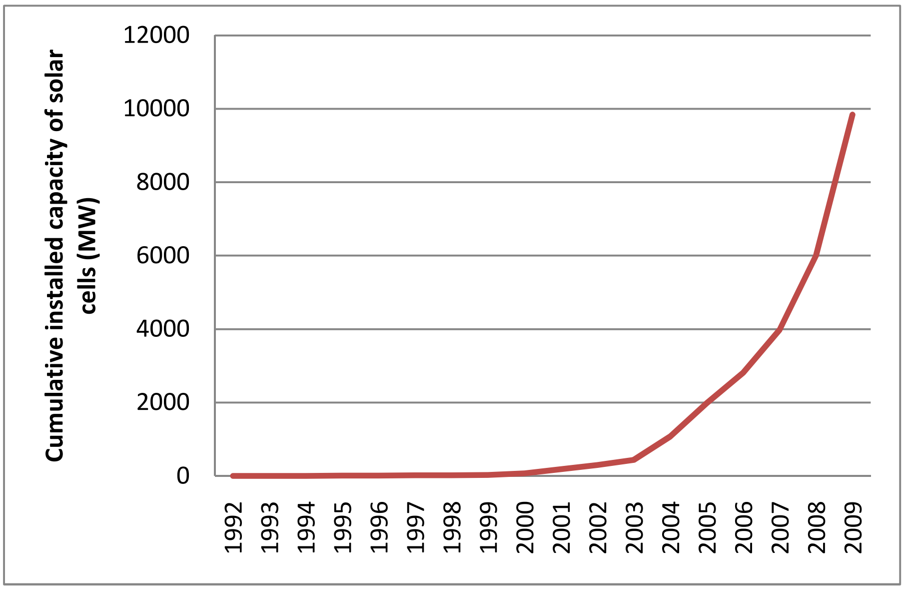

Figure 4 Cumulative installed capacity of solar cell power in Germany (International Energy Agency, 2010a)

b) Institutions

Research at academic institutions alone is not sufficient as without a connection with the industry to develop the research achievements, the benefits of the achievements will go overseas (Marinova & Balaguer, 2009).The achievements of the German universities and research institutions were transferred to the firms in the solar cell industry with the help of the government which fostered industry-academia linkages (Jacobsson, Andersson, & Bångens, 2002).The manpower to do research as well as sustain the industry is produced by the universities and technical schools. The German education system is well developed and students can study up to doctorate programmes in engineering.

Environmental education is taught at all primary schools in Germany and also technology education was offered within the school system as early as the sixties (Höpken). Boerner (2000) states that by the nineties solar cell courses were conducted at secondary schools as well as by module manufacturers(cited in Jacobsson, Andersson, & Bångens, 2002).Hence solar cell studies were integrated into the school curriculum (Berger, 2001). In order to increase the awareness of the students to solar cells, solar cell systems are installed on on the rooftops of selected schools which increase their exposure to the technology (Berger, 2001).

The German technical standards associated with solar cells are extensive which cover standards for measuring principles, modules, grid connection, components and system in general (DKE, 2011). On top of this the German energy conservation act was enacted to reduce energy requirements for heating and hot water to make buildings more energy efficient. (BMVBS, 2011).

In the financial sector, the state owned bank KfW Bankengruppe provides loans for solar cell for individuals as well as local authorities while the fiscal authorities provide tax credits for solar cell investments (International Energy Agency, 2010a).This bank also provide finances to upgrade houses to make them more energy efficient (BMVBS, 2011).The financial sector of Germany is advanced with a mature stock exchange that helps to facilitate entrepreneurship.

c) Government Policy

With the oil crisis of the 1970s, Germany started a Federal funding RDD(research, development and demonstration)programme for solar cells which guided the direction of search into solar cells, created new knowledge (in solar cell development and application) as well as induced new firms to enter into solar cell development (Jacobsson, Andersson, & Bångens, 2002).The German Federal funding for RDD was followed by the 1000 roof programme in 1990 which enabled the creation of a viable market for solar cells (Jacobsson, Andersson, & Bångens, 2002)and also strengthened installation technologies and grid connectivity technologies (Gabler, Heidler, & Hoffmann, 1997).In 1991 a 'cost covering feed-in-law' was passed in Germany which was proposed by advocacy coalitions of renewable energy. The advocacy coalitions included Förderverein Solarenergie and Eurosolar who created the concept as well as other industry associations, owners of renewable energy plants and parliamentarians (Jacobsson, Andersson, & Bångens, 2002).The feed-in-law was vigorously opposed by the utilities but the lobbying of the renewable energy advocates was enough to preserve the feed-in-law (Jacobsson, Andersson, & Bångens, 2002).The feed-in-law gave the renewable energy electricity supplies 90% of the domestic market price for electricity, but as the market was liberalized in 1998 the prices of electricity dropped. Hence the feed-in-law was revised in 2000 and the feed-in-tariff rate was changed from a factor of domestic market price to a fixed price for a period of 20 years with differentiations among the fixed price depending on the renewable energy technology (Jacobsson, Andersson, & Bångens, 2002).This was done as the maturity of different renewable technologies were different such as the case of wind and solar where the electricity production cost of wind power was lower than the electricity production cost of solar cells. The feed-in-law known as the Renewable Energy Sources Act (EEG) is the most effective tool driving the solar cell market in Germany. The EEG states that the feed-in-tariff price depends on the system size and the type of the system (Hunnekes, 2011).In 2009 a new tariff was introduced for self consumed power on top of the power that is fed into the grid (Hunnekes, 2011).The feed-in-tariff price is reduced annually to put pressure on manufacturers to make the systems less costly and more efficient and also the feed-in-tariff price is adjusted to the growth of the market. Apart from the support rendered by the EEG, tax credits and soft loans are also available for solar cell investments (International Energy Agency, 2010a). BMU is the key player in the dissemination of renewable energy in Germany who conducts subsidy programs and R&D funding for solar cells in Germany.

Solar cells catered for 2% of the domestic electricity consumption in 2010 and under the German Renewable Energy Action Plan, this percentage is to be increased to 7% by the year 2020 (Hunnekes, 2011).

5.1.2) Case of Japan

A) Industry

The start of the solar cell industry in Japan was due to the Japanese governments R&D initiative of solar cells under the Sunshine Project (Kamp, Negro, Vasseur, & Prent, 2009).The Sunshine Project motivated the entry of firms from different disciplines to pursue solar cell development in Japan (Watanabe, Wakabayashi, & Miyazawa, 2000).The solar cell R&D programmes are coordinated by New Energy and Industrial Technology Development Organization (NEDO) which is a semi-government organization. NEDO helps in bringing industry, academia and government together in the solar cell R&D initiative to generate superior results (New Energy and Industrial Technology Development Organization, 2011).Apart from R&D, demonstration projects are also conducted with focus on grid-connected solar cell application technologies such as smart grids (Yamamoto & Ikki, 2011).R&D for solar cells is currently aimed at achieving the technological targets based on the Roadmap PV2030+ (Yamamoto & Ikki, 2011).

In order to develop the solar cell market, the Japanese government initiated the 70,000 solar roof subsidy program in 1994.A residential monitoring program was also conducted in 1997 where the operation data of the subsidized systems were collected to increase the solar cell system application knowledge (Ogawa, 2000).The Japanese solar cell subsidy programmes are mostly focused on residential households, hence by the end of 2004, 92.3% of solar cell grid connections were residential and public buildings(Foster,2005).Due to these programmes the housing manufacturers offer solar cell systems as an option when selling prefabricate houses (Foster, 2005).With prefabricated housing accounting for 14.1% of the total newly built houses in 2008 and the number expected to increase, it is expected to give and extra boost to the solar cell dissemination process (Noguchi & Kim, 2010).A whole variety of solar cells are available in the Japanese market such as flexible solar cells for roofs, wall integrated solar cells, colour coded solar cells and many more varieties which give the users the ability to use the solar cells in different design with different functions (Ogawa, 2000).

By the end of 2009, the Installed capacity of grid-grid-connected solar cells was 2532 MW with 479 MW being installed in 2009 out of which 99% were grid-connected residential systems (International Energy Agency, 2010a). The accelerated growth was due to the restart of the subsidy programme which was stopped in 2006 and also due to a newly formulated energy act which calls for utilities to purchase surplus power from solar cell systems at almost double the normal electricity price for systems below 10kW (International Energy Agency, 2010a).These purchase prices are set to be periodically reviewed in line with changes in the solar cell system prices.

Figure 5 below shows the increase in the solar cell installed capacity from 1992 to 2009.There has been steady growth in installation of new capacity which stared from 1995 when the subsidy program was started till 2006 when the subsidy program was stopped which affected the growth a little. The subsidy program was reinstated in 2009.

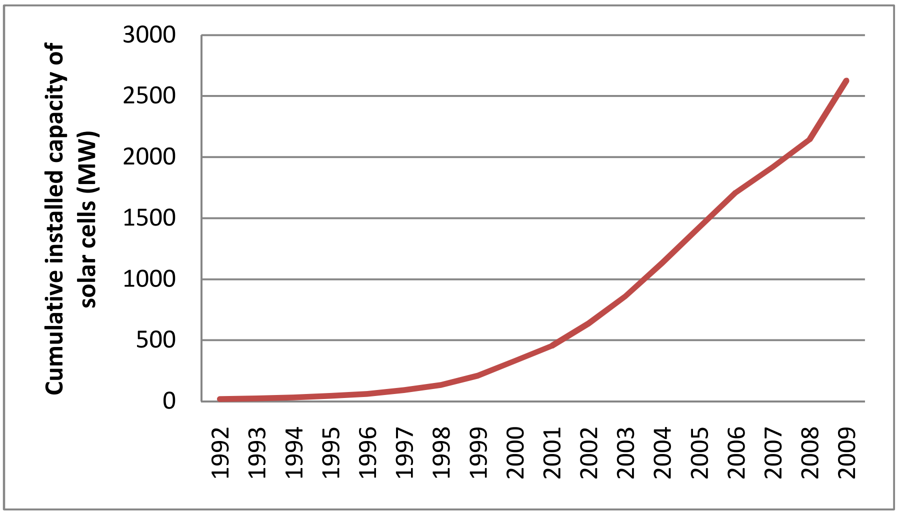

Figure 5 Cumulative installed capacity of solar cell power in Japan (International Energy Agency, 2010a)

In 1999 the, the Japanese electricity market was partially deregulated to foster competition which paved the way for large industrial and commercial customers to chose their power supplier according to their needs (Bird, Wustenhagen, & Aabakken, 2002). The following year the utilities created programmes where customers can contribute to a green power fund to support wind and solar technologies (Bird, Wustenhagen, & Aabakken, 2002). The contributions are not fixed and can vary from 100 Yen per month to more than 500 Yen per month and contribution is voluntary. This is a different kind of green power marketing as in the case of Germany where the consumers pay a premium for the green power they consume while in Japan the premium is a donation to develop green power rather than a factor of their consumption levels. Utilities introduced the net-metering system where solar cell systems connected to the grid produces the electricity and the shortfall is met by the utility power supply and if any surplus power has been generated by the solar cell system, then the surplus amount is purchased by the utility at the electricity selling rate (Ogawa, 2000).This feed-in electricity rate has now been revised in 2009 which is now double the current electricity selling rate (Yamamoto & Ikki, 2011).

Apart from the contribution programmes, cooperatives are formed where customers can invest in future renewable energy projects and yield dividends from the sale of the electricity produced (Bird, Wustenhagen, & Aabakken, 2002).The Japan Natural Energy Company which was formed in 2000 sells electricity to large commercial and industrial customers at a premium price which mimics the German green power marketers model (Bird, Wustenhagen, & Aabakken, 2002).In order to certify the Japan Natural Energy Company's products, the Green Energy Certification Centre was established at the Institute of Energy Economics (The Green Energy Certification Center, 2009).The Japan Natural Energy Company's portfolio of renewable energy sources include biomass, wind, hydro and solar with biomass leading in terms of capacity followed by wind and solar (Japan Natural Energy Company, 2011).Japanese utilities have started advertising their green power products but as competition is not high the marketing activities are not very aggressive. One reason for this maybe that the electricity market it not fully deregulated. Unlike the case of Germany where advocacy coalitions are led by renewable energy interest groups, the initiatives in Japan are led by the utility companies. For example the Japan Natural Energy Company is a joint venture company of Tokyo Electric Power Company and 10 other companies (Bird, Wustenhagen, & Aabakken, 2002).

b) Institutions

The R&D of solar cell in Japan is conducted though industry-academia collaborations which are facilitated and fostered by NEDO. The universities and technical schools in Japan offer advanced courses in solar cells to cater for the industry needs. Japanese universities currently offer doctorate programs in solar cell technologies.

Environmental education is taught in schools but special solar cell education programmes are not offered at secondary schools. In 1997 the eco-school programme was started to make schools more environmentally friendly. Under the eco-school programme more than 600 schools were equipped with eco-friendly technologies such as solar cells (Mori, 2007).These initiatives help students to get more exposure to solar cell technologies.

The Japanese solar cell installation standards are very simple and electricians trained by the industry install the solar cell systems (Foster, 2005).The industry self regulates the installation of the systems as well as the quality of the systems and this is possible because the companies doing the installations act in a responsible manner as it is a matter of honor and pride for the installation companies to serve the customer well (Foster, 2005). In Japan energy conservations standards are created to increase the energy efficiency of the housing sector, but compliance is of a voluntary nature (Laustsen, 2008). In order to reduce energy consumption, the government started the "eco points" program where points are offered for buying energy efficient appliances and these points can be redeemed for other goods and services (Yoshida, Inahata, Enokibori, & Matsuhashi, 2010).

Some banks in Japan provide low interest loans for the introduction of residential solar cell systems and the amount of banks that give these kinds of loans are increasing each year (Yamamoto & Ikki, 2011). Apart from these low interest loans, tax credits are also offered to support the dissemination of solar cells. Though the financial system of Japan is very strong, entrepreneurship is very low mainly due to social and cultural reasons.

c) Government Policy

Solar cell development and dissemination in Japan shares a similar story to the Germans. After the oil shock of 1973 the Japanese government started the development of solar cells under the

Sunshine Project (Watanabe, Wakabayashi, & Miyazawa, 2000).Under this project, R&D of solar cells increased as well as the production of solar cells and the price of solar cells decreased. The 70,000 solar roof subsidy programmes became the ideal tool to keep the momentum of the reduction in prices by creating a market for the industry to thrive on.

In Japan the policy making process takes place behind closed doors where the government interacts with stakeholders through advisory committees (Kamp, Negro, Vasseur, & Prent, 2009).

Ministry of Economy, Trade and Industry (METI) is the key player in the dissemination of solar cells in Japan. METI conducts the subsidy program for residential, public and industrial applications as well as the surplus power purchasing programme (International Energy Agency, 2010b).METI also supports local governments to conduct their own programs such as low-interest loans and tax credits (International Energy Agency, 2010b).To date over 500 municipalities have their own subsidy programmes (International Energy Agency, 2010a).

METI gives subsides to systems which fit in the range of maximum output capacity below 10kW and the price of the system should not be more than 650,000 yen per kW (International Energy Agency, 2010b).The rate of subsides decrease gradually as the price of the systems decrease (Marinova & Balaguer, 2009). The subsidies which started in 1994 was stopped in 2006 which slowed the dissemination of solar cells within Japan, hence the subsidy program was reinstated in 2009.

Since November 2009, METI has been conducting the program to purchase surplus power of solar cell systems based on the “Act on the Promotion of the Use of Non-fossil Energy Sources and Effective Use of Fossil Energy Source Materials by Energy Suppliers” (International Energy Agency, 2010b).For residential solar cell system with a capacity less than 10kW, the purchase price is 48 JPY/kWh which is almost double the normal residential electricity tariff rate. The time period for the purchase is 10 years and the purchase cost is evenly distributed among all the electricity users

(International Energy Agency, 2010b). The subsidy program and the surplus power purchase program are well aligned to benefit the residential customers which accelerated the dissemination of solar cells in Japan.

Japan has set a target of 28GW installed capacity of solar cells by 2020 and 53GW by the year 2030 under the Action Plan for Achieving a Low carbon Society and the J-Recovery Plan (Yamamoto & Ikki, 2011).

5.2) Study of Users

Though studies have been done about the market, policies and institutions regarding solar cells, few studies have been done regarding the consumers of the solar cells in the context of Germany or Japan. Due to this reason the study about the maturity of the users of the solar cells is analyzed using general literature rather than the case of Germany or Japan.

Lund (2007) proposes three major technological changes that need to take place for renewable energy to successfully contribute to sustainable development. They are energy savings on the demand side, efficiency improvements in energy production and replacement of fossil fuels by renewable energy. Consumers have a potential role to play in all three changes and their actions and awareness will have a positive effect on making renewable energy a part of sustainable development as well as achieving a low carbon society.

Potential adopters of a new product are faced with high uncertainties during the adoption process which are reduced through the accumulation of knowledge about the product.(Arkesteijn & Oerlemans, 2005).This knowledge of the consumers has a say in their actions with regard to adoption which can be defined in the maturity of the consumer to adopt a certain product or service. As global warming is one of the reasons for the development of renewable energy technology, the knowledge of global warming of the consumer plays a role in the adoption of renewable energy technology. As solar cells have still not reached grid-parity (the point at which the cost of electricity produced by solar cells is the same as the cost of electricity produced by conventional energy sources), adoption of the technology is strongly supported by the governments. This knowledge is important as the government support is what makes the solar cell feasible for adoption.

The Eurobarometer survey on ‘Attitude Towards Energy’ (Eurostat, 2006) asks citizens of EU regarding their willingness to pay a premium price above the normal electricity price for renewable energy for which 37% said they are willing to pay a premium for electricity produced from renewable energy sources while 54% said they are not willing to pay a premium. Though stating the willingness to pay does not mean that the person will definitely go ahead with the action, it is considered an indicator of the consumer demand for the product (Wustenhagen & Bilharz, 2006).The demand drives the market which led to successful renewable energy projects in the United States (Bird, Bolinger, Gagliano, Wiser, Brown, & Parsons, 2005).The willingness to pay also has policy advantages as it helps to determine the financial incentive which bridges the gap between the cost of the electricity produced and the willingness to pay amount. Failure to accurately estimate the consumers’ willingness to pay have led to overestimations of the financial incentives which if estimated correctly could have helped promote more renewable energy (Haas, 2003).

Olsen (1981) states that people who anticipate personal consequences as a result of household energy consumption are likely to act on it by reducing consumption. Whether the action is to save money or to act on the energy problems, the action contributes to reduction in demand which helps to achieve a low carbon society as the demand that needs to be catered for by low carbon technologies decreases. Hence the act of reducing consumption or conserving energy is an informed decision which reflects the maturity of the consumer towards energy issues. A European Commission survey (The European Opinion Reserch Group, 2002) asks citizens of EU about the actions to save energy and future intentions to save energy from a designated list of eight actions that can be taken to reduce energy consumption. The results show that Europeans take an average of two actions and intends to take one action to conserve energy.

Knowledge is the core foundation of adoption which manifests into intentions and actions. In terms of helping the dissemination of renewable energy two main actions are possible which are paying a premium for electricity produced from renewable energy and adopting a renewable energy system. One of the main reasons behind the development and use of renewable energy is the impact it will have on the global warming process. The following two hypotheses are therefore formulated:

H1: The more a person has awareness of global warming, the higher the willingness of a person to pay a premium for renewable energy.

H2: The more a person has awareness of global warming, the higher the willingness of a person to install a solar cell system.

Figure 6 summarizes all the hypotheses.

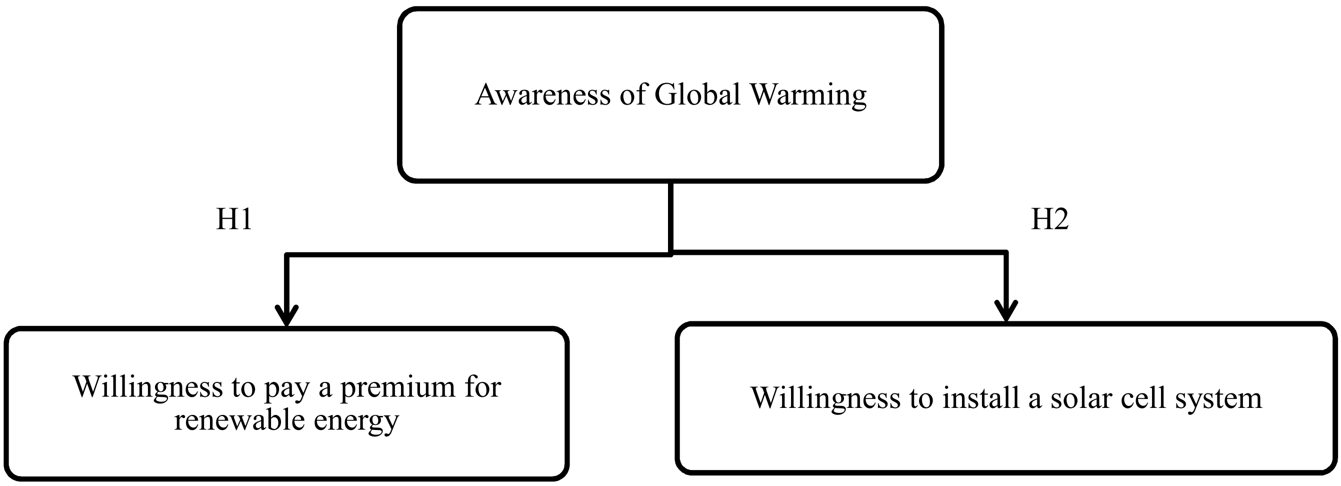

Figure 6 Hypotheses

It may be argued that income of the consumer plays a role in the adoption process, however investigations from Berlin and Munich in Germany show that solar cells are marginally installed in the wealthiest areas of the cities (Berger, 2001).The solar cell programmes are created to minimize the financial burden on the adopters in order to increase the adoption level so the awareness level towards renewable energy is more significant than the financial capability of the person who adopts solar cell systems. But in terms of willingness to pay for electricity produced from renewable energy sources, the income of the consumer plays a crucial role in combination with awareness of renewable energy (Eurostat, 2006).

5.3) SGMM

The electric grid is an interconnected network for delivering electricity from the point of power generation to the point of power consumption. The electric grid consists of power generation facilities, transmission facilities as well as distribution facilities. The modern day alternating current electric grid is developed on the design of Nikola Tesla in 1888 (IEEE, 2011).Till today most of the initial design concepts are still used in the modern electricity grid. Though innovation has radically changed other areas such as communication technology, innovation is yet to come to the electric grid which is ageing and becoming more unreliable day by day. The modern electric grid heavily relies on fossil fuel energy sources for the production of electricity and contributes heavily to pollution. The urgent need to decrease carbon emission and reduce the impact of global warming combined with the depletion of fossil fuel resources has required for radical changes to be brought to the electric grid. One of these radical changes is the integration of information and communication technology (ICT) into the current electric grid to create a smart grid. The US Department of Energy (US Department of Energy, 2009) identifies seven characteristics that are present in a smart grid as (1)enabling of active participation by consumers,(2)accommodation of all types of generation and storage options,(3)enabling new products, services and markets,(4)Providing power quality for the digital economy,(5)optimize asset utilization and operation efficiency,(6)anticipate and respond to system disturbances and finally(7) operate resiliently against attack and natural disasters.

One of the most important features of the smart grid is the ability to integrate all type of generation into the smart grid which includes decentralized energy sources such as solar cells. Renewable energy like solar cells are used by consumers to feed electric power into the grid and also play a crucial part is other characteristics of the smart grid such as enabling new products and services, becoming resilient and optimizing of asset utilization. The general trend of grid-connected solar cells is increasing annually as can be seen in figure 7 below.

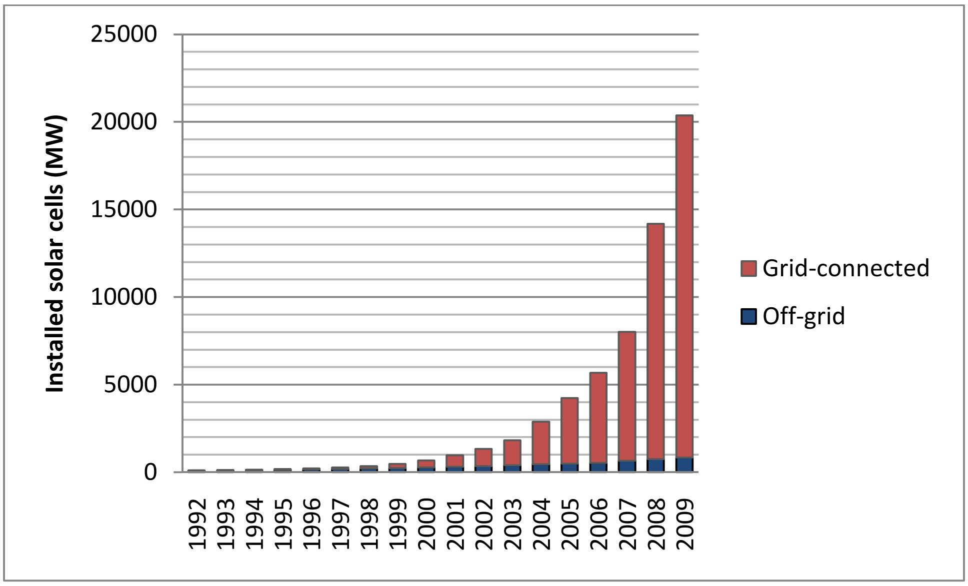

Figure 7 Cumulative installed solar cells in IEA PVPS reporting countries (International Energy Agency, 2010a)

Figure 7 shows the cumulative installed capacity of grid-connected and off-grid solar cell installations in countries affiliated with the International Energy Agency. The annual growth rate of grid-connected solar cells far outweighs the growth rate of off-grid solar cell systems. Hence a move to a smart grid is becoming ever important in order to accommodate the increasing rate of grid-connected decentralized renewable energy sources which are used to reduce global warming and attain a sustainable energy supply.

In order to realize the goals of achieving a smart grid, the Global Intelligent Utilities Network Coalition which consist of IBM and seven utilities from four continents created the SGMM to help utilities in transforming their electric grid into a smart grid (Ferro, 2009).The SGMM shows a framework of defined stages and options to enable the grid transformation process for a utility and helps to bridge the gap between strategy and execution that may exist (Ferro, 2009).The SGMM is now under the under the stewardship of the Software Engineering Institute at Carnegie Mellon

University where it was upgraded to the current version 1.1 (SGMM Team, 2010).The SGMM has eight domains which are (1)Strategy, Management and Regulatory (2)Organization and Structure (3)Grid Operations (4)Work and Asset Management (5)Technology (6)Customer (7)Value Chain Integration and (8) Societal and Environmental. The SGMM Model Definition (SGMM Team, 2010)explains the characteristics of each of these domains as follows.

The Strategy, Management and Regulatory domain represents the capabilities and characteristics to successfully develop a smart grid vision and a strategy and to implement the smart grid strategy through strengthening internal governance, management processes as well as relationships with stakeholders. Maturity in this domain consist of the emergence of smart grid leadership to implement the smart grid vision which leads to grid modernization that drives organizational strategy and open new business opportunities due to the smart grid.

The Organization and Structure domain represents the organizational capabilities that enable an organization to achieve a smart grid. These capabilities are associated with competence and skills within the organization as well as a cultural change in order to achieve the smart grid vision.

The Grid Operations domain represents the capabilities and characteristics that enable the reliable and efficient operation of the electric grid. Maturity in this domain is associated with the electric grid being capable of supplying reliable and efficient power as well as integrating decentralized energy sources.

The Work and Asset Management domain represents the capabilities and characteristics that support the optimal management of workforce and assets through the use of information gathered from smart grid technologies.

The Technology domain represents the capabilities and characteristics needed for technological planning and adoption of smart grid technologies which leads to the creation of new markets and business services for the organization. This includes the adoption of enterprise information technology architecture throughout the organization to support the smart grid technologies.

The Customer domain represents the capabilities and characteristics needed to enable customer participation within the smart grid operations. This includes giving the customer the option to manage and control their energy consumption to enable better utilization of energy within the electric grid.

The Value Chain Integration domain represents the capabilities and characteristics needed to successfully integrate the smart grid into the utility value chain and optimize profitability and performance of the value chain.

The Societal and Environmental domain represents the capabilities and characteristics to support societal goals such as resiliency and security of the electric grid as well as promoting environmental mitigation solutions.

The SGMM Model Definition is the core document of the SGMM and explains the characteristics of each domain in detail as well as the characteristics of each level within each domain. In order to measure these characteristics and apply the SGMM, a utility need to complete the SGMM Compass Assessment Survey. Completing this survey gives a utility a maturity level rating for each domain within the SGMM. This shows the utility their current standing in terms of achieving a smart grid as well as the next step that the utility should take in order to achieve a smart grid with respect to each domain.

In order to use the SGMM Compass Assessment Survey within the SLMM , Level 1 assessment questions will only be used for each domain as most utilities who have been assessed with the SGMM Compass Assessment survey are at Level 0 and Level 1 for all the domains (Software Engineering Institute, 2009).As of April 2009,40 utilities have participated in the SGMM with a customer representation of over 100 million (Ferro, 2009).As it is highly unlikely that a utility can achieve a level higher than level1 in any domain, in this paper the assessment questions pertaining to level 1 for each domain will be used. Please refer to Appendix B for the assessment criteria of each level within each domain as in the SGMM Compass Assessment Survey.

The eight domains in the SGMM are represented in the technological infrastructure domain of the SLMM as eight sub-domains. But for visual representation, all the eight sub-domains will be shown as one single domain.

6) Creation of the SLMM

6.1) Structure of the SLMM

A domain is a logical group of characteristics that help to increase the dissemination of solar cells within a technological system. The details of each domain are described through the characteristics of each level of the domain. The levels are progressive in nature with the characteristics of a lower level achieved before progressing to the next level. Hence the criteria of level 1 must be achieved before the criteria of level 2 is achieved and a ranking of level 2 means the criteria of level 1 has been achieved. The levels within one domain are independent of the levels within another domain so that each domain can be assessed and ranked individually. Ranking of each domain corresponds to meeting the criteria of each level of the domain. So if all the criteria of level 2 of a domain has been achieved it means the ranking of that domain is level 2.If only half the criteria of level 2 has been achieved, but the full criteria of level 1 has been achieved it means that the ranking of that domain is level 1.

The SLMM consist of six maturity levels which are consistent with the maturity levels of the SGMM. The maturity levels are;

1. Default (Level 0)
2. Initiating(Level 1)
3. Enabling(Level 2)
4. Integrating(Level 3)
5. Optimizing(Level 4)
6. Pioneering(Level 5)

Default (Level 0): The default level is the level below the initiating level. The initiating level will have certain characteristics to be met at that level. If those characteristics of the initiating level are not met, then it is said that the default level has been reached. The default level is not defined with characteristics. A default level means that the solar cell technological system has not developed or is in its very initial stages of development.

Initiating (Level 1): The initiating level represents the first implementation steps taken within the domain. This level is associated with the creation of a vision, strategy and identifying the options available within each domain in order to reach the final goal. These options are explored and evaluated by doing pilot projects and studies.

Enabling (Level 2): The enabling level is associated with the necessary actions that need to be done within a domain in order to achieve the primary function of that domain. This level is associated with commitments, formation of strategies and establishment of relationships with stakeholders.

Integrating (Level 3): The integrating level is where all the implementation features of Level 2 are combined to achieve the basic functions of each domain. These basic functions are not fully developed and have room for improvement. Hence the basic functions of a solar cell technological system are achieved to disseminate solar cells.

Optimizing (Level 4): The optimizing level is the level where the basic functions of level 3 are fine-tuned and used to further increase the dissemination of solar cells and reduce the carbon emissions by strengthening the actions taken within each domain.

Pioneering (Level 5): Pioneering level is the highest level achievable in each domain and is the level where innovation takes place. In terms of a solar cell technological system, new ground breaking measures and actions are implemented which become the standards for others to follow.

The SLMM is created by expanding the SGMM (which is taken as the technological infrastructure domain) into other domains which are industrial organization, institutional infrastructure and government policy. Hence the structure of the SGMM needs to be maintained throughout the SLMM so that uniformity exists within all the domains.

6.2) Industrial Organization

The industrial organization domain consists of the suppliers of solar cell systems, producers of electricity using solar cells (green power marketers) and users who consume the electricity. The analysis of the industrial organization domain is designed so that the maturity pertaining to suppliers of solar cell systems and green power marketers will be analyzed using national studies and reports. The analysis of users who consume the electricity will be analyzed using a questionnaire survey.

Initiating: Level 1

Users: The initial steps taken by a user are associated with having awareness of global warming and awareness of government initiatives to achieve a low carbon society. The global warming awareness level is measured by asking respondents of the questionnaire four questions regarding global warming. Correctly answering two questions out of the four questions means the person is aware of global warming issues. To test the respondents knowledge of government initiatives to achieve a low carbon society, for which the respondent has to acknowledge that he/she is aware and correctly identify a renewable energy technology that is going to be used by the government to achieve a low carbon society. The knowledge of government initiatives is important as it is the government's support that makes solar cell use feasible. In order to proceed to the next level the majority of the respondents should be aware of global warming as well as aware of government's initiatives to achieve a low carbon society.

Suppliers and green power marketers: The Japanese residential monitoring program and the German 1000 roofs program were the initial demonstration programmes conducted to start the dissemination of solar cells in these countries. The main aim of these decentralized pilot projects were to increase the application knowledge, standards and awareness towards solar cells.

In Germany the liberalization of the electricity markets fostered the emergence of green marketers and also the adoption of renewable energy by the utilities. The liberalization of the electricity sector provides a choice for the consumers who were previously locked into the services that the utility exclusively provided. Liberalization gives the consumer the purchasing power to support renewable energy (Stanford, 1998).Prior to liberalization the grid was owned by the utilities and as the grid is the medium over which trade of green power is delivered, it is important that this grid be accessible to green power marketers. So assessment for this level will be

- Awareness of global warming (>50%)
- Awareness of governments initiatives to achieve a low carbon society (>50%)
- Are decentralized solar cell demonstration pilot projects taking place which are well monitored?
- Is the electricity sector deregulated?

<u>Enabling: Level 2</u>

Users: Enabling relates to people committing to install solar cell as well as their actions and intentions to decrease the carbon footprint by adopting eco friendly solutions as well as their willingness to pay for renewable energy. Willingness to pay is an indicator of market potential for renewable energy and this voluntary nature of consumers to support renewable energy is a crucial element for successful market development of renewable energy. The European average of willingness to pay is 37% hence in order to proceed to the next level a willingness to pay of 37% should be achieved. The energy conserving patterns of the consumers are critical to achieving a low carbon society as every kilowatt of energy conserved is a kilowatt that need not be replaced with renewable energy technologies. On average Europeans intend to take two measures to save energy and intend to take one measure to save energy in the future. So in order to proceed to the next level an average of two actions and one intention must be scored by the respondents. Willingness to pay helps in the formation of the market which eventually leads to an increase in the renewable energy dissemination rate but willing to adopt a solar cell system directly leads to the increase in the dissemination of solar cells. So in order to proceed to the next level the majority of respondents should be willing to adopt a solar cell system.

Suppliers and green power marketers: With the demonstration projects, the German and the Japanese governments increased the resources for the adoption of solar cells. These resources include the subsidy given to the German 1000 and 100,000 roofs programme and the Japanese 70,000 solar roofs programme. These resources also include the availability of solar cells for the users to adopt. In Germany and Japan due to their governments R&D programmes, manufacturing facilities were setup to cater for local demand.

It is hard for the consumers to differentiate the product attributes of green power from electricity produced by fossil fuels. Also consumers need to know if the green power they are purchasing is subsidized or not. Hence in order to differentiate the products and shape the markets, co-labeling and green energy certification schemes are created. In Germany eco-labeling schemes were provided by independent parties so that the green marketers can differentiate their products. Also in Japan green energy certification schemes were available. So assessment for this level will be

- Actions and intentions to decrease carbon footprint(actions >2 & Intentions >1)
- Willingness to pay (>37%)
- Willingness to install a solar cell system (>50%)
- Are resources available for adoption of solar cell systems?
- Are solar cells readily available within the market?
- Are mechanisms to verify the attributes of the green power established?

Integrating: Level 3

Users: The integration stage relates to consumers adopting solar cell and using them for personal consumption or feeding to the grid or both. This is the stage where the commitments and secondary actions taken to achieve the goal integrate to make the solar cell adoption a reality. So people's willingness to install a solar cell system manifests into an action at this stage. To proceed to the next level the majority of the respondents should have solar cells systems installed in their homes and which are connected to the electric grid.

Suppliers and green power marketers: Once the supplies of resources are available, people will start adopting the solar cell systems. Once this process was started as well as while this process was starting, incumbents in the fossil fuel technologies started working against the momentum of renewable energy as can be seen in the case of Germany. Hence advocacy coalitions were formed from a wide spectrum of renewable energy technologies which strengthened the coalition and were able to ward off the opposition caused by incumbents who especially included the utilities. Hence advocacy coalitions are essential for the successful dissemination of a technology.

In the initial process of market formation for green energy, the product is initially offered to large customers and it takes a delay of a few years before the product is available to residential customers. In Germany it took one year delay before residential customers were offered green power offerings. This trend is also seen in Japan where green power products are offered to large commercial and industrial customers. The option to purchase green power by residential customers is a sign that a green market has emerged. So assessment for this level will be

- Are solar cells systems used in domestic houses (>50%)
- Are the systems connected to the grid (>50%)
- Are advocacy coalitions present to support solar cells?
- Is the option to purchase green power from solar cells available to residential customers?

Optimizing: Level 4

Users: The optimizing level. This level is associated with optimizing the use of the solar cell system, such as insulating the house to get better energy efficiency, feeding excess power to the grid as well as taking initiative to decrease energy consumption to improve performance and effectiveness of the solar cell system. To proceed to the next level the majority of the respondents should have invested in technologies to reduce their electricity consumption and also are feeding the excess electricity generated by the solar cell system into the grid.

Suppliers and green power marketers: The development of the solar cell industry in Germany saw the use of building integrated solar cell such as roofing facades and in Japan solar cells became a standard option when purchasing a new house and a variety of solar cells became available which can be used for different designs and purposes. In both countries the first solar cell systems were roof mounted systems but as the industry developed the solar cell systems started evolving to better suit the consumers demands. These options make adoption of solar cells easier.

The majority of renewable energy installations in Germany are due to the government's subsidy program. The amount of installed capacity from green power marketing still lags behind the amount installed from government subsidies. This same trend is observed in Japan. This shows that the green marketing is still not effective at disseminating renewable energy. The main reason for this is the price of renewable energy, hence as the price of renewable energy decreases, the green marketing activity will be able to contribute more towards dissemination while the support of subsidies will decrease. For a green power marketer the prime objective maybe to differentiate their products and command a better profit while for a utility the goal maybe to diversify their product range and increase loyalty among customers as well as portray an environmentally friendly image while for a specialized green power marketer, the main goal is to increase the customer base, revenue and market share (Wustenhagen & Bilharz, 2006).But for green power consumers, their willingness to pay comes with expectations of additional environmental benefits in terms of an increase in renewable energy capacity by the green power marketer. In the case of a customer who supports solar cells will be expecting the green power marketer to install new solar cell capacity. So assessment for this level will be

- Are people investing in energy efficiency technologies (e.g. Eco appliances) (>50%)
- Are people feeding excess electricity created by their solar cell system into the grid (>50%)
- Are specialized solar cell products available as per consumer demand?
- Are new installations of solar cells by green power marketers surpassing the new installation due to government subsidy?

Pioneering: Level 5

Users: At this stage the consumers are actively collaborating with industry to support innovative solutions. For example using solar powered cars and using their electric vehicles as power storage that can be fed into the grid when needed. Also consumers are knowledgeable enough to become early adopters of low carbon technologies. To complete this stage the majority of the consumers must be taking part in an industry initiative to develop solar cells or are early adopters of new solar cell technologies.

Suppliers and green power marketers: At the most ideal scenario, the market becomes the driving force for the development as well as the dissemination of solar cells. This means that the industry is subsidy free and in direct competition with fossil fuel technologies. At this stage the majority of the customers are using renewable energy produced by solar cells compared to other renewable energy sources as well as conventional energy sources. So assessment for this level will be

- Are consumers taking part in industry initiatives to develop solar cell technology?
- Are consumers becoming early adopters of new solar cell technology (e.g. use of flexible solar cells)?

- Are solar cells dominating generation capacity as well as market share in terms of green power supply?

6.3) Institutional Infrastructure

The institutional infrastructure consists of the education, financial and the regulatory sector. The start of the solar cell innovation system in Germany and Japan was initialized with R&D of solar cells. The basic necessity for R&D is the resources which include finance provided by the government and manpower which is provided by the educational institutions. The successes of the R&D projects are mainly due to the strong industrial infrastructure led by large firms combined with the industry-academia linkages and the local demand for the new technology. In order for these factors to be present, the size of the country (Argenti, Filgueira, & Sutz, 1990), the financial capabilities of the country as well as the educational infrastructure of the country are very important. Small countries do not have the resources to develop new technologies but depend on technology transfer from industrialized countries for their technology needs. So R&D on a small scale needs to be done to absorb foreign technology and adapt it to the local environment.

Solar cell is a new technology and is a branch of energy studies which also include other renewable energy technologies as well as non-renewable energy technologies. Renewable energy is taught as a graduate course or a post graduate course which includes a component of solar cells. Doctorate level courses specializing in solar cells are also available and people from different aspects of engineering are able to specialize in this course. Education in solar cell is very wide as solar cells are a product which combines many technologies such as quantum physics and material technology. The German and the Japanese were industrialized countries when they started R&D on solar cells so their education systems were technically advanced to cater for the needs of the industry. Hence with regard to technical education, there is no pathway of improvements with regard to solar cells in their education system. But in order to rank the education system in a pattern to support the R&D of installation technologies in a local context, improvements in the educational system are proposed.

Initiating: Level 1

As awareness leads to adoption of a product (Arkesteijn & Oerlemans, 2005), it is important that people are made aware in order to increase the dissemination of the product. The educational system is an avenue which can be used to make children aware of the environmental concerns faced by the world and their solutions. Environmental education gives the knowledge to form judgments and take actions in addressing environmental issues. Environmental education is important in understanding the concepts of renewable energy as well as the successful implementation of environmental policies. Both Japan and Germany have environmental education taught within their school system and Germany has gone a step further and started teaching about solar cells in their secondary schools. Teaching solar cells at a young age has the benefits of increasing the adoptability of the technology when the kids become mature, as their gained knowledge decreases their uncertainties about solar cells which increases adoption (Arkesteijn & Oerlemans, 2005).Apart from adopting it also fosters the advancement of solar cell knowledge as more students get interested in the subject and pursue higher studies. Apart from increasing awareness about solar cells, technical education for the industry needs to be developed. Hence at the initial stage the solar cell training needs are identified which includes the training needs for the industry as well as institutional infrastructure.

As solar cells have not achieved grid-parity and one factor for rapid growth of solar cells is the financial incentives given by the governments. In Germany the government provides tax credits while financial institutions provided loans for solar cell investments while in Japan the government provides subsidies, tax credits while financial institutions provide low interest loans. As solar cells being a new technology, the German 1000 roofs programme as well as the Japanese 70,000 solar roofs programme not only helped develop installation knowledge but also financing knowledge for the dissemination of solar cells. So assessments for this level are;

- Are pilot projects being conducted with mechanism to gain knowledge about financing and creating standards for solar cells apart from installation and application knowledge?
- Does the education system teach the environmental advantages of renewable energy?
- Are solar cell education training needs identified?

Enabling: Level 2

Once the solar cell training needs are identified, a solid training plan needs to be implemented so that schools and universities can follow the plan in meeting the technical manpower needs of the industry and institutions. Also a national R&D roadmap needs to be implemented so that universities and research institutions can focus on those areas. In Germany the BMU specifies the trajectory of R&D while in Japan the R&D plan is created by METI.

Standards for solar cells should be created and the building codes should facilitate these standards. The German building codes specifies the insulations standards needed in a building while the Japanese focus on energy management within buildings. Also a regulatory framework for solar cell grid connection needs to be formulated. These standards and regulatory framework are necessary to build consumer confidence and enhance adoption of solar cells (International Energy Agency, 2010c). So assessments for this level are;

- Are solar cell training plans created?
- Is a national solar cell R&D plan created?
- Are solar cell standards and regulatory framework for grid connection created?

Integrating: Level 3

One of the outcomes of the German 1000 solar roofs programme was that it helped develop the technical standards necessary for solar cell dissemination. With the success of the pilot projects, and the gained knowledge in financing solar cells, finance becomes available to the general public for installing solar cell systems.

Though environmental education is taught within the education system to raise awareness, technical education focused on solar cell courses need to be conducted to train people in the solar cell professions. Certification courses which cover the solar cell standards and installation technologies need to be conducted for the industry and institutions. These certification programmes should mainly be targeted at solar cell system installers, electrical installation inspectors, financial managers as well as specialized sectors such as the housing sector(architects, planners) and local governments (International Energy Agency, 2010c).Certification programs lead to the enhancement of the solar cell profession (Robitaille & Etcheverry, 2005).And to cater for R&D, higher education university programs in solar cells need to be conducted as per the solar cell training plans.

Entrepreneurs in new technologies increases with the development of regulative institutions as the risks involved decreases (Sine, Havema, & Tolbert, 2005). In order for the market and the industry to develop, new entrants into the solar cell sector must increase which depends on the support of the regulative institutions to reduce the risks of adopting solar cells. Also this lowered risk should be accompanied by resources such as venture capital to foster entrepreneurship. A stable investment climate is created in Germany and Japan with the feed-in-tariff fixed for a period of 20 years and 10 years respectively. This gives the green power marketers a locked-in customer base which guarantees the market for a good investment return on the investments. On top of that the governments have made commitments such as adopting the Kyoto protocol and also announcing installation targets such as Germanys target of matching 7% of domestic energy consumption by solar cells in the year 2020 and Japans target of 53GW installed capacity of solar cells by 2030.These actions of the governments give assurance to the investors that potential exists in solar cells. In Australia an uncertainty about the need for renewable energy technologies is created due to their non-compliance of the Kyoto Protocol (Marinova & Balaguer, 2009). So assessments for this level are;

- Is finance readily available for solar cell adoption for all potential users?
- Is a stable investment climate created?
- Are standard certification courses on solar cell installation and design available?
- Are university programs in solar cells available?

Optimizing: Level 4

In Germany as well as in Japan, industry-academia linkages were fostered by the R&D project managers NEDO and PtJ. This helped to increase the solar cell knowledge as well as transfer knowledge created by the academia to the industry.

The importance of the advocacy coalitions is to bring institutional alignment to the dissemination of the solar cell technology. Hence is it not a matter of subsidy alone but all the institutional barriers that hider the dissemination of solar cells must be removed. For example elimination of import tax on solar cells. So assessments for this level are;

- Are industry-academia collaborations taking place?
- Are solar cell related institutional barriers identified and removed?

Pioneering: Level 5

The final output of the education system is conducting research and contributing to knowledge in terms of patents and scientific publications. The number of scientific publications and patent applications are used as a measure of innovation (Dodgson & Hinze, 2000).In order to bring the R&D outputs to the market, finance is needed to support the startups. Hence financial mechanism need to be advanced to support high risk ventures to foster innovation. So assessments for this level are;

- Are scientific publications and patent applications being generated through the education system?
- Are startups emerging from the education system?

6.4) Government Policy

Incumbent technologies such as oil and coal have had decades to mature and in order for new technologies to compete with them, government support is needed. Strong government support for nuclear energy in the 1950s and 1960s contributed to the increased share of nuclear power generation in the United States (Goldberg, 2000).The government polices of Germany and Japan supported the development of solar cells by guiding the direction of search in to solar cell development for firms, creating new knowledge in solar cell development and application and also inducing new firms to enter the solar cell industry. The market development programmes such as the 1000 Roofs Programme and the 100,000 Roofs programme as well as the 70,000 Solar Roof Subsidy Programme strengthen the installation knowledge and grid-connectivity knowledge.

<u>Initiating: Level 1</u>

A policy is a position and actions taken by the government in relation to a problem (Dovers, 2005). Implementing policy takes time and is initiated by a vision with a goal and as the policy lessons from Germany and Japan states, takes a long time to have a meaningful effect. A long term vision or a strategic energy plan is considered an initiation step towards a meaningful policy. A long term vision will be backed by studies to assess the feasibilities of the vision and the necessary feedback from the stakeholders involved needs to be considered before the vision is drafted into a policy. These studies will be crucial in assigning the dissemination target limit as the case of Germany (supplying 7% domestic electricity consumption by solar cells by the year 2020) and Japan (53GW of installed solar cell capacity by the year 2030) states. So assessments for this level are;

- Has a long term government vision been developed that addresses the role of solar cells as a means reduce carbon emission in a utility grid?
- Are experimental studies conducted to see if solar cells are feasible in the current utility grid? Have the experiments shown a target forecast of how much carbon reduction can be achieved with specific dissemination targets of solar cells?

Enabling: Level 2

The policy creation process in Germany was hugely affected by the lobbying of the renewable energy advocacy coalitions. In Japan the scenario was different as the Japanese government used advisory committees to communicate with the stakeholders to get their inputs in the creation of renewable energy policies. The German an the Japanese approach may be different which may have cultural reasons behind it but both the Japanese and the German lobbying system has the same effect as when the policy is formulated the inputs of the actors are considered which makes institutional alignment easier and contributes to the success of the policy. The advantage of collaboration with stakeholders during the making of a policy to support renewable energy contributes to a stable policy framework which leads to high investment security and high exploitation of renewable energy resources. In order to reduce uncertainties for the actors, the policy should be created with participation from the actors and the governments vision and objectives should be well communicated with the actors prior to the implementation of the policy (Van Rooijen & Van Wees, 2006).The actors need to be able to predict the governments strategies and their direction for the policy to be a success (Haas, 2003).

By the time the 100,000 Solar Roof Programme commenced in Germany, the feed-in-law as well as the necessary standards were developed thanks to the pilot projects and the advocates of the technology who made them happen. In the Japanese case the standards were developed by the industry in response to the governments initiatives (Marinova & Balaguer, 2009).As solar cells have still not reached grid-parity, resources in terms of subsidy needs to be given for people to adopt solar cells. Hence in order for the policy to be effective the resources should be available to backup the policy. So assessments for this level are;

- Are advocacy coalitions formed that favor the dissemination of solar cells and are they representative of academic, political, industrial and institutional arena? Has the government discussed the policy with the advocacy coalitions to bring institutional alignment during initial stages of making of policy?
- Has the necessary laws and technical standards created to support the policy with allocation of resources for the implementation of the policy?

<u>Integrating: Level 3</u>

The policy challenges faced by Germany were the resistance to technological change by actors with vested interests in incumbent technologies, an adequate learning period to stimulate firms to enter the solar cell technological system and strengthen the advocacy coalitions and finally the creation of variety in the system (Jacobsson, Andersson, & Bångens, 2002; Kamp, Negro, Vasseur, & Prent, 2009). The implementation of the government policies were led by METI and BMU, who through their leadership conducted the R&D activities and made government ministries and agencies work cohesively and coherently in the solar cell dissemination process. So assessments for this level are;

- Does the policy guides the search process, have a mutual vision with other stake holders and is created with a long term vision?
- Has a government focal point been established to implement policy objectives?

Optimizing: Level 4

Even though a long term vision is ideal for an effective policy, it must be also flexible enough to counter for the technological advancements and market conditions (Klein, 2008).Results of this flexibility can be found in the German policy as seen by the revision of the German feed-in-tariff law in 2000 as market price of electricity started decreasing due to liberalization of the electricity market, hence the feed-in-tariff was calculated as a factor of market growth and system prices. In the case of Germany, even though the policy is flexible in determining the feed-in-tariff rate, the current rate at which the system is installed stays fixed for 20 years which gives stability to the policy and minimizes the risk faced by the system owners. This same mechanism is found in the Japanese policy where the feed-in purchase term is 10 years which gives the government flexibility to counter for decrease in system prices. The subsidy given to the installation of new systems also decreased in Japan as the prices of modules decreased. So assessments for this level are;

- Is the policy dynamic in nature which provides the stability for investment security as well as the flexibility to react to technological advancements and market conditions?

Pioneering: Level 5

The pioneering stage is where the domain has advanced beyond the level 4.The main purpose for the existence of a policy for solar cells is to make it more competitive with fossil fuel technologies. At level 4 the policy is dynamic and the support given to solar cells decreases as the solar cell technology becomes mature and is able to compete with fossil fuel technologies. The point at which solar cell technologies are competitive with fossil fuel technologies is when grid parity has been achieved and the policy is no longer needed to support solar cells. Hence assessment question for this level are:

- Has the policy been able to help achieve grid parity for solar cells?

6.5) Technological Infrastructure

The assessment questions for the level 1 of the eight domains of the SGMM are presented here which is acquired from the SGMM Compass Assessment Survey (Software Engineering Institute, 2010).

Strategy, Management and Regulatory

At Level 1 of this domain, the utility develops a smart grid vision and begins to implement it. Also discussions are being held with regulators and initial implementation concepts are experimented. Assessments questions for this level are;

- Has a smart grid vision that addresses operational improvement been developed?
- Are experimental implementations of smart grid concepts being conducted?
- Have discussions with regulators regarding the smart grid vision taken place?

Organization and Structure

At level 1 the utility recognizes the need to achieve a smart grid and start building the necessary competencies to transform the electric grid. Assessments questions for this level are;

- Has the utility communicated the competencies needed to achieve a smart grid to its workforce?
- Has the leadership demonstrated a commitment to achieve a smart grid?
- Is the workforce being made aware of the smart grid initiatives in order to get their support for the smart grid activities?

Grid Operations

At level 1 the utility analyzes the smart grid capabilities such as automation of grid operations and process optimizations. Assessments questions for this level are;

- Are new equipments and systems related to smart grid being experimented at least within one department?
- Are new sensors, switches and communications technologies for grid monitoring and control being evaluated to be used in the electric grid?
- Is grid monitoring and control projects being conducted?
- Are distribution management systems linked to substation automation being explored and evaluated (beyond SCADA as SCADA monitoring to substations is not considered substation automation)?

Work and Asset Management

At level 1 the utility is exploring ways to enhance asset and workforce management capability by using the smart grid implementation features. Assessments questions for this level are;

- Has a business case for work and asset management enhancement via smart grid been developed?
- Has the potential uses of remote asset monitoring been evaluated?
- Has the asset and workforce management system been evaluated for potential alignment with the smart grid vision?

Technology

At level 1 the utility is exploring the capabilities of the existing information technology infrastructure in order to use it as the foundation for the smart grid information infrastructure. Assessments questions for this level are;

- Is an enterprise information technology infrastructure present or is under development?
- Is the existing information technology infrastructure evaluated for the quality attributes that would support smart grid applications?

- Is a process in place to evaluate and select technologies in alignment with the smart grid vision?

Customer

At level 1 the utility explores new ways to enable customer participation in order to achieve a smart grid as well as to enhance the customer's smart grid experience. Assessments questions for this level are;

- Is research being conducted on ways to use the smart grid to enhance the benefits of the smart grid to the customer?
- Are the security and privacy measures needed to enable customer participation in the smart grid being researched?
- Are the smart grids vision and its benefits being communicated with the customer?

Value Chain Integration

At level 1 the utility identifies the supply and distribution requirements for products and services as well as collaboration needs within the value chain. Assessments questions for this level are;

- Are assets and programs needed to facilitate load management identified?
- Are the decentralized generation sources and the capabilities needed to support them identified?
- Are the energy storage options identified with the capabilities needed to support then?

Societal and Environmental

At level 1 the utility acknowledges the importance of societal and environmental issues and addresses them in their smart grid strategy. Assessments questions for this level are;

- Does the smart grid strategy address societal and environmental issues such as the integration of renewable energy into the grid?
- Are the environmental benefits of the smart grid being promoted publicly?
- Are the utility's compliance records with environmental regulations made available for public inspection?
- Does the smart grid strategy address the need for protecting the electrical infrastructure from attacks and natural disaster?

7) Application of SLMM to the Maldives

7.1) Country background and Current Situation

Maldives is an archipelago of 1190 low lying islands in the Indian Ocean with a population of 298,000 spread over 200 inhabited islands (Ministry of Planning and National Development, 2006). The islands are scattered in a chain of atolls within the Indian Ocean stretching 860km in length. The Maldives archipelago contains 26 geographic atolls which are grouped into seven administrative regions.85% of the inhabited islands are less than 1 km2 in size and only three inhabited islands have an area exceeding $4km^2$ (Ministry of Home Affairs, Housing and Environment, 2001).85% of the land area is 1m above mean sea level (Ministry of Home Affairs, Housing and Environment, 1999) making the islands highly vulnerable to sea level rise. One third of the population live on the capital called Male' and is the political and economic capital of the Maldives. The difference between Male' and the rest of the islands can be seen by the value of the average income of a household, where in Male' a household earns USD 1,672 while in the rest of the islands the value is USD 734 (Department of National Planning, 2011).The main industry in the Maldives is tourism with a contribution of 26.5% to GDP in 2009 (Ministry of Tourism, Arts and Culture, 2010).Apart from the 200 inhabited islands 97 islands have been developed as tourist resort islands (Ministry of Tourism, Arts and Culture, 2011).

For energy needs, especially in the power sector the country depends on imported fossil fuel which makes it vulnerable to oil price fluctuations in the international market. The electricity generation in the Maldives is heavily subsidized which has a negative impact on the public finances. Electricity in the Maldives is mainly generated by diesel power generators. The main electricity provider in the country is the State Electric Company (STELCO) which is a wholly owned government company. Prior to 2009 STELCO supplied power to 32 inhabited islands which constitute to 35% of total electric generation capacity of the country. The rest of the capacity was shared by Island Development Communities (IDC) and Resort island which are 17% and 48%

respectively (Van Alphen, Hekkert, & van Sark, 2008).Resort islands in the Maldives are developed on the concept of 'one resort, one island' which means that all infrastructure of the resort is exclusive to the resort island. Hence the power grid of each resort island is used by the resort only and is not linked to the utility power grids of neighboring islands. Resort island power systems are well maintained and efficient as Maldivian resorts are considered up market resorts and power expenditure is a very minimal amount compared to the revenue. In this study the resort island power systems are not included in the solar cell technological system as their electric grids are exclusively for their own use. Even though STELCO was the only government electric utility, it was unable to supply power to all the islands due to the dispersed nature of the islands as well as scale of operation. The dispersed nature of the islands prevents the use of a unified electric grid to supply electricity in the country.

The average population of these islands are small with 131 islands having a population less than 1000 people and only 3 islands having a population more than 5000 excluding Male' (Ministry of Planning and National Development, 2006), hence it is not feasible economically to supply electricity to them from a utility's perspective. Hence the small island communities developed their own IDCs and operate their own power plants which are mainly financed by the government. The government assistance is mainly for the purchase of generator sets and cables for the network. Due to the limited amount of finance the generator sets are often inadequate to cater for the total demand in the islands which causes rationing of electricity consumption in terms of power cuts during certain times.

In 2009 the government acted on the principles of decentralized administration laid out in chapter eight of the 2008 constitution, under which the Maldives was divided into seven regions with each region having their own utility company to supply electricity, gas and sewerage services. All the utilities are wholly government owned companies and are mandated with giving utility services to their respective region. Hence the utilities started taking over the IDC owned power plants in order to bring all electricity generation in their region under their umbrella. Some of these utilities are in preliminary stages of adopting low carbon technologies such as solar cells, wind, gas and energy efficiency technologies.

Due to the decentralization act the amount of islands that STELCO supplied power to decreased from 32 to 8 (STELCO, 2009).Even though the number of islands under the STELCO umbrella decreased, STELCO is still the largest power generation utility in the Maldives with the STELCO electric grid in Male' being the largest and most advanced power grid in the Maldives.

7.2) Industrial Organization

To analyze the users of the solar cells, an online questionnaire was developed and uploaded on an online survey website called www.surveymonkey.com. The questionnaire was designed to obtain information on awareness of global warming issues, the government's carbon neutral activities, consumer's actions and willingness to pay, their current activities regarding conserving energy as well as adopting solar cell systems. Please refer to appendix A for the questionnaire used in this survey. The survey was administered as an advertisement on a social networking site called Facebook. The advantages of using a social networking site like Facebook to administer the survey was due to the simplicity of administering and the time efficient manner of online surveys as well as the convenience and flexibility it provides the person answering the questionnaire (Evans & Mathur, 2005). The population of The Maldives is 298,000 and Facebook identified 87,320 people above the age of 18 as registered with their website living in the Maldives. The respondents of the online survey were self selected as they voluntarily respond to the advertisement; hence this allows randomness in responses. A total of 323 people responded to the survey within the time period 25th February to 25th April, 2011. To analyze the suppliers and green power marketers, national studies and reports were used.

Initiating: Level 1

Users: For the assessment of level 1 the respondents were asked four questions regarding global warming to test their awareness of global warming for which 70% scored an above average of 2 points out of a possible 4 points. This shows that Maldivians are very aware of global warming issues.

Regarding the government initiatives to achieve a low carbon society, 66% responded saying that they were aware of governments low carbon initiatives and identified at least one technology that is going to be used to achieve a low carbon society.

Suppliers and green power marketers: In 2009 the government acted on the principles of decentralized administration laid out in chapter eight of the 2008 constitution, under which the Maldives was divided into seven regions with each region having their own utility company to supply electricity, gas and sewerage services. All the utilities are wholly government owned companies and are mandated with giving utility services to their respective region. The electricity market is highly regulated with conventional electricity subsidized to keep the cost of electricity at an affordable level to the public (Van Alphen, Hekkert, & van Sark, 2008).

There is no open market for renewable energy in the Maldives (Van Alphen, Hekkert, & van Sark, 2008) and the number of actors in the supply of electricity has decreased with the creation of wholly government owned provincial utilities who took over the power generation and supply services of Island Development Committees creating a large scale to provide better services and lower prices as well as monopolize the electricity sector.

Five centralized power system pilot projects involving solar cell hybrid systems with other power generation sources have been conducted in the Maldives with a total capacity of 32.8kW of solar cell power. These projects were poorly planned and lacked monitoring and documenting components. Maintenance of the systems was a problem as trained personnel were not created to maintain the systems. The first decentralized solar cell project is currently being conducted in Male with Japanese government aid. Under this project 390kW solar cell system will be installed at 5 locations within Male and is expected to be completed by March 2012 (Ali, 2011).This project will be instrumental in the dissemination of grid-connected solar cell systems as it is the first decentralized solar cell project conducted in the Maldives to date. Hence this project needs to be well monitored and documented to facilitate the dissemination of solar cells in the Maldives.

Enabling: Level 2

Users: For the assessment of level 2 the respondents were asked questions about what they are doing to reduce energy consumption as well as what they intend to do in the future. The overall average of the number of actions and intentions was calculated. The average of actions for the respondents was 2.57 and the average of intentions was 1.98.

When asked if they were willing to pay a premium for renewable energy, 46% said they were prepared to pay a premium for renewable energy with 25% prepared to pay no more than a 5% premium for energy produced from a renewable energy source.

When asked if they were willing to install a solar cell system in their house, 79% of the respondents said they were willing to install solar cell system in their house.

Suppliers and green power marketers: Resources such as subsides and grants as well as supply of solar cell systems are currently unavailable in the Maldives. The Maldivian government has yet to supply the resources to foster the development of a solar cell market within the Maldives by creating and implementing a renewable energy policy. As there is no renewable energy market in the Maldives, mechanisms to verify the attributes of green power are not established.

Integrating: Level 3

Users: Solar cells for power generations is very rare in the Maldives, hence to keep the length of the questionnaire short, respondents were not asked if they have installed a solar cell system which corresponds to the assessment of level 3. As solar cell systems are rare in the Maldives and as utilities do not allow connectivity of solar cell system to the grid (Japan International Cooperation Agency, 2009) this level cannot be measured in the Maldives. Energy demand and supply survey of 2002 shows that solar cell accounts for 0.1% of primary energy supply and is limited to powering telecommunication and navigation equipments (Japan International Cooperation Agency, 2009).

Suppliers and green power marketers: Solar cell advocacy coalitions are not present in the Maldives at the moment as the government needs to educate the people and the energy industry on the benefits of solar cells as well as inject resources into the energy industry to foster the use of solar cells. Green power offerings are not available to residential customers.

Optimizing: Level 4 and Pioneering: Level 5

As solar cell products are not available in Maldives and there is no viable green power market in the Maldives as well as no industry initiative to develop solar cell technologies, answers to all the questions in level 4 and level 5 are negative.

7.3) Hypothesis

The results of the questionnaire were also used to analyze the hypotheses formulated.

H1: The more a person has awareness of global warming, the higher the willingness of a person to pay a premium for renewable energy.

Figure 8 below shows the relationship between awareness of global warming and willingness to pay a premium for renewable energy. From the figure 8 it can be seen that an increase in the global warming awareness increases the willingness to pay of the respondents. The correlation coefficient of the relationship is 0.46. Hence this hypothesis has been proven.

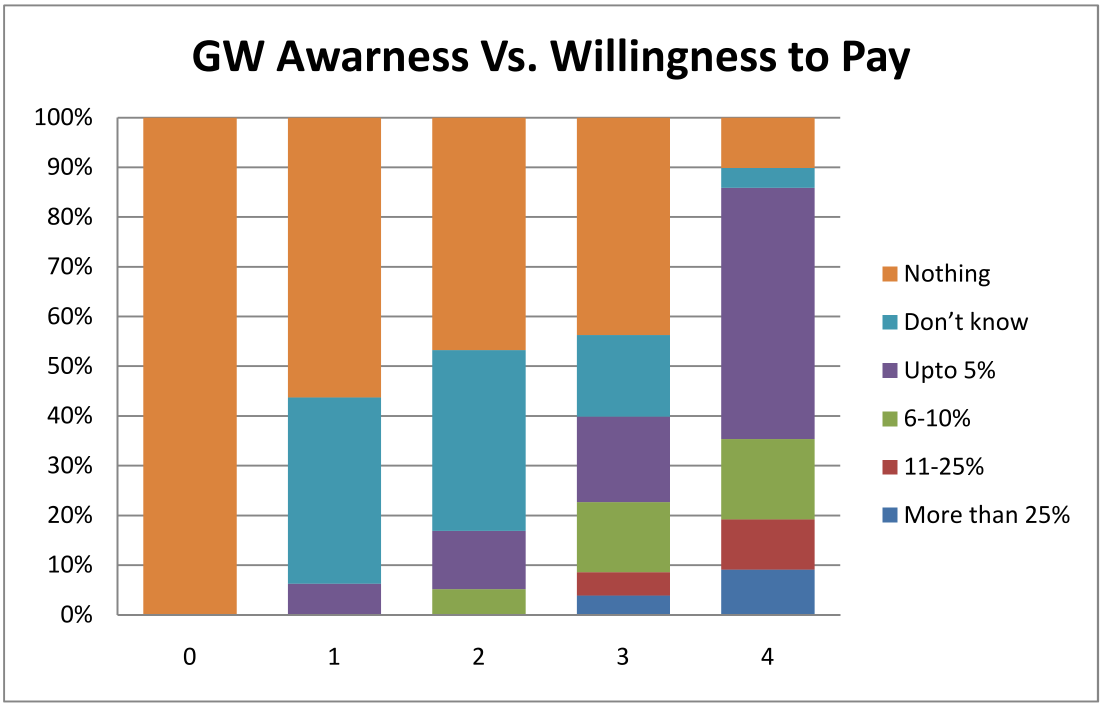

Figure 8 Graph of awareness of global warming and willingness to pay a premium for renewable energy.

H2: The more a person has awareness of global warming, the higher the willingness of a person to install a solar cell system.

Figure 9 below shows the relationship between the awareness of global warming and the willingness to install a solar cell system. From figure 9 it can be seen that the people with a higher level of awareness of global warming are more likely to install a solar cell system than people with a lower level of awareness of global warming. The correlation coefficient of the relationship between the level of awareness of global warming and willingness to install a solar cell system is 0.41.Hence this hypothesis has been proven.

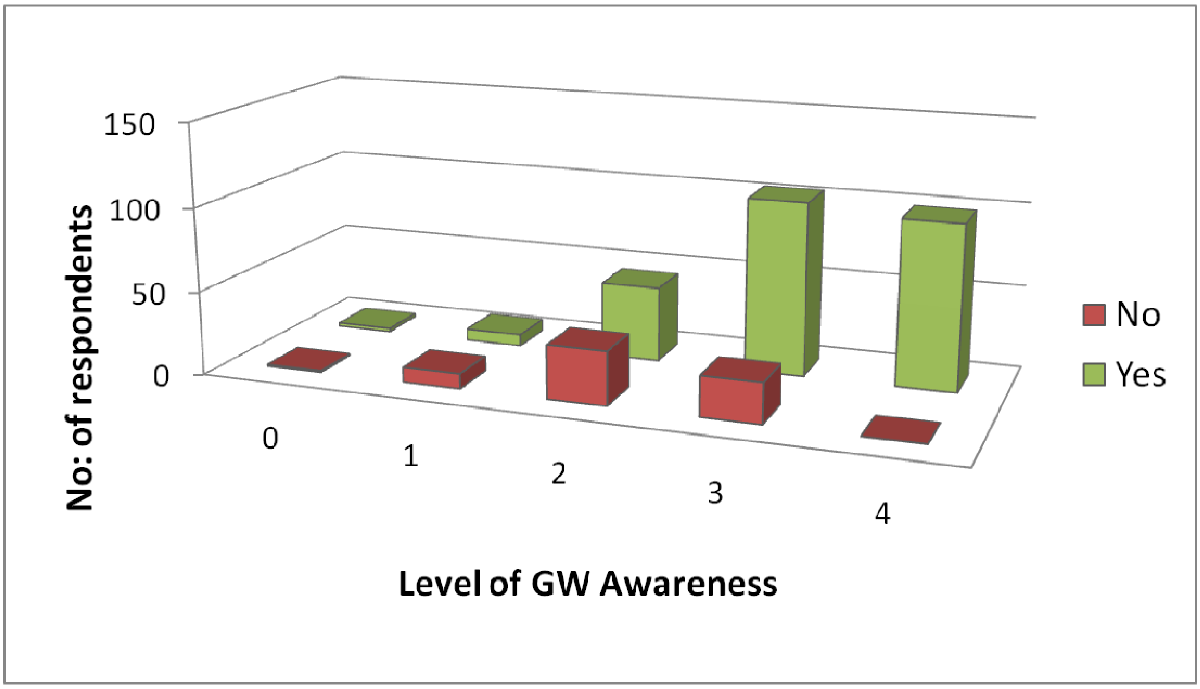

Figure 9 Graph of awareness of global warming and the willingness to install a solar cell system

Figure 10 below shows the results of the correlations.

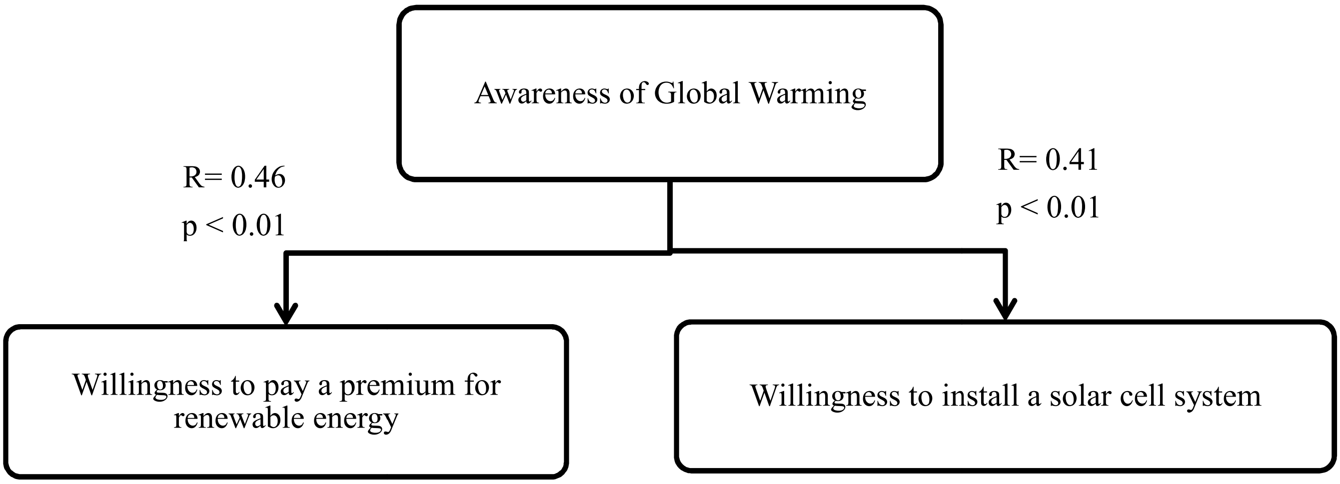

Figure 10 Results of correlations

The questionnaire also asked the respondents the reasons behind their willingness to install a solar cell system and the reasons why they are not-willing to adopt a solar cell system.

Figure 11 below shows the three main reasons why respondents were willing to install a solar cell system.

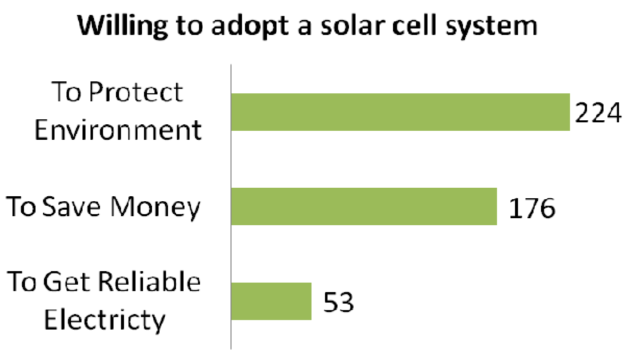

Figure 11 Reasons for willing to install a solar cell system

Figure 12 below shows the main reasons for not willing to install a solar cell system.

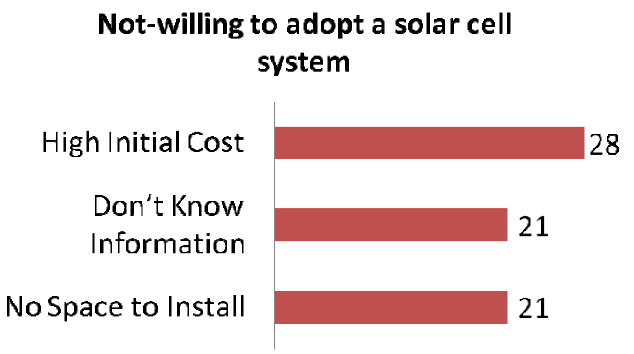

Figure 12 Reasons of not willing to install a solar cell system

As can be seen from figure 11 the main reason that people want to install a solar cell system is to protect the environment which correlates with the fact that people with higher global warming awareness are more likely to install a solar cell system. Hence this supports the hypothesis 2; meaning people with higher awareness of global warming are more likely to adopt a solar cell system. Apart from protection of the environment the other two major reasons for willing to install a solar cell system are to save money and get reliable electricity. From figure 12 the main reasons for not willing to install a solar cell system are high cost, lack of information and inadequate space to install the solar cell system.

Based on the results of the hypothesis it’s fair to assume that the awareness of global warming has an impact on the dissemination of renewable energy. This is an important finding for policy measures such as the education policy in relation to the dissemination of renewable energy.

7.4) Institutional Infrastructure

Initiating: Level 1

The biggest renewable energy project being conducted in the Maldives is the Renewable Energy Technology Development and Application Project(RETDAP) of the United Nations Development Programme which was started in 2004.The project is still being conducted but the performance of the project is not satisfactory (United Nations Development Programme, 2009).One objective of RETDAP was to strengthen the institutions and train financial institutions in renewable energy financing schemes. RETDAP created a renewable energy fund of USD 250,000 to finance renewable energy projects. The fund was not successful due to the lack of capabilities within the financial sector to support green financing projects (Japan International Cooperation Agency, 2009).The fund was administered through the Bank of Maldives which is public company with the Maldivian government as the majority shareholder. The RETDAP project also focuses on the development of technical standards for solar cells but as the project is not completed, the outcome is yet to be concluded.

The education system is very much focused on environmental issues such as global warming as it has direct effects on the fragile ecosystem of the Maldives. In terms of mitigation measures such as use of renewable energy and their benefits, the education system does emphasize on their benefits (Educational development Centre, 2010).

Solar cell education training needs have not been identified as a solid action plan to become carbon neutral by the year 2020 is still being formulated (Ali, 2011).It is expected that this plan will address the education training needs for renewable energy including solar cells.

Enabling: Level 2

No training plan and R&D plan has been formulated yet. The regulation for power generation is focused on diesel power generation and does not have components for renewable energy technologies and the existing electrical standards are weak. Standards pertaining to solar cell installation and use are still yet to be made. The National Building Code which deals with electrical installations and safety in buildings is yet to be formulated into a Building Act and approved by the Parliament to have any legal binding force (Japan International Cooperation Agency, 2009).The standards and regulation development section of the Maldives Energy Authority is not functioning due to lack of staff (Japan International Cooperation Agency, 2009).

Integrating: Level 3

Finance for solar cell adoption is not available as a renewable energy policy has not been implemented by the government. Finance from private institutions is also not available for renewable energy projects. In terms of creating a stable investment climate, the government has set a goal of becoming carbon neutral by 2020 and also has adopted the Kyoto Protocol. Being a country heavily dependent on fossil fuels, the government's commitment to climate mitigation efforts means that there is a high potential for renewable energy businesses in the future. As the solar cell standards have not been created, certification courses are not conducted. Advanced technical courses are not taught within the educational system.

Optimizing: Level 4

Solar cell R&D initiatives are not taking place as the direction of R&D has not been initiated by the government. The biggest institutional barrier apart from availability of finance is the unequal tax burden of 25% import duty levied on solar cells systems and related components compared to 20% import duty set on fossil fuel generators (Maldives Customs Service, 2011).This barrier needs to be removed to make solar cells more competitive with fossil fuel generators.

Pioneering: Level 5

Advanced technical courses are not taught within the educational system. The only university in the Maldives is the Maldives National University which does not offer engineering courses; hence it is highly unlikely that a scientific publication or patent can be generated from Maldives. This limits the possibility of startups emerging from the education system which is also due to the lack of finance options.

7.5) Government Policy

Initiating: Level 1

A long term vision has been established where the Maldives aims to become carbon neutral by the year 2020.A national energy policy has been drafted and approved by the cabinet but a solid action plan to implement the policies is still not formulated (Ali, 2011).Hence the role of solar cells in the energy policy is not defined.

Experimental studies of solar resource assessment has been conducted (Akker & Saleem, 2007).A detailed analysis of solar cell feasibility study for the capital Male' shows that 13,644 tons of carbon dioxide could be reduced by year 2020 with an installed capacity of 13.49MW (Japan International Cooperation Agency, 2009).But this study was conducted only for Male' so more studies like this needs to be done for the whole country to assess how much solar cell capacity can be integrated into the utilities electric grids.

Enabling: Level 2

A wide range of stakeholders were not consulted during the formulation of the national energy policy and the reason for this maybe lack of knowhow within the potential actors about renewable energy as well as the lack of collaboration of the energy policy implementing agency which is the Ministry of Housing Transport and Environments Climate Change, Sustainable

Development and Energy Department (Japan International Cooperation Agency, 2009).The lack of knowledge about solar cells within potential actors constrain the formation of advocacy coalitions to support the solar cell dissemination initiatives. Standards and laws for the use of solar cells are yet to be made (Japan International Cooperation Agency, 2009)

Integrating: Level 3

A government focal point to implement the policy has been allocated as the Ministry of Housing Transport and Environments Climate Change, Sustainable Development and Energy Department but a solid action plan of how to implement the policy is still not formulated.

Optimizing: Level 4 and Pioneering: Level 5

As the national energy policy has not been implemented, the answers to these levels are negative.

7.6) Technological Infrastructure

The assessment criteria of the technical infrastructure was answered through an interview with the Mr. Ibrahim Nashid, the engineer overseeing all operations of the electric grid at STELCO (Nashid, 2011).Below are his response to the assessment questions in the technological infrastructure of the SLMM.

Strategy, Management and Regulatory

The concept of a smart grid is being discussed as a future option within the management of STELCO, but to date no smart grid vision has been developed.

Organization and Structure

As no smart grid vision has been developed the answers for the assessment questions in this domain are all negative.

Grid Operations

New equipments and systems related to a smart grid are not being experimented. New grid monitoring and control projects are not being undertaken and the current monitoring mechanism for distribution management is SCADA monitoring.

Work and Asset Management

As no smart grid vision has been developed the answers for the assessment questions in this domain are all negative.

Technology

An enterprise information technology infrastructure is not currently present or under development at STELCO.

Customer

As no smart grid vision has been developed the answers for the assessment questions in this domain are all negative.

Value Chain Integration

Currently STECLO is generating, distributing and supplying electricity to all customers in its region. Decentralized generation sources have not been identified or the capabilities to support them.

Societal and Environmental

As no smart grid vision has been developed the answers for the assessment questions in this domain are all negative. STELCO's compliance records with environmental regulations are not available for public inspection.

8) Analysis of Results

8.1) Findings and Discussion

The findings of the application of the SLMM to the Maldives show that Maldivians are very aware of global warming issues as well as the Maldivian government's carbon neutral initiatives. This shows that the government has been effective in raising the awareness towards global warming as well as its low carbon goals. Maldivians are more conscious about energy consumption and conservation than Europeans. This shows that electricity demand management programmes focused towards consumers have a high probability of being successful. There is a ripe market for green power in the Maldives as 46% of the respondents were prepared to pay a premium for green power. The upper ceiling for green pricing must be set at a 5% premium rate to help the green power market expand as rapidly as possible. Solar cell systems have a high potential in the Maldives with 79% of the respondents willing to install a solar cell system in their homes. The main reasons for willing to install a solar cell system are the environmental benefits as well as cheap and reliable electricity. Maldivians impression of solar cells as a cheap electricity source is due to the climate conditions of the Maldives which are ideal for the operation of solar cells as well as due to the high cost of electricity in the Maldives. Electricity in the Maldives is set a fixed rate but changes in global oil prices are passed on to the consumer as a fuel surcharge. Hence there is no limit to the increase in the electricity bill due to global fuel prices. Electricity supply in the Maldives is not reliable as the electricity sector is playing catch-up in terms of demand created by high economic activity. Main reasons for not willing to install a solar cell system are the high initial cost of the system as well as lack of information. Lack of installation space is also cited as a major reason for not willing to install a solar cell system.

The use of solar cells in the Maldives is currently limited to powering telecommunication and navigation systems. The future consumers of solar cells in the Maldives are ready to adopt solar cell systems; hence government policies, standards, education, awareness and supply of resources need to be strengthened to foster the adoption of solar cells in the Maldives.

The hypothesis formulated in this study show that people with higher awareness of global warming are more likely to support renewable energy as well as adopt a solar cell systems.

The electricity market is highly regulated in the Maldives where the customers are locked into the services provided by the utilities which use fossil fuel generators. The only pilot projects involving solar cells have been centralized hybrid projects. These hybrid projects which have solar cells integrated with fossil fuel generators to supply electricity were not implemented well or monitored to disseminate the knowledge gained by these projects. A decentralized solar cell power project is currently being conducted in Male'. This project and needs to be well monitored and documented in order to increase grid-connected solar cell knowledge. The importance of decentralized solar cell projects is that the technical challenges faced in a decentralized power system is high and the knowledge attained from these projects are more suited to foster grid-connected solar cell adoption in residential and public buildings.

As a solar cell policy has not been implemented in the Maldives, the government has not distributed financial resources. As the demand for solar cells is very low due to lack of financial resources, the solar cell supply sector as well as market for green power is not present in the Maldives. Advocacy coalitions are yet to emerge in the Maldives with the help of government backed awareness programmes as well as resource mobilization initiatives.

From the industrial organization perspective the level of the Maldives is at level 0 which is the default level.

The financial sector is not well versed in renewable energy financing which was the reason for the failure of the RETDAP renewable energy fund. The financial sector needs to be actively involved in these renewable energy pilot projects and also specialized courses need to be conducted to financial executives to make them aware of renewable energy and its potential. The educational system is helping to increase awareness of global warming and the benefits of renewable energy. Educational training needs for solar cells and R&D plans for solar cells have not been formulated as they are to be addressed in the country's carbon neutral action plan.

The solar cell regulations and standards are not developed as solar cells are not currently being used in a wide scale in the Maldives and also because the country lacks the capacity to develop these standards and laws. The carbon neutral goal and the Kyoto Protocol is not enough for a good investment climate as a feed-in-tariff rate with a fixed duration need to be formulated. This should backed by finance in the form of subsidies or low interest loans. These measures should be addressed in the renewable energy policy.

Solar cell education programmes are not offered at the university level because the Maldives has only one university which was established in 1999.Engineering courses are not offered in the university due to lack of local demand to justify conducting courses. This is expected to change with the formulation of solar cell education training plans and the injection of resources to develop the solar cell industry.

Unequal import tax burden on solar cells is a major barrier for the diffusion of solar cells which need to be removed so that solar cell can be more competitive with fossil fuel technologies.

From the institutional organization perspective the level of Maldives is level 0 which is the default level.

A long term vision to achieve carbon neutral by the year 2020 has been set. An energy policy has been drafted in line with this vision but a solid action plan of how the policy is going to be implemented is yet to be made. Once this action plan has been developed, the role of solar cells in the energy policy will be defined. This is necessary for the education sector to produce the manpower for the solar cell industry as well as the creation of a stable investment climate for entrepreneurs.

Experimental studies have been conducted for connecting solar cells into the electric grid in the capital Male'. Due to the geographical distribution of the utilities in the Maldives, electric grids are not connected to each other and have different characteristics, hence experimental studies need to be conducted in these utilities to assess the carbon reduction that can be achieved by integrating solar cells into their electric grids. These studies will help in the formulation of the policy to achieve the carbon neutral goals.

Advocacy coalitions of solar cells have not been formed due to the lack of knowledge about solar cells within potential actors. Solar cells are not widely used in the Maldives and the current system favors fossil fuel technologies. Hence awareness programs need to be conducted to educate potential advocates of solar cells. During the drafting of the energy policy, potential stakeholders of solar cells were not consulted. This is because the policy formation process is conducted with less transparency which may affect the policy implementation process. The regulations and standards for the use of solar cells are yet to be made, which is expected to be addressed in the solid action plan to implement the policy.

A government focal point for the implementation of the energy policy objectives has been set as the Ministry of Housing, Transport and Environment's Climate Change, Sustainable Development and Energy Department.

From the government policy perspective the Maldives is at level 0 which is the default level.

The technical infrastructure domain shows that STELCO has not formulated a smart grid vision but the concept of the smart grid is being discussed within the management as a future option for the current power grid. Experimental smart grid projects are not conducted at STELCO. The current grid monitoring mechanism is SCADA monitoring which is not capable of monitoring the entire power system as not all sub-stations in the power system are connected to the SCADA system.

At the moment no enterprise information technology infrastructure exists within the utility. The information technology infrastructure is segregated within different departments with no connection to each other. This is because different departments have adopted different types of software to cater for their needs.

STECLO is a vertically integrated company which generates, distributes and supplies electricity and is the sole electricity service provider in its region. STELCO is the sole provider of electricity for the capital Male' and does not allow private power generation sources to be integrated into the STELCO electric grid for security reasons.

STELCO's environmental compliance record is not available for public inspection. Environmental compliance standards are not developed in the Maldives and as the company is a wholly owned government company, it is expected that the company will take the necessary measures to operate in an environmentally friendly manner.

All the domains of the SGMM which are the sub-domains of the technological infrastructure domain of the SLMM are at level 0.Hence from the technological infrastructure perspective the Maldives is at level 0 which is the default level.

8.2) Overall Model

Figure 13 below shows the overall model with the maturity level of the Maldives marked with an 'X'. The gray shaded area is the SGMM and the green shaded area is the contribution of this study to enhance the originality of this paper.

	Technological Infrastructure (SGMM)	Government Policy	Industrial Organization	Institutional Infrastructure
Level 0	X	X	X	X
Level 1				
Level 2				
Level 3				
Level 4				
Level 5				

Figure 13: Model of SLMM applied to the Maldives

8.3) Limitations

Limitations of the research are the relatively small population sample of the survey for gathering data on the users which may have an impact on the findings. The use of social networking sites may limit the demographic scope of the survey and using online survey has the disadvantage of excluding the computer illiterate and people inaccessible to the internet. Conducting the survey on a wider scale with door to door surveying could be a strategy for dealing with this problem. Adopting a solar cell system in a household is mainly a decision made by the head of the household; hence most respondents may not be in a position to make that decision which affects the current estimation of the demand for solar cell systems. But all respondents are potential future household decision makers which makes the demand estimation relevant in the future. Stating the willingness to do an action is not a guarantee that the action will be done, hence in responding to the survey the respondents may have cited willingness to do an action while that action may not materialize.

9) Policy Recommendations

A solid action plan on how to reduce carbon emission using renewable energy sources need to be formulated. This action plan should address the training needs for the development of the solar cell profession, conducting of R&D for solar cells as well as conducting of grid-connected solar cell feasibility studies for the whole country.

The government needs to conduct awareness programs about global warming and about solar cells to increase the willingness of the people to adopt solar cell systems and support renewable energy as well as to foster the formation of solar cell advocacy coalitions. The advocacy coalitions for solar cells need to be well engaged in the policy formation process for renewable energy.

The Maldives needs to conduct successful grid-connected decentralized solar cell pilot projects. These projects should focus on developing standards as well as financing knowledge apart from the primary function of developing application knowledge.

People are willing to adopt solar cells and willing to pay a premium for renewable energy which should be set at no more than 5%. Hence resources such as financial assistance and supply of solar cells need to be made available to foster adoption of solar cells and green power market formation. The financial system needs to be better developed to foster entrepreneurship with institutional barriers such as import tax on solar cells removed. The electricity market needs to be liberalized to foster competition as well as to develop a viable green power market.

The utilities in the Maldives need to create a smart grid vision and a strategy. The utilities need to adopt an enterprise information technology infrastructure as a foundation for the smart grid and conduct pilot projects on smart grid technologies. Also the utilities need to analyze ways to enhance grid operations, asset and workforce capabilities, customer participation, supply chain management as well as societal and environmental issues through the use of the smart grid.

10) Conclusion

In 2009 the Maldives set a goal of becoming carbon neutral by the year 2020.The country is heavily dependent on fossil fuels for its electricity production which is also the main contributor of carbon emission in the country. In order to reduce carbon emission in the electricity sector by increasing the amount of grid-connected solar cells, a new maturity model is created .The new maturity model named the Solar cell Low carbon Maturity Model is used to understand the current state of the solar cell technological system in the Maldives and to improve that technological system to help the Maldives achieve its low carbon goals. The SLMM was created based on case studies of Germany, Japan, users of a technology and the Smart Grid Maturity Model (SGMM). The resulting SLMM enabled the ranking of the Maldives which shows that the Maldives is at level 0 (Default Level) for the domains industrial organization, institutional infrastructure, government policy and technological infrastructure.

Based on this result the following findings were observed. Maldivians are aware of global warming issues and are more conscious about energy consumption and conservation than Europeans. Maldivians are willing to support a green power market as well as adopt solar cells. The role of solar cells in the reduction of carbon emissions has not been defined at a policy level and countrywide experimental studies of solar cells as well as decentralized solar cell pilot projects have not been successfully conducted. Regulatory framework and standards for the use of solar cell has not been formulated. A stable investment climate for solar cells is not present. A major barrier for the diffusion of solar cells is the import tax set on solar cells. There are no resources available for the adoption of solar cells and advocates of solar cells are not present in the Maldives. The education system teaches the environmental benefits of renewable energy but does not offer technical education programs in solar cells. The electricity sector in the Maldives is highly regulated. The concept of a smart grid is being discussed as a future option at STELCO but so far no smart grid vision of smart grid pilot projects have been implemented.

Based on the application of the SLMM to the Maldives the following recommendations are proposed. A solid action plan on how to reduce carbon emission using renewable energy sources need to be formulated. This action plan should address the training needs for the development of the solar cell profession, conduction of R&D for solar cells as well as conduction of grid-connected solar cell feasibility studies for the whole country. Decentralized solar cell pilot projects need to be conducted successfully with a focus on developing standards and financing knowledge. Awareness programs about global warming as well as solar cell technology need to be conducted to create advocates of solar cells as well as foster adoption of solar cells and a green power market. With these awareness programs, resources need to be supplied to foster adoption of solar cells. The advocates of solar cells need to be engaged in the policy formation process. Financial institutions need to induce entrepreneurship and import tax of solar cells need to be abolished. The electricity market needs to be liberalized to foster competition as well as to develop a viable green power market. The electric utilities need to formulate a smart grid vision and conduct experimental smart grid projects.

In order to gain more insights about the users of renewable energy and solar cells, two hypotheses were proposed. These two hypotheses were verified showing that the more a person has awareness of global warming, the higher is the person's willingness to pay a premium for renewable energy as well as the higher the person's willingness to adopt a solar cell system.

The SGMM which enables a utility to improve its electric grid was the inspiration for the development of the SLMM. The originality of this paper is that the SGMM is taken as the technological infrastructure and is expanded to accommodate the industrial organization, government policy and the institutional infrastructure. The structure of the SGMM was maintained throughout the SLMM. The SGMM was created to be applied at a utility level where as the SLMM was created to be applied at a country level. It is expected that papers like this will contribute to existing knowledge in this area which eventually will lead to a solution to achieving a low carbon society and their economic and environmental benefits. This paper is also considered a starting point for future research on maturity models for enhancing the diffusion of a technology within a country.

Reference

Akker, J. v., & Saleem, M. (2007). *Maldives: Renewable Energy Technology Development and Application Project(Mid-term Review).* United Nations Development Programme.

Ali, A. (2011, April 5). Assistant Director,Ministry of Housing and Environment (Energy Engineering Section). (A. M. Thoufeeg, Interviewer)

Argenti, G., Filgueira, C., & Sutz, J. (1990). From standardization to relevance and back again: Science and technology indicators in small, peripheral countries. *World Development 18/11* , 1555-1567 .

Arkesteijn, K., & Oerlemans, L. (2005). The early adoption of green power by Dutch households: An empirical exploration of factors influencing the early adoption of green electricity for domestic purposes. *Energy Policy 33* , 183–196.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy 37* , 407–429.

Berger, W. (2001). Catalysts for the Diffusion of Photovoltaics - A Review of Selected Programmes. *Progress in Photovoltaics Research and Application 9* , 145-160.

Bird, L., Bolinger, M., Gagliano, T., Wiser, R., Brown, M., & Parsons, B. (2005). Policies and market factors driving wind power development in the United States . *Energy Policy 33/11* , 1397-1407 .

Bird, L., Wustenhagen, R., & Aabakken, J. (2002). A review of international green power markets: Recent experience, trends and market drivers. *Renewable and Sustainable Energy Reviews 6* , 513-536.

BMVBS. (2011). *Energy Conservation ordinance.* Retrieved June 4, 2011, from Federal Ministry of Transport, Building and Urban Development : http://www.bmvbs.de/DE/BauenUndWohnen/EnergieeffizienteGebaeude/energieeffiziente-gebaeude_node.html

Carlsson, B., & Stankiewics, R. (1991). On the nature,function and composition of technological systems. *Journal of Evolutionary Economics 1/2* , 93-118.

Carlsson, B., Jacobsson, S., Holmén, M., & Rickne, A. (2002). Innovation systems: analytical and methodological issues. *Research Policy 31* , 233–245.

Cropper, M. (1980). Pollution aspect of nuclear energy use. *Journal of Environmental Economics and Management 7* , 334-352.

De Bruin, T., Freeze, R., Kulkarni, U., & Rosemann, M. (2005). Understanding the main phases of developing a maturity assessment model. *16 th Australasian Conference on Information Systems*, (pp. 1-10). Sydney,Australia.

De Souza, R.-M., Williams, J., & Meyerson, F. (2003). Critical links: Population, health and the environment. *Population Bulletin 58/3* , 1–44.

Department of National Planning. (2011). *Household Income and Expenditure Surveys 2009/2010.* Retrieved June 3, 2011, from www.planning.gov.mv: http://www.planning.gov.mv/en/images/stories/news/2011/June/HIES%20indicator%20sheet%20NEW%20-%2009.06.2011.pdf

DKE. (2011, March). *List of standards, drafts and specifications specially developed for PV applications.* Retrieved June 5, 2011, from www.vde.com: http://www.vde.com/en/dke/DKEWork/NewsfromtheCommittees/Documents/List%20of%20standar ds,%20drafts%20and%20specifications%20specially%20developed%20for%20PV%20applications.pdf

Dodgson, M., & Hinze, S. (2000). Indicators used to measure the innovation process: defects and possible remedies. *Research Evaluation 8/2* , 101–114.

Dovers, S. (2005). *Environment and Sustainability Policy.* NSW,Australia: The Federation Press.

Educational development Centre. (2010). *Environmental Studies in the National Curriculum.* Retrieved June 4, 2011, from www.edc.edu.mv: http://www.edc.edu.mv/sites/default/files/Environmental%20Studies%20Syllabus%20Grades%201%20-%205.pdf

Eurostat. (2006). *Special Eurobarometer 247:Attitude towards energy.* Luxembourg: European Commision.

Evans, J. R., & Mathur, A. (2005). The value of online surveys. *Internet Reserch 15/2* , 195-219.

Faure, M., Gupta, J., & Nentjes, A. (2003). *Climate Change and the Kyoto Protocol: The Role of Institutions and Instruments to Control Global Change* . Cheltenham,UK: Edward Elgar Publishing Limited.

Ferro, E. (2009, April). Global Intelligent Utility Network Coalition-The power of partnerships.

Foster, R. (2005). *Japan photovoltaics market overview.* Sandia National Laboratories (U.S. Department of Energy).

Gabler, H., Heidler, K., & Hoffmann, U. (1997). Market Introduction of Grid-Connected Photovoltaic Installations in Germany. *Fourteenth European Photovoltaic Solar Energy Conference* (pp. 27-32). Barcelona,Spain: H.S. Stevens and Associates, Bedford, UK.

Goldberg, M. (2000). *Federal Energy Subsidies: Not all technologies are created equal.* Washington DC,USA: Renewable Energy Policy Project.

Government of Maldives. (2009). *"Aneh Divehi Rajje" Strageic action plan.National Framework for development 2009-2013.* Male',Maldives: Government of Maldives.

Haas, R. (2003). Market deployment strategies for photovoltaics: an international review . *Renewable and Sustainable Energy Reviews 7/4* , 271-315 .

Höpken, G. (n.d.). *Technology Education in Germany.* Retrieved June 5, 2011, from www.Unesco.org: http://www.unesco.org/education/educprog/ste/pdf_files/connect/H%F6pken.PDF

Hunnekes, C. (2011). *Photovoltaic power systems programme, annual report 2010 (Case of Germany).* Paris,France: IEA.

IEEE. (2011). *Smart Grids*. Retrieved June 4, 2011, from www.ieee.org: http://www.ieee.org/portal/site/emergingtech/techindex.jsp?techId=1220

International Energy Agency. (2010a). *Photovoltaic power systems programme-Trends in photovoltaic applications:Survey report of selected IEA countries between 1992 and 2009.* Paris,France: IEA.

International Energy Agency. (2010b). *Renewables Information.* Paris, France: IEA Publications.

International Energy Agency. (2010c). *Technology roadmap:Solar photovoltaic energy.* Paris,France: IEA Publications.

International Energy Agency. (2001). *Technology without borders. Case studies of successful technology transfer.* Paris,France: International Energy Agency.

Jacobsson, S., Andersson, B. A., & Bångens, L. (2002). Transforming the energy system - the evolution of the German technological system for solar cells (Electronic working paper series- paper no.84). *Science and Technology Policy Research* . Falmer, Brighton, UK: University of Sussex.

Japan International Cooperation Agency. (2009). *Feasibility study for the application of photovoltaic power on Male' and Hulhumale' Islands in the Republic of Maldives.* Male' Maldives: Japan International Cooperation Agency.

Japan Natural Energy Company. (2011). *Information top power plant*. Retrieved June 4, 2011, from www.natural-e.co.jp: http://www.natural-e.co.jp/powerplant/index.html

Johnson, A. (1998). Functions in Innovation System Approaches.Unpublished working paper. Department of Industrial Dynamics, Chalmers University of Technology, Goteborg.

Johnson, B. (2010). Institutional Learning. In B.-A. Lundvall (Ed.), *National Systems of Innovation-Toards a theory of innovation and interactive learning* (pp. 203-43). London: Anthem Press.

Kamp, L. M., Negro, S. O., Vasseur, V., & Prent, M. (2009). The functioning of photovoltaic technological innovation systems-A comparison between Japan and the Netherlands. *DRUID Summer Conference 2009* (pp. 1-31). Copenhagen, Denmark: DRUID.

Klein, A. (2008). *Feed-in-tariff designs: Options to support electricity generation from renewable energy sources.* Saarbrucken,Germany: VMD Verlag Dr.Muller Aktiengesellschaft & Co.KG.

Lashof, D. A., & Ahuja, D. R. (1990). Relative contributions of greenhouse gases to global warming. *Nature 344* , 529 - 531.

Lauber, V., & Mez, L. (2004). Three decades of renewable electricity policies in Germany. *Energy & Environment 15/4* , 599-623.

Laustsen, J. (2008). *Energy efficiency requirements in building codes,energy efficency policies for new buildings(IEA information paper).* Paris,France: IEA.

Lund, H. (2007). Renewable energy strategies for sustainable development. *Energy 32/ 6* , 912-919.

Maldives Customs Service. (2011). *Import Tariff 2011.* Male,Maldives: Maldives Customs Service.

Marinova, D., & Balaguer, A. (2009). Transformation in the photovoltaics industry in Australia, Germany and Japan: Comparison of actors, knowledge, institutions and markets . *Renewable Energy 34 (2)* , 461-464.

Ministry of Foreign Affairs. (2010, January 29). *Submission of the Maldives to the United Nations Framework Convention on Climate Change.* Retrieved May 5, 2011, from www.unfccc.int: http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/maldivescphaccord_app2.pdf

Ministry of Home Affairs, Housing and Environment. (2001). *First national communication of the Republic of Maldives to the United Nations Framework Convention on Climate Change* . Male',Maldives: Ministry of Home Affairs, Housing and Environment.

Ministry of Home Affairs, Housing and Environment. (1999). *Second National Environment Action Plan.* Male',Maldives: Ministry of Home Affairs, Housing and Environment.

Ministry of Planning and National Development. (2006). *Population and Housing Census 2006.* Male',Maldives: Ministry of Planning and National Development.

Ministry of Tourism, Arts and Culture. (2011). *Registered Resorts*. Retrieved June 3, 2011, from www.tourism.gov.mv: http://www.tourism.gov.mv/downloads/lists/tourist_resorts_list.pdf

Ministry of Tourism, Arts and Culture. (2010). *Tourism Yearbook 2010.* Male',Maldives: Ministry of Tourism,Arts andCulture.

Mori, M. (2007). *Japan's Eco-school Programme.* Retrieved June 5, 2011, from www.oecd.org: http://www.oecd.org/dataoecd/36/62/39344177.pdf

Nashid, I. (2011, June 5). Engineer,Transmission and Distribution Department. (A. M. Thoufeeg, Interviewer)

National Institute for Environmental Studies. (2006). Developing Visions for a Low-Carbon Society through Sustainable Development:Executive Summary. *The first workshop for Japan-UK joint reserch project.* Ibaraki,Japan: National Institute for Environmental Studies.

New Energy and Industrial Technology Development Organization. (2011). *Mission and Policies*. Retrieved June 4, 2011, from www.nedo.go.jp: http://www.nedo.go.jp/english/introducing_mis_poli.html

Noguchi, M., & Kim, J.-T. (2010). *Impact of the zero-energy mass custom home mission to Japan on industry education towards commercialization.* Retrieved June 5, 2011, from www.iea-shc.org/: http://www.iea-shc.org/publications/downloads/Task40c-Impact_of_the_Zero_Energy_Mass_Custom_Home_Mission_to_Japan_on_Industry_Education_Toward_Commercialisation.pdf

Ogawa, K. (2000). *IEA Photovoltaics Power Systems Programme Annual Report 2000 (Case of Japan).* Paris,France: International Energy Agency.

OK-Power. (2011). *Home*. Retrieved June 4, 2011, from www.energie-vision.de: http://translate.google.com/translate?hl=en&sl=de&u=http://www.energie-vision.de/&ei=Bxr2Teh7hJK7A5PxmdwG&sa=X&oi=translate&ct=result&resnum=1&ved=0CCIQ7gEwAA&prev=/search%3Fq%3DOK%2BPower%26hl%3Den%26client%3Dfirefox-a%26hs%3DaPT%26rls%3Dorg.mozilla:en-G

Olsen, M. E. (1981). Consumer attitudes towards energy conservation. *Journal of Social Issues 37/ 2* , 108-131.

Paulk, M., Curtis, B., Chrissis, M. B., & Weber, C. (1993). *Capability maturity model for software version 1.1(Report: CMU/SEI-93-TR-024 ESC-TR-93-177).* Pittsburgh,USA: Carnegie Mellon University.

Perlin, J. (1999). *From space to earth : the story of solar electricity.* United States of America: Harvard University Press.

Renne, D., George, R., Marion, B., Heimiller, D., & Gueymard, C. (2003). *Solar resource assessment for Sri Lanka and Maldives.* Colorado,USA: National Renewable Energy Laboratory.

Robitaille, L., & Etcheverry, J. (2005, August 20-24). *Training, Education, and Public Awareness: Key Components for Developing a Strong and Vibrant Canadian Solar Industry.* Retrieved June 4, 2011, from www.sesci.ca: http://www.sesci.ca/sites/default/files/pdfs/Sol_Spring06_paper.pdf

SGMM Team. (2010). *SGMM Model Definition.* Pittsburgh,USA: Carnegie Mellon University.

Sine, W. D., Havema, H. A., & Tolbert, P. S. (2005). Risky business? Entrepreneurship in the new independent-power sector. *Administrative Science Quarterly 50* , 200-232.

Skea, J., & Nishioka, S. (2008). Policies and practices for a low carbon society. *Climate Policy 8* , 5-16.

Software Engineering Institute. (2009). *SGMM: First annual report on smart grid implementation.* Pittsburgh,USA: Carnegie Mellon University.

Software Engineering Institute. (2010). *Smart Grid Maturity Model Compass Assessment Survey.* Pittsburgh,USA: Carnegie Mellon University.

Stanford, A. (1998). Liberalisation of the UK energy market: An opportunity for green energy. *Renewable Energy 15/1-4* , 215-217.

STELCO. (2009). *Powerhouses.* Retrieved June 3, 2011, from Stelco.com.mv: http://stelco.com.mv/male.php

Sung, T. K., & Carlsson, B. (2003). The evolution of a technological system:the case of CNC machine tools in Korea. *Journal of Evolutionary Economics 13* , 435–460.

The European Opinion Reserch Group. (2002). *Energy: Issues, Options and Technologies Science and Society. (A Report produced for the Directorate-General for Research, European Commission).* Luxembourg: European Communities.

The Green Energy Certification Center. (2009). *About GECCJ.* Retrieved June 4, 2011, from www.eneken.ieej.or.jp: http://eneken.ieej.or.jp/greenpower/eng/01-1.htm

Tominaga, K. (2001). East Asia: Environmental Issues. *International encyclopedia of social & behavioral sciences* , 3943-3947.

Tsoutso, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. . *Energy Policy 33* , 289–296.

U.S Department of Energy. (2011). *What is the Smart Grid?* Retrieved June 5, 2011, from www.smartgrid.gov: http://www.smartgrid.gov/the_smart_grid#smart_grid

United Nations Development Programme. (2007). *Maldives: Renewable Energy Technology Development and Application Project: Mid-term Review.* Male,Maldives: UNDP.

United Nations Development Programme. (2009). *Regional summary report on annual performance report/project implementation review for the climate change mitigation projects in asia pacific.* UNDP.

United Nations Environment Programme. (n.d.). *Climate Change:Introdcution*. Retrieved May 5, 2011, from United Nations Environment Programme: http://www.unep.org/climatechange/Introduction/tabid/233/Default.aspx

United Nations Environment Programme. (2010). *UNEP Yearbook 2010:new science and developments in our changing environment.* Nairobi, Kenya: United Nations Environment Programme.

US Department of Energy. (2009). *What is a smart grid?* Retrieved June 4, 2011, from www.netl.doe.gov: http://www.netl.doe.gov/smartgrid/referenceshelf/factsheets/OE_DER-008_APPROVED_2009_04_15.pdf

Van Alphen, K., Hekkert, M., & van Sark, W. (2008). Renewable energy technologies in the Maldives-Realizing the potential. *Renewable and Sustainable Energy Reviews, 12* , 162-180.

van Alphen, K., van Sark, W. G., & Hekkert, M. P. (2007). Renewable energy technologies in the Maldives-determining the potential. *Renewable and Sustainable Energy Reviews 11/8* , 1650-1674.

Van Rooijen, S., & Van Wees, M. (2006). Green electricity policies in the Netherlands: An analysis of policy decisions. *Energy Policy 34* , 60–71.

Watanabe, C., Wakabayashi, K., & Miyazawa, T. (2000). Industrial Dynamism and the creation of a" virtuous cycle" between R&D,market growth and price reduction-The case of photovoltaic power generation development in Japan. *Technovation 20* , 299-312.

Weisser, D. (2004b). On the economics of electricity consumption in small island developing states:A role for renewable energy technologies? *Energy Policy 32/1* , 127-140.

Weisser, D. (2004a). Power sector reform in small island developing states: what role for renewable energy technologies? *Renewable and Sustainable Energy Reviews 8/2* , 101-127.

Wustenhagen, R., & Bilharz, M. (2006). Green energy market development in Germany: Effective public policy and emerging customer demand. *Energy Policy 34* , 1681-1696.

Yamamoto, M., & Ikki, O. (2011). *Photovoltaic power systems programme, annual report 2010 (Case of Japan).* Paris,France: IEA.

Yoshida, Y., Inahata, Y., Enokibori, M., & Matsuhashi, R. (2010). Estimating CO2 Emission Reduction in Eco-Point Program for Green Home Appliances in Japan . *Procedia Environmental Sciences 2* , 605-612.

Appendix A

QUESTIONNAIRE ON CONSUMER ATTITUDE TOWARDS RENEWABLE ENERGY

This survey is designed to understand consumer awareness towards energy related issues. The information collected in this questionnaire will remain confidential and will be used only for the purpose of Master's level research. Please take 4 minutes of your time to fill this questionnaire. Thank you very much for your cooperation.

First some information about yourself (for statistical purposes)

1) Are you:

1. Male
2. Female

2) How old are you?

1. 15-24
2. 25-39
3. 40-54
4. 55+

3) How many years of formal school education (or their equivalent) did you complete (starting with primary school)?

1. 10 years or less
2. 11-12 years
3. 13-14 years
4. 15-16 years
5. 17-18 years
6. Over 18 years

4) For each of the following, please tell me if it is the case, or not? (PLEASE TICK IN THE BOX)

	Yes, it is the case	No, it is not the case	Don't know
1. Global warming and climate change are serious issues which need immediate action			
2. The use of fossil fuels (coal, oil, gas, etc.) contributes significantly to global warming and climate change			
3. Global warming contributes to human sickness			
4. Global warming can increase the probability of hurricanes			

5) Are you aware of Maldivian Government energy-related activities to become carbon neutral or not?

(IF YES) Using which technologies? (MULTIPLE ANSWERS POSSIBLE)

1. No, I am not aware
2. Yes, gas
3. Yes, solar cell power
4. Yes, wind power
5. Yes, energy efficiency technologies
6. Yes, other ………………..

6) a) What have you done or are you doing to save energy? (MULTIPLE ANSWERS POSSIBLE) (PLEASE TICK IN THE BOX)

b) And what do you intend to start doing? (MULTIPLE ANSWERS POSSIBLE) (PLEASE TICK IN THE BOX)

	a) Actions	b) Intentions
1. Cut down on air conditioning		
2. Cut down on lighting and/or the use of domestic electrical appliances		
3. Use renewable energy		
4. Taking initiatives to save energy at work		
5. Drive electric vehicle		
6. Insulate (d) my house (walls, windows, etc.)		
7. Use public transport		
8. Nothing		
9. Other		
10. Don't know		

7) Would you be prepared to pay more for energy produced from renewable sources than for energy produced from other sources? (IF YES) How much more would you be prepared to pay? (ONE ANSWER ONLY)

1. No, I am not prepared to pay more
2. Yes, I would pay up to 5% more
3. Yes, I would pay 6 to 10% more
4. Yes, I would pay 11 to 25% more
5. Yes, I would pay more than 25% more
6. Don't know

8) Would you want to install a solar cell power system in your house?

1. Yes, I do want to **(go to question 11)**
2. No, I don't want to **(go to question 12)**

9) What are the reasons why you want to install a solar cell power system? (MULTIPLE ANSWERS POSSIBLE)

1. To protect the environment
2. To save money
3. To get reliable electricity
4. It's maintenance free
5. It's easy to install
6. To increase the value of my home
7. Others………………..
8. Don't know

10) What are the reasons why you don't want to install a solar cell power system? (MULTIPLE ANSWERS POSSIBLE)

1. High cost of the system
2. Long payback time
3. No financial assistance from government
4. Don't know much information
5. Low performance of the system and low reliability
6. No space to install
7. Cannot connect to electric grid
8. No installation technicians in Male'
9. Not sold in Male'
10. Others………………..
11. Don't know

Appendix B

LEVEL	Strategy, Management, and Regulatory (SMR)	
Level 1	**SMR-1.1**	Has your organization developed a smart grid vision that addresses operational improvement?
	SMR-1.2	Are experimental implementations of smart grid concepts supported within your organization?
	SMR-1.3	Have you had discussions with regulators about your smart grid vision?
Level 2	**SMR-2.1**	Has an initial smart grid strategy and business plan been approved by executive management?
	SMR-2.2	Is a common smart grid vision accepted across your organization?
	SMR-2.3	Are your organization's operational investments aligned to the smart grid strategy and business plan?
	SMR-2.4	Are budgets established specifically for funding the implementation of the smart grid?
Level 3	**SMR-3.1**	Has your smart grid vision, strategy, and business case been incorporated into your organization's vision and strategy?
	SMR-3.2	Have you established a smart grid governance model for smart grid management and decision-making roles, processes, and tools?
	SMR-3.3	Do you have one or more smart grid leaders with explicit authority across functions and lines of business to ensure proper implementation of smart grid strategy?
Level 4	**SMR-4.1**	Does your smart grid vision and strategy drive strategy and direction at the highest level (e.g., enterprise or corporate level)?
	SMR-4.2	Is smart grid a core competency throughout your organization?
	SMR-4.3	Is your smart grid strategy communicated and revised collaboratively with external stakeholders, excluding some sensitive aspects?
Level 5	**SMR-5.1**	Does your organization capitalize on smart grid as a foundation for the introduction of new services and product offerings?
	SMR-5.2	Do your smart grid business activities provide sufficient financial resources to enable continued investment in smart grid sustainment and expansion?
	SMR-5.3	Have you implemented new business models as a result of smart grid capabilities?

LEVEL		Organizational Structure (OS)
Level 1	**OS-1.1**	Has your organization articulated (communicated) its need to build smart grid competencies in its workforce?
	OS-1.2	Has your leadership demonstrated a commitment to change the organization in support of achieving smart grid?
	OS-1.3	Have awareness efforts within the workforce been initiated to support your smart grid activities?
Level 2	**OS-2.1**	Has your smart grid vision begun to drive change and affect related priorities (e.g., addressing the need for an adequately skilled workforce)?
	OS-2.1	Has your smart grid vision begun to drive change and affect related priorities (e.g., addressing the need for an adequately skilled workforce)?
	OS-2.3	Do smart grid implementation and deployment teams include participants from all impacted functions and lines of business?
Level 3	**OS-3.1**	Is your smart grid vision and strategy driving organizational change (e.g., roles, interactions, compensation, hiring criteria)?
	OS-3.2	Does your organization's measurement system incorporate smart grid measures (e.g., on balanced scorecard)?
	OS-3.3	Are performance evaluation and/or compensation linked to smart grid success (i.e., tangible benefits resulting from smart grid deployment or application)?
Level 4	**OS-4.1**	Are management systems and organizational structures capable of taking widespread advantage of the increased visibility and control capabilities provided through smart grid?
	OS-4.2	Does your organization have end-to-end grid observability that can be leveraged by both internal and external stakeholders?
	OS-4.3	Is decision making occurring at the closest point of need as a result of an efficient organizational structure and the increased availability of information due to smart grid?
Level 5	**OS-5.1**	Does your organizational structure enable collaboration with other grid stakeholders to optimize overall grid operation and health?
	OS-5.2	Is your organization and its structure readily adapting to support new ventures, products and services as they emerge as a result of smart grid?
	OS-5.3	Are channels established to harvest ideas, develop them, and reward those that help to shape future advances in process, workforce competencies, and technology?

LEVEL	Grid Operations (GO)	
Level 1	**GO-1.1**	Do you have a business case for new equipment and systems related to smart grid for at least one business function (e.g., AMI, remote disconnect, PMUs, etc.)?
	GO-1.2	Are you evaluating new sensors, switches and communications technologies for grid monitoring and control?
	GO-1.3	Do you have proof-of-concept projects and/or component testing for grid monitoring and control underway?
	GO-1.4	Are distribution management systems linked to substation automation being explored and evaluated (beyond SCADA as SCADA monitoring to substations is not considered substation automation)?
Level 2	**GO-2.1**	Have you implemented distribution to substation automation?
	GO-2.2	Are you implementing advanced outage restoration schemes that automatically resolve (self-heal) or reduce the magnitude of unplanned outages?
	GO-2.3	Aside from SCADA, are you piloting remote asset monitoring of key grid assets to support manual decision making?
Level 3	**GO-3.1**	Is smart grid information made available across systems and organizational functions?
	GO-3.2	Has implementation of new control analytics improved across line-of-business decision-making?
	GO-3.3	Has grid operations planning transitioned from estimation to fact-based using grid data made available from smart grid deployment?
	GO-3.4	Have smart meters become important grid management sensors within your network?
Level 4	**GO-4.1**	Is operational data from smart grid deployments being used to optimize processes across the organization?
	GO-4.2	Is your grid operational management based on near real-time data (dynamic grid management)?
	GO-4.3	Are your operational forecasts based upon data gathered through smart grid capabilities?
	GO-4.4	Has grid operations information been made available across functions and lines of business (is there end-to-end observability)?
Level 5	**GO-5.1**	What percentage of your operational grid employs self-healing operations?
	GO-5.2	Do you have analytics-based and automated decision-making in place system-wide (applying proven analytics-based control)?

LEVEL		Work and Asset Management (WAM)
Level 1	**WAM-1.1**	Do you have an approved functional-level business case for work and asset management enhancements via smart grid?
	WAM-1.2	Are you evaluating potential uses of remote asset monitoring?
	WAM-1.3	Are you evaluating or have you evaluated asset and workforce management equipment and systems for potential alignment to the smart grid vision?
Level 2	**WAM-2.1**	Have you established an approach to track, inventory, and maintain event histories of assets using smart grid capabilities?
	WAM-2.2	Have you developed an integrated view of GIS (Geographical Information Systems) for asset monitoring based upon location, status and interconnectivity (nodal)?
	WAM-2.3	Has an organization-wide mobile workforce strategy been developed?
Level 3	**WAM-3.1**	What percentage of individual components in your cyber and physical systems has performance, trend analysis, and event audit data available?
	WAM-3.2	For what percentage of key components have you implemented condition-based maintenance?
	WAM-3.3	Have you integrated remote asset monitoring with asset management?
	WAM-3.4	Have you integrated remote asset monitoring capabilities with mobile workforce systems to automate work order creation?
Level 4	**WAM-4.1**	For what percentage of asset classes do you have a complete view (including location, interrelationships) based upon status (including security state), connectivity and proximity?
	WAM-4.2	What percentage of your asset models are based upon real (both current and historical) performance and monitoring data?
	WAM-4.3	Are you optimizing the performance and use of assets (from procurement through retirement) in consideration of the entire asset fleet and across asset categories?
Level 5	**WAM-5.1**	Are you optimizing the use of assets between and across supply-chain participants?
	WAM-5.2	Are your assets leveraged to maximize utilization, including just-in-time asset retirement, based on smart grid data and systems?

LEVEL	Value Chain Integration (VCI)	
Level 1	**VCI-1.1**	Have you identified the assets and programs needed to facilitate load management?
	VCI-1.2	Have you identified distributed generation sources and the capabilities needed to support them?
	VCI-1.3	Have you identified energy storage options and the capabilities needed to support them?
Level 2	**VCI-2.1**	Are you providing support for home energy management systems (e.g., via customer portals or in-home displays)?
	VCI-2.2	Have you redefined the value chain based upon smart grid capabilities (including DG, micro-generation, energy storage, and other new customers and suppliers)?
	VCI-2.3	Are you conducting pilots to support a diverse resource portfolio (e.g., distributed generation, demand-side management, demand response, storage)?
Level 3	**VCI-3.1**	Do you have an integrated resource plan in place that includes new targeted resources and technologies (e.g., Volt/Volt-Ampere Reactive (VAR) management systems, demand response, distributed generation)?
	VCI-3.2	Have you enabled customer (including commercial, industrial, and residential) premise energy management solutions with market and usage information?
	VCI-3.3	Additional resources (e.g., PHVs, storage, DR) are being enabled or deployed to provide substitutes for market products to support reliability or other objectives?
Level 4	**VCI-4.1**	Are your energy resources (including resources such as Volt/Var, DR, DG) dispatchable and tradeable?
	VCI-4.2	Have you implemented portfolio optimization models that encompass available resources and real-time markets (e.g., to enable response to dynamic market/supply conditions)?
	VCI-4.3	To what percentage of residential customers do you offer secure two-way communication via Home Area Networks (HAN)?
Level 5	**VCI-5.1**	Have you automated the optimization of energy assets across the full value chain?
	VCI-5.2	Are your resources adequately dispatchable and controllable so that you can take advantage of granular market options (e.g., locational marginal pricing)?
	VCI-5.3	Do your automated control and resource optimization schemes consider and support regional and/or national grid optimization?

LEVEL	Societal and Environmental (SE)	
Level 1	**SE-1.1**	Does your smart grid strategy or vision address your organization's role in societal and environmental issues?
	SE-1.2	Have you publicly promoted the environmental benefits of your smart grid vision or strategy?
	SE-1.3	Is your compliance record with environmental regulations made available for public inspection?
	SE-1.4	Does your smart grid vision or strategy specify your role in protecting the nation's critical infrastructure?
Level 2	**SE-2.1**	Do your smart grid strategies and work plans address societal and environmental issues (cost increases, global warming, pollution, hazardous materials, spill control, "not in my backyard," and other public concerns)?
	SE-2.2	Have you established energy efficiency programs for customers?
	SE-2.3	Does your organization consider a "triple bottom line" view when making decisions (considering social, environmental, and financial performance measures)?
Level 3	**SE-3.1**	Are your societal and environmental programs within your smart grid strategy measurably effective?
	SE-3.2	Does your organization make available to customers (including commercial, industrial, and residential) segmented and tailored information that includes environmental and societal benefits and costs?
	SE-3.3	Has your organization established programs to encourage off-peak usage by customers?
	SE-3.4	Does your organization regularly report on the sustainability and the societal and environmental impacts of its smart grid programs and technologies?
Level 4	**SE-4.1**	Does your organization collaborate with outside stakeholders to address societal and environmental issues?
	SE-4.2	Does your organization maintain a public environmental and societal scorecard?
	SE-4.3	Have you implemented smart grid programs (e.g., demand response programs, dynamic pricing signals, and managed control of devices) to shave peak demand?
Level 5	**SE-5.1**	Do your organization's triple-bottom-line goals align with local, regional, and national objectives?
	SE-5.2	What percentage of customers are enabled to control their energy-based environmental footprint through automatic optimization of their end-to-end energy supply and usage level (energy source and mix) based on customer-selected preferences?
	SE-5.3	Is your organization a leader in developing and promoting industry-wide resilience best practices and/or technologies for protection of the national critical infrastructure?

LEVEL	Technology (TECH)
Level 1	**TECH-1.1** Do you have an enterprise IT architecture? **TECH-1.2** Have you evaluated your existing or proposed enterprise IT architecture for the quality attributes that would support smart grid applications? **TECH-1.3** Do you have a change control process (e.g., configuration management, patch updates) for applications and IT infrastructure?
Level 2	**TECH-2.1** Do you align tactical IT investments to your enterprise IT architecture? **TECH-2.2** Are changes to your enterprise IT architecture to enable smart grid being deployed? **TECH-2.3** Have you selected standards that support your smart grid strategy within your enterprise IT architecture?
Level 3	**TECH-3.1** Are smart grid-impacted business processes aligned with your enterprise IT architecture across LOBs? **TECH-3.2** What percentage of your systems adhere to your enterprise IT architectural framework for smart grid? **TECH-3.3** Have you implemented smart grid-specific technology to improve cross-LOB performance (e.g., peak demand management, fault detection, integrated VVO)? **TECH-3.4** Do you have distributed intelligence and analytical capabilities that are enabled through smart grid technologies?
Level 4	**TECH-4.1** Do you have end-to-end data flow from customer to generation (where permitted by security, privacy, and other requirements)? **TECH-4.2** What percentage of your business processes are optimized by leveraging your enterprise IT architecture? **TECH-4.3** Do your systems have sufficient wide-area situational awareness to enable real-time monitoring/ control/mitigation in response to complex events (e.g., natural disasters, severe weather, extreme demand fluctuations, etc.)?
Level 5	**TECH-5.1** Have you implemented autonomic computing using machine learning? **TECH-5.2** Do your information systems automatically identify, mitigate, and recover from cyber incidents?

LEVEL	Customer (CUST)	
Level 1	CUST-1.1	Are you conducting research on how to use smart grid technologies to enhance your customers' experience, benefits, and participation?
	CUST-1.2	Are you investigating the security and privacy implications of the new technologies and business functions that enable customer participation in the smart grid?
	CUST-1.3	Are you communicating and explaining your vision of the future grid to your customers (e.g., by explaining smart grid benefits and describing potential use case scenarios)?
Level 2	CUST-2.1	Have you piloted Advanced Metering Infrastructure (AMI) and /or Automated Meter Reading (AMR) to residential customers?
	CUST-2.2	Do you collect residential customer usage data more frequently than monthly for use in operational analytics and planning?
	CUST-2.3	Are you modeling reliability of grid equipment?
Level 3	CUST-3.1	Do you have residential customer segmentation that can enable more tailored customer programs?
	CUST-3.2	What percentage of residential customer meters has two-way communication capabilities (e.g., an advanced metering infrastructure)?
	CUST-3.3	For what percentage of residential customers have you enabled remote connect/disconnect capability?
	CUST-3.4	For what percentage of residential customers have you enabled demand response or remote load control?
Level 4	CUST-4.1	Do you provide support to customers to help them analyze and compare their actual usage against all available pricing programs?
	CUST-4.2	What percentage of circuits are equipped with automatic outage detection and proactive notification?
	CUST-4.3	What percentage of customers have on-demand access to near real-time (up to the minute) usage data?
Level 5	CUST-5.1	What percentage of customers can manage their end-to-end energy supply and usage levels (energy source and mix)?
	CUST-5.2	What percentage of customers (including residential) have automatic outage detection at the premise or device level?
	CUST-5.3	What percentage of customers is supported by plug-and-play customer-based generation (including necessary support infrastructure such as net billing, control, etc.)?