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Scenario Based Technology Road Mapping to Transfer Renewable Energy Technologies to Sri Lanka

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Abstract As per the International Energy Agency (IEA) 2009 report, rapidly growing energy demand in developing countries is projected to double by 2030. After ending the three decades of civil war, the Sri Lankan economy has also shown a robust growth; hence the country has shown a continuous growth in energy demand. In 1995 Sri Lanka met 95% of the total electricity demand using major hydro power plants. But due to the escalating demand for electricity and government policies favouring the coal powered power plants, a completely different power mix exists today. By the end of year 2012, more than 70% of the total electrify requirements of the country was met with fossil based energy sources. Today, as responses to the threats of climate change manifest, following many other nations, Sri Lanka also considered renewable energy in their energy mix. However, the lack of technological capabilities has hindered the development of renewable energy technologies in the Country. The solution to such constrains lies with effective technology transfer and cooperation of renewable energy technologies. Technology Road-mapping and scenarios are two widely used future techniques to support strategic and long-range planning. This paper provides a combined approach of technology road mapping and scenario planning in order to foster the renewable energy technologies of Sri Lanka via effective technology transfer mechanisms. The combined approach consists with six steps, and foresight analysis tools such as literature review, expert's interviews, STEEPV analysis, and Delphi technique were used along the process. Four scenarios named 'Land of Republic', 'Green Paradise,' 'Drowning Island' and 'Black Island' were developed. Out of the four scenarios, 'Green Paradise' was considered as the most favourable scenario for Sri Lanka and technology roadmap was developed targeting this scenario. The proposed technology roadmap consists with six steps and the roadmap suggests effective technology transfer mechanism to foster the renewable energy technologies of the country.

Keywords: *renewable energy, road-mapping, scenario planning, sri lanka, technology transfer*

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1. Introduction

Energy is undoubtedly the basic need for continuity of economic development and human welfare. In modern societies, electrical energy proves to be one of the crucial forms of energy used by human beings in manufacturing products and providing service. As the human population increases, the amount of electricity usage grows as well. It is projected that the world electricity usage will reach 32,922TW-hours by 2035[1].

In 1995 Sri Lanka produced 95% of its grid electrical energy needs from conventional hydro power plants. However, expansion of household electricity consumption and the boost in the industrial sector of the country have forced the country to depend on alternative energy resources such as fossil fuels. The total amount of electricity generated during 2012 was 11,878.8 GWh out of which 70.9% was from thermal power plants (both oil and coal), while 23.0% was from major hydro and the balance 6.2% was from Non-Conventional Renewable Energy (NCRE) which comprised of small hydro, wind power, biomass and solar [2].

1.1. Rising Demand for Local Electricity Generation

In parallel to many emerging Asian countries, Sri Lanka has been struggling to meet the rising demand for power. After ending the 30years of civil war, the country's economy has been showing robust growth, in turn accelerating the demand for power. Electricity demand growth rate in the past has most of the time revealed a direct correlation with the growth rate of the country's economy.

The Central Bank of Sri Lanka expects an average GDP growth rate of 8% in real terms in the four years from 2012 to 2015. The demand for power is expected to accelerate on the back of the expanding economy, and the current statistics show that the country's electricity demand has been growing at an average rate of 5.9% per annum [3]. The overall favourable economic prospects, increased investments in the industrial and manufacturing sectors, coupled with the government's long-term vision of providing electricity to all households, is expected to increase the demand further in the medium and long term.

1.2. Need of Clean Energy

Considering the fact that Sri Lanka's large reserves of hydro power have already been utilized, the CEB had diversified to thermal power, resulting in a gradual shift in the industry power mix [4]. Based on World Bank reports, Table 1 exhibit the per capita carbon dioxide emissions of different regions compared with Sri Lanka.

Table 1. Average co$_2$ emission metric tons per capita in year 2010

Country/ Region	2010 CO2 Emissions (MT/capita)
World	4.9
Low middle income countries	1.6
South Asia	1.4
Sri Lanka	0.6

The per capita carbon dioxide emission in Sri Lanka at present is only 0.6 metric tons per year, which is far below the global average of 4.9. This indicates that Sri Lanka has adequate carbon space for establishing fossil fuel power plants [5]. As evident by many international publications, the unprecedented levels of economic growth emerging in the developing nations will make them responsible for future growth in energy demand [6]. In catering to the rapid demand growth, current electricity generation expansion plan of Sri Lanka is mainly concentrated on imported coal. Coal has been identified as the least cost option taking into consideration mainly the cost of production [7]. Based on the published data, energy sector is the main contributor to the GHGs emission [8]. Thus clean energy is an essential requirement in combating the climate change.

1.3. Why Technology Transfer & Collaboration?

In today's context the technology behind renewable energy has been evolved so rapidly and the advancements gained by many developed and rapidly developing nations like China and India provide good examples for developing countries like Sri Lanka. The two countries have seen Technology transfer as a cornerstone in reaching a global solution to climate change.

Concerning the limited technological capabilities, firms in developing countries find that internal development of technology needed for new products, new processes and operational improvement is somewhat difficult. Hence, technological progress in developing countries relies heavily on imported technology, which is based on the transfer, absorption and adaptation of existing knowledge [9]. The success of technology transfer implementation and utilization, however, relies very much on the internal capacity to absorb and accumulate foreign knowledge by technology acquirers.

1.4. Significance of the Study

As stated earlier countries like China and India teach us a valuable lessons as they have managed to bypass most of the mistake made by European countries and have managed to reach the current level of developments in just a couple of years' time. Literature reveals that a clear vision on the future along with robust technological roadmap aided these nations to reach the current level of development. Technology road mapping and scenarios are two widely used future techniques to support strategic and long-range planning. This paper provides a combined approach of technology road mapping and scenario planning in order to foster the renewable energy technologies of Sri Lanka via effective technology transfer mechanisms.

2. Literature Review

In this section of the paper we present a comprehensive literature review conducted in both scenario planning and technology road mapping during the course of this study. The two methods are widely used approaches in technology foresight. This section of the paper also discusses the limitations of scenario planning and technology road mapping and also shows how the combined approach has managed to overcome the weaknesses of the two individual approaches.

2.1. Scenario Planning

In literature we could find much evidence where scenario planning was used for future development routes. For instance, the International Panel of Climate change (IPCC) has created scenarios focusing on the future development of energy and environment on the future developments of green house gas emissions [10]. In addition, Brown et al. (2001) have studied scenarios focusing on clean energy future. Also Shell has utilized scenarios to identify opportunities and challenges in the global business environment [11]. These examples states that most successful Corporations and Nations have used scenarios as a tool to lead the energy sector, as when people can visualize a future, they can begin to create it [12].

2.1.1. Scenarios – A brief History

Like many other early forecasting techniques, the scenario method is a post-war planning concept. Following the work of Herman Kahn and others at RAND and the Hudson Institute in the 1960s, scenarios reached a new dimension with the work of Pierre Wack in Royal Dutch/Shell [13]. From there on throughout the history scenarios has been used by many industries and nations to shape their future for the betterment of all the stakeholders. Consequently many scholars have attempted to define and developed much scholarly literature on this method.

2.1.2. Definitions of Scenarios

According to the classic reference of Kahn and Wiener, scenarios are hypothetical sequences of events, built with the intent of attracting attention to causal processes and points of decision. Some authors in turn define scenarios as archetypical descriptions of alternative images of the future, created from mental maps or models which reflect different perspectives on past, present and future developments [14]. Combining all these views, Finland study on future prospects of alternative agro-based bio energy suggest that the scenario will be developed towards an internally consistent story about the path from the present to the future [14]. In parallel to the above arguments International Energy Agency defined scenarios as a tool for helping us to take a long view in a world of great uncertainty [15]. Similarly scenarios are stories that anticipate the future. They are narratives created by researchers, or by participants in a workshop [13].

2.1.3. Characteristics of Scenarios

According to literature, well written scenarios have the following characteristics:

01. A scenario is not a forecast of the future [14].

02. At least two scenarios are needed to reflect uncertainty and each of the scenarios must be plausible [13].

03. It is also notable that a scenario planning approach does not make a stand on, e.g. the most probable scenario [14].

04. This means that they must grow logically (even cautiously) from the past and the present and they must be internally consistent [13].

05. Typically there will be a mixture of quantifiable and non-quantifiable components. But by integrating quantitative models to the scenario building, we will not be able to predict the future nor to quantify the probabilities of a scenario. By quantifying these scenarios will be able to make the results more tangible [16].

06. Scenarios must also be relevant to the issues under scrutiny. In other words, they should provide useful and comprehensive idea generators and test conditions, against which the plans and strategies can be considered [14].

07. They may be presented in discursive, narrative ways (illustrated with vignettes, snippets of fiction and imitation newspaper stories, etc.) or tabulated in the form of tables, graphics, and similar systematic frameworks [17].

08. In order to be challenging, scenarios must take under consideration potential surprises which may cause discontinuities in future [14].

09. Link historical and present events with hypothetical events in the future [13].

2.1.4. Different Types of Scenarios

In literature, scenario has been divided into two main approaches. As per UNIDO Technology Foresight Manual, scenarios can be both exploratory and normative. Exploratory scenarios start from the present and ask questions such as “What next?” and “What if?” for the development of explorative scenarios. Normative, or inward scenarios, involve back casting, typically starting with the most desirable future. The main questions are “Where to?” and “How to?” [17]. While exploratory scenarios are designed to explore several plausible future configurations of the world, IEA suggest a forecasting type scenario which we are pretty much familiar to us. This type of scenario is often referred to as a "business-as-usual (BAU) scenario", which assumes the continuation of historical trends into the future and that the structure of the system remains unchanged or responds in predetermined forms [15].

2.1.5. Drawbacks of Scenarios

Traditionally scenarios have been developed to support formulation of a vision and mission statement driven by the most desired vision. However in literature scenarios have been criticized for several reasons. These criticisms comprises with:

01. Scenarios are too distant to support strategy development [18].

02. Though scenarios are multidimensional, there is no real ‘search’ for possible futures in the plural sense [19].

03. History of forecast in Norway state that some of the predictions made were so wrong that a scenario builders who, by accident, were able to suggest the right price of oil prices at the time being when the forecasts were made, immediately would have been categorized as an illusionary wizard telling fairytales or creating wild cards [19].

These drawbacks suggest that we need an approach that is not focusing at what seems probable today but which may open up for surprises, ideas and perspectives that are a bit more “far out” and “political incorrect.” Scenarios should be developed in such a way that breaks the demand for probability.

2.1.6. Advantages of Scenarios

Irrespective of such limitations in scenario process, literature backed the advantages of scenario as a very strong tool in any futuristic study. The following list comprises with some of such evidences.

01. Through the development of scenarios and other related approaches, foresight techniques add value to long term planning by explicitly transferring the complexity and contingency of future into commonly understood decision points, challenges and potentials [16].

02. Among the futurists, it is common sense that the future is an open space. In case of predictions which simply extrapolate past developments into the future fails to recognize disruptions. Scenarios have proven to be very effective instrument to organize the option space and include disruption [16].

03. National attempts in developing scenarios (Norway 2030) have provided an early basis for long-term thinking in relation to a broad range of challenges for the country. Thus scenarios have contributed to readjustments in important areas where changes usually take longer time to accomplish [19].

04. The use of scenarios in research related studies have shown that it is especially useful when the uncertainty of the research question is high and there are multiple resolutions to the issue [20].

05. Scenarios were also considered as a tool that can be used to bridge the gap between thinking and actions when addressing a specific question [12].

In today’s competitive world successful firms act in advance rather than react, by going ahead rather than by running behind. Identifying the advantages of this approach scenario planning has been used in various organizations for decades. General Electric and Shell are well known examples of large firms that have been among the pioneering adopters’ of scenario approaches as strategic management tools. Thus in strategic planning scenarios are arguably one of the most effective tools especially when the uncertainties related to business and future plays a significant role in the industry [20].

2.2. Technology Road-mapping

In the introduction of this paper we looked at adverse impact of non-renewable energies such as oil and coal to a sustainable energy future. In this backdrop renewable energies are gaining importance in the discussion in the new paradigm of sustainable development. To guide these developments it can make use of technological foresight tools in order to pave the path for a sustainable development. Among examples of such tools it could cite the Technology Roadmap, which is a widely used technique in the industry for the development of long term planning strategies, making it possible to align market, product and technology over time. Literature provides ample examples on the use of technological road-mapping in countries like United States, countries of the European Union (EU), and also emerging economies in East-Asia. Further various types of organizations perform or commission studies road map, which features businesses, universities, research centres, industry associations, government departments, and ministries. Among the organizations, one can emphasize the participation of the United State Department of Energy (USDOE) and the International Energy Agency (IEA) [21].

2.2.1. Technology Road-mapping: A Brief History

Technological forecasting has a long history as a management technique. However it is Motorola who brought this technology prominence in management planning. In early 1980s Motorola used the technique ‘technology road-mapping’ as a way of anticipating technology needs alongside further production developments. Since then road-mapping has been used in a variety of contexts, particularly in the industry at corporate level (e.g. BP, Philips Electronics) and sector level (e.g. US Aluminum), as well as in Government Laboratories (e.g. Sandia Labs) [13].

2.2.2. Definitions of Road-mapping

In literature, scholars have taken multiple approaches to define the term road-mapping. A very general definition has been given by Schaller (2004) and referred roadmap as layout of paths or routes exists or may exist in a particular geographic area to help travellers in planning the trip in order to reach a particular destination [21]. A more futuristic approach has been taken by Robert Galvin, former Motorola chairman, and he defined the roadmap as “an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of the change” [13]. Combining this general and futuristic approach, Lizaso and Reger defined road-mapping as a process of assuming a given future(s) and providing paths to get it, by means of a certain amount of foresight and a certain amount of consensus. Then, they further defined the aim of road-mapping as to evaluate what is technically possible, desirable and expected, and to understand what needs to happen for moving ahead [12].

Apart to this more generic approach, number of scholars have also tried to defined road-mapping in a more managerial approach. For example Lizaso and Reger (2004) portray roadmaps as the evolution of markets, products and technologies to be explored, together with the linkages between the various perspectives. They are time based plans that help organisations to determine where they are, where they want to go and how to get there. Similarly dos Santos et al (2013) define road-mapping as a flexible method whose main objective is to assist in strategic planning for market development, product and technology in an integrated manner over time.

2.2.3. Types of Roadmaps

Due to a high number of application areas, types of roadmaps have varied. Some examples include science/research roadmaps, cross-industry roadmaps, industry roadmaps, technology roadmaps, product roadmaps, product-technology roadmaps and project/issue roadmaps [13]. In terms of intended purpose Phaal, et al (2004) has identified eight types of roadmaps. The list comprises with product planning, service/capability planning, strategic planning, long-range planning, knowledge asset planning, program planning, process planning, and integration planning. Out of the listed types of roadmaps by far the most common type of technology roadmap, is the product planning, which relates to the insertion of technology into manufactured products [22].

2.2.4. Drawbacks of Roadmap

The above list of applications indicates the highest potentiality of road-mapping as a foresight tool in the diverse range of fields. However just like any foresight method, road-mapping also comprises with shortcomings which needs to be overcome. Saritas and Aylen (2010) list the following weaknesses of road-mapping approach. Road-mapping is normative, rather than exploratory; they encourage linear and isolated thinking, thus there is little scope for creativity, communication and collaboration; Dissemination is difficult, thus only experts can understand the output, especially if it is couched in technical terms [13].

2.2.5. The Advantages of Roadmap

The advantage of road-mapping has been extensively discussed in literature by number of scholars. Saritas and Aylen suggest that the road-mapping is an effective tool for; (a) portraying structural relationships among science, technology and applications, thus (b) improving coordination of activities and resources in increasingly complex and uncertain environments, (c) identifying, evaluating, and selecting strategic alternatives that can be used to achieve desired science and technology objectives, (d) communicating visions to attract resources, (e) stimulating investigations, (f) monitoring progress [13].

More specific advantages of technology road-mapping has been discussed by the Phaal et al (2003) and they specify that the technology road-mapping has the grate potential with the following; (i) Supporting the development and implementation of integrated strategic business, product and technology plans, providing companies have the information, process and tools to produce them. (ii) Provide a means for enhancing an organization’s ‘radar’, in terms of extending planning horizons, together with identifying and assessing possible threats and opportunities in the business environment [22].

3. Methodology

The methodology adopted in study encompasses two distinct foresight techniques. The scenario building process was combined with the technology road mapping and the proposed methodology comprises with six steps.

Following table (Table 2) illustrate the research architecture used in our study.

3.1. Step 01

The preliminary phase covers preparatory work for technology road mapping process. The preliminary step was obtained by conducting a detailed literature survey in the renewable energy sector. Literature pertaining to the renewable energy sector of Sri Lanka the world developments was thoroughly studied in order to understand the current developments and constrains in the sector.

The influencing factors pertaining to the renewable energy sector of Sri Lanka was further studied through experts' interview. The policy makers, academics, Independent Power Producers (IPPs), and government officials were interviewed to narrow the factors that were identified in literature review. As stated in Table 2, the broad picture of Sri Lanka's renewable energy sector was the outcome of stage 01.

Table 2. Research architecture which combine scenario planning with technology road mapping

Architecture	Method	Outcome
Step 01: Road mapping preparation	01. Literature review 02. Expert interview	Current status of the renewable energy sector
Step 02: Tine assessment	01. Literature review	Year 2030
Step 03: System analysis	01. STEEPV analysis 02. Two round Delphi survey	Most important factors which are crucial for the development of the renewable energy sector of Sri Lanka.
Step 04: Scenario projection	01. Framework scenarios based on the prioritized key factors in Step 03.	The four scenarios of Sri Lanka's renewable energy future
Step 05: Scenario Building	01. Outcome of Step 04 02. Literature reviews 03. Expert Interviews	Elaborated scenarios
Step 06: Road-mapping	01. Focused group interviews 02. Literature on Sri Lanka's policy papers	Technology roadmap.

3.2. Step 02

Assessing the time for the road-mapping process is one of the crucial factors, as most of the work thereafter depends on the defined time horizon. Thus the selected time horizon should be far enough to develop scenarios and at the same time should be a feasible to attain the required goals. However some literature on technology road mapping do not emphasize on a particular time horizon. But Kappel, researcher who has contributed heavily in the technology road mapping literature have stated that the roadmap should contain the explicit time scope [23]. Literature indicates that about 32% of the roadmaps identified make predictions for the year 2020, using a long-term period range from 15 to 20 years. However, further studies shows that some road maps have targeted year 2050, which highlights the importance given to global sustainable energy in the energy analysis of countries, institutions, companies and universities.

When looking into the Sri Lankan perspective, the government of Sri Lanka has already obtained targets for year 2020 to generate 20% of the total electricity generation using renewable energy power options [24]. The 'Long term generation expansion plan', developed by the Ceylon Electricity Board (CEB) of Sri Lanka has already predicted the country's renewable energy scenario till year 2032. However the stated scenario was purely a technical analysis and has failed to look in to the qualitative characteristics and factors [25]. Concerning all these facts, this study has decided to develop scenarios for year 2030.

3.3. Step 03

The purpose of the 3rd step in the scenario building and technology road mapping process is to identify the most important factors which are crucial for the development of the renewable energy sector of Sri Lanka. In order to attain said objectives technology foresight techniques such as STEEPV and Delphi surveys were used at this stage. STEEPV is an acronym for Social, Technological, Economical, Environmental, Political and Values [26]. Thus a workshop was conducted with twelve experts representing these six thematic areas of the country and eight factors were identified, which are crucial for the development of the renewable energy sector of Sri Lanka. Thereafter two round Delphi survey was conducted to prioritize the outcomes of STEEPV and finally two most important factors were identified.

3.4. Step 04

The four scenarios are constructed based on two identified uncertainties and prioritized factors from the previous stage [18]. This will be the pillars of scenarios, as this will creates the foundation to develop and elaborate the scenarios of Sri Lanka's renewable energy future.

3.5. Step 05

The framework developed in the previous step is rather skeletal and, in order to be called scenarios, they are complemented with the qualitative arguments. The qualitative content analysis of the arguments gives this option by revealing the rationale and context around the quantitative statements. The contexts can be interpreted and written down as a more narrative 'story' of the future. The narrative interpretation is here written as four scenarios of the future of renewable energy in Sri Lanka up to 2030 [14].

3.6. Step 06

As stated by Lizaso and Reger (2004), road mapping is about assuming a given future(s) and providing paths to get it, by means of a certain amount of foresight and a certain amount of consensus [12]. Thus, once we identified the equally plausible futures of Sri Lanka's renewable energy sector by year 2030, next step is to evaluate what is technically possible, desirable and expected, and to understand what needs to happen for moving ahead. In order to attain this goal number of literature pertaining to the technical evaluation in Sri Lanka as well as the policy papers on the local energy sector was evaluated. Finally the local experts who are already heavily engaged in the renewable energy sector of the county were interviewed to sharpen the technology roadmap.

4. Results & Discussion

The objective of conducting the scenario planning process was to develop scenarios of Sri Lanka's renewable energy future by year 2030. As the outcome of the environmental scanning which we conducted under the six thematic areas of the country (STEEPV Analysis) following eight factors were highlighted.

1. Public concern on environmental impact
2. Energy intensive lifestyle of the public
3. Government supportive policies
4. Private and public sector participation
5. High cost of fossil based thermal energy
6. International pressure on emission of GHGs
7. Technical limitations in the grid
8. Global technological advancements

Two round Delphi survey was conducted with a panel of 10 experts and the results were analyzed using a combined Delphi, AHP model called Delphic Hierarchy process or DHP. Eight key factors were taken into the Delphi survey and outcomes were analyzed based on the level of importance and the expected probability of occurrence of each of the factor. The results were presented in Table 3.

Table 3. Factors ranked based on their contribution to the development of renewable energy sector of Sri Lanka by 2030

Factors	Weighting of factors based on the level of importance	Probability of occurrence
Government moving towards rational policies to promote renewable energy	0.2828	Probable
Real cost of the fossil fuels going up	0.2724	Probable
Global technological advances are conducive to renewable energy advancements	0.2334	Highly Probable
Growing energy intensive lifestyle of the public	0.0678	Highly Probable

As illustrated by the above table 'Government moving towards rational policies to promote renewable energy' and 'rising real cost of the fossil fuels' are the two most important factors that were derived from the experts survey. However the experts have considered these two factors to be 'probable' in respect of occurrence of the two events by 2030. Thus while they are highly important compared to other factors they also associated with a level of uncertainty as well. Literature state that the scenarios should be frame based on key factors which also associate with a certain level of uncertainty as well [13]. Thus these two factors have created the ideal foundation for us to frame scenarios of Sri Lanka's renewable energy future.

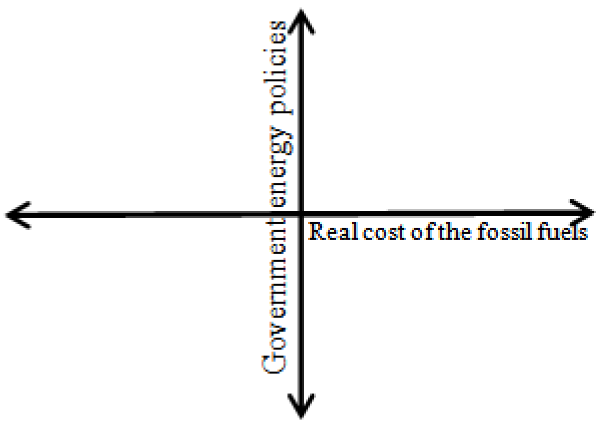

Figure 1. Scenario sketch

On the other hand, the last two factors 'global technological advances are conducive to renewable energy advancements and 'growing energy intensive lifestyle of the public' are less important compared to the government policies and rising real cost of the fossil fuels. But experts have considered these two events to be highly probable. This implies that irrespective of which ever scenario that's going to occur in the future. The stated two factors will occur. Thus concerning its probability we will consider 'Global technological advances' and 'Growing energy intensive lifestyle of the public' as given assumptions in writing scenarios. The frame working of scenarios under step 04 was accomplished by taking the stated important and uncertain factors in to the scenario grid. This is illustrated in Figure 1.

Then we identified and defined the extremes of the key uncertainties to visualize a better picture of the stated scenarios. The four extremes of each of the two factors can be presented as below.

- ***Government moving towards rational policies to promote renewable energy:*** Government will be formulating objective policies towards the right balance between renewable and non-renewable energy.
- ***Government take policy decisions to promote fossil based energy sources ignoring renewable energy options:*** Government will be formulating policies favouring the fossil based energy options ignoring the renewable based power generation options.
- ***Real cost of the fossil fuels going up:*** Real cost (without including government subsidies and taxes) of fossil fuels going up and making investments in renewable becoming more attractive in economic terms.
- ***Real cost of the fossil fuels barely increase:*** Real cost (without including government subsidies and taxes) of fossil fuels barely increases. Thus investments in renewable will not be that attractive in economic terms.

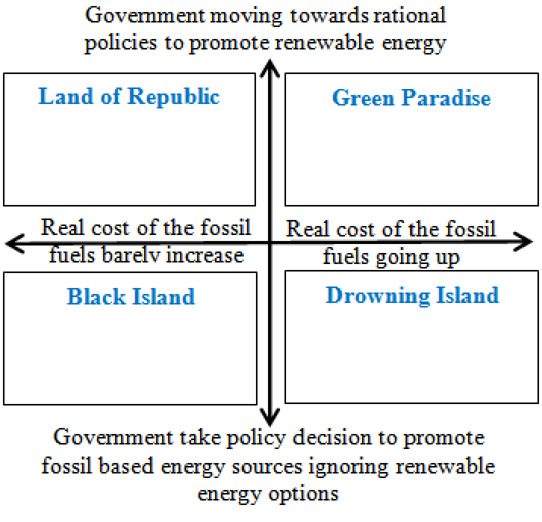

Figure 2. Name the Scenarios

Based on the four extremes defined above, we sketched the four scenarios of Sri Lanka's renewable energy future. The results are shown below in Figure 2.

Moving forward to the next stage of the study (Step 05), scenarios were elaborated based on three key variables. The path to the scenario, the outcome of the scenario and finally the early warning signals were presented when describing the scenarios. Table 4; summarize the outcome of scenario planning process.

Considering the four scenarios the obvious choice was the second scenario (Green Paradise) in which the scenario was developed based on the rising fossil fuel prices and favourable government policies towards renewable energy. The study claims that the nation should target the "Green Paradise" as our ultimate destination by year 2030. Thus the technology roadmap was developed to reach said destination.

Table 4. Outcome of scenario planning process

(W01) Land of Republic
Irrespective of slowly rising (Real) cost of the fossil fuels, Government moving towards rational policies to promote renewable energy.

Path	The energy intensive lifestyle of the public will continue to grow. Real cost of fossil fuels barely increases. Thus investments in renewable will not be that attractive in economic terms. Irrespective of such concerns Sri Lankan government move towards rational policies to promote renewable energy.
Outcome	With some effort Sri Lanka will meet 20% of electricity supply from NCRE sources by 2020. By 2030 country will retain the 20% share. Global technological advancements will conducive to the development of renewable energy sector of the country making such renewable energy applications affordable, usable, safe and available.
Intended Energy Production	Approximated electricity demand by 2030 = 5,800MW Total generation from NCRE by 2030 (20%) = 1,160MW Energy production from different sources by 2030

NCRE Source	Total Genera(MW)	Share from NCRE
Small Hydro	812	70%
Wind	267	23%
Biomass	58	5%
Solar	23	2%
Other	0	0%
Total	**1,160**	**100%**

Early warning signals	Balance of payment will reduce as there is lesser foreign exchange requirement to import fossil fuels. However payback period will also be extended for RE power projects as savings on fossil fuel is less.

(W02) Green Paradise
When (Real) cost of the fossil fuels going up, Government moving towards rational policies to promote renewable energy.

Path	The energy intensive lifestyle of the public will continue to grow. Government will be formulating objective policies towards the right balance between renewable and non-renewable energy. Rising cost of fossil fuels will encourage the government and private sector to invest in renewable energy power projects.
Outcome	Thus Sri Lanka will easily meet country's target of generating 20% of electricity supply from NCRE sources by 2020. By 2030, 25% to 30% of the country's electricity mix will be catered via NCRE sources. Global technological advancements will conducive to the development of renewable energy sector of the country making such RE applications affordable, usable, safe and available.
Intended Energy Production	Approximated electricity demand by 2030 = 5,800MW Total generation from NCRE by 2030 (30%) = 1,740MW Energy production from different sources by 2030

NCRE Source	Total Genera (MW)	Share from NCRE
Small Hydro	696	40%
Wind	609	35%
Biomass	252	14.5%
Solar	174	10%
Other	9	0.5%
Total	**1,740**	**100%**

Early warning signals	Balance of payment will reduce as there is lesser foreign exchange requirement to import fossil fuels. The saving of the fuel cost of the fossil fuel plants by the replacement by renewable power plants will make it possible to recover the RE (capital) cost within a few years.

(W03) Drowning Island
Government take policy decision to promote fossil based energy sources ignoring renewable energy options. Low cost of fossil fuels further encourages government decision.

Path	The energy intensive lifestyle of the public will continue to grow. Real cost of fossil fuels going up and making investments in renewable becoming more attractive. Irrespective of such benefits, Sri Lankan government will formulate policies favouring the fossil based energy options ignoring the renewable based power generation options.

<table>
<tr><td></td><td>Global technological advancements will conducive to the development of renewable energy sector of the country making such renewable energy applications affordable, usable, safe and available.</td></tr>
<tr><td>Outcome</td><td>But due to the lack of policy support only 12% to 13% of electricity will generate from NCRE sources by 2020. Due to the rising demand, the share of NCRE will further reduce to 10% to 11% by 2030.</td></tr>
<tr><td>Intended Energy Production</td><td>Approximated electricity demand by 2030 = 5,800MW
Total generation from NCRE by 2030 (10%) = 580MW

Energy production from different sources by 2030
<table>
<tr><th>NCRE Source</th><th>Total Genera (MW)</th><th>Share from NCRE</th></tr>
<tr><td>Small Hydro</td><td>383</td><td>66%</td></tr>
<tr><td>Wind</td><td>162</td><td>28%</td></tr>
<tr><td>Biomass</td><td>32</td><td>5.5%</td></tr>
<tr><td>Solar</td><td>3</td><td>0.5%</td></tr>
<tr><td>Other</td><td>0</td><td>0.0%</td></tr>
<tr><td>Total</td><td>580</td><td>100%</td></tr>
</table></td></tr>
<tr><td>Early warning signals</td><td>Balance of payment will be highest of all the scenarios, as the government encourages investments in fossil based power plants while the cost of fossil sources is advancing. But payback period will be less for renewable energy power projects as savings on fossil fuels are high.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">(W04) Black Island
Irrespective of rising (Real) cost of fossil fuels, Government takes policy decision to promote fossil based energy sources ignoring renewable energy options.</td></tr>
<tr><td>Path</td><td>The energy intensive lifestyle of the public will continue to grow. Taking advantage of barely increasing real cost of fossil fuels government will formulate policies favouring the fossil based energy options ignoring the renewable based power generation options. Global technological advancements will conducive to the development of renewable energy sector of the country making such RE applications affordable, usable, safe and available.</td></tr>
<tr><td>Outcome</td><td>But due to the lack of policy support county will generate less than 10% share from NCRE sources. By 2030 the share of NCRE will further reduce to 6% to 7% of total generation.</td></tr>
<tr><td>Intended Energy Production</td><td>Approximated electricity demand by 2030 = 5,800MW
Total generation from NCRE by 2030 (6%) = 348MW

Energy production from different sources by 2030
<table>
<tr><th>NCRE Source</th><th>Total Genera (MW)</th><th>Share from NCRE</th></tr>
<tr><td>Small Hydro</td><td>226</td><td>65%</td></tr>
<tr><td>Wind</td><td>117</td><td>33.5%</td></tr>
<tr><td>Biomass</td><td>3</td><td>1.0%</td></tr>
<tr><td>Solar</td><td>2</td><td>0.5%</td></tr>
<tr><td>Other</td><td>0</td><td>0.0%</td></tr>
<tr><td>Total</td><td>348</td><td>100%</td></tr>
</table></td></tr>
<tr><td>Early warning signals</td><td>Balance of payment will be widening as the government spending on fossil sources is very much high over the price advantage in fossil fuels. However payback period will also be high for the renewable energy power plants as the as savings on fossil fuel is less.</td></tr>
</table>

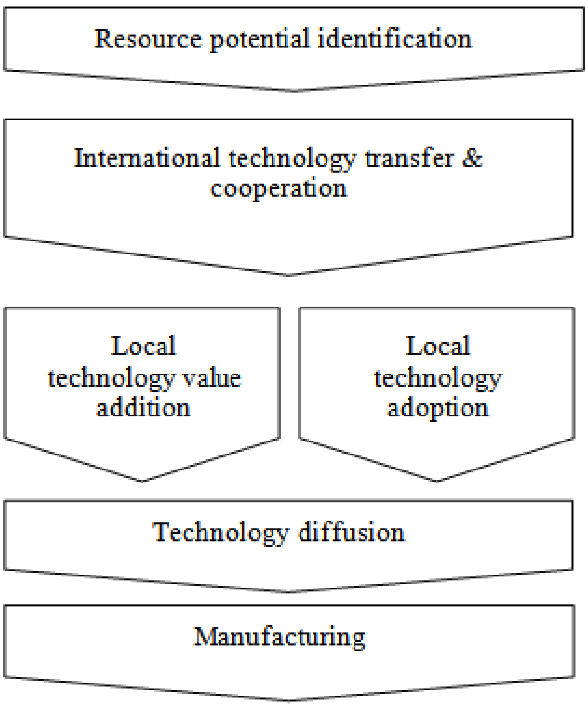

Figure 3. Renewable energy technology roadmap to Sri Lanka

The presentation of roadmap is very important in technology road mapping process. Roadmaps presented in multiple layers, bars, tables, graphs, pictures, flow charts, single layers, and text are some of such approaches [22]. Literature revels that the multiple layer roadmap with short medium and long term time horizons, clear definition of critical factors and suggested actions to be implemented are the most common form of technology road mapping available. However in our study we used flow charts to graphically represent the flow of activities that needed to manifest "Green Paradise" by year 2030. Thus the outcome of this study is presented in Figure 3 and technology roadmap for Sri Lanka to reach desired destination was developed in six sequential steps.

- **Resource potential identification**

The future of the renewable energy sector depends on the availability of the resources and the exploitation capacity. Presently the investors initiate the renewable energy power projects by identifying the resources potential by themselves. In our technology roadmap we propose to change this system, in which the authorities should initiate the renewable energy power project by identifying and allocating the resources to the IPPs based on resource optimization criteria. Thus the resources should be allocated under the condition that the investors have to optimally use the resource to generate the power.

Interviews conducted with the wind power experts of the country claim that the lack of information in the respective power sector is one of the major challenges faced by the renewable energy power producers of the country. Experts claim that the country has a comprehensive data base on the hydro power sector as it's been used comprehensively in the country. But still the authorities are trying to map the other renewable energy potential such as wind, solar and biomass to develop an accurate data base. Without comprehensive and consistent database, country will not be able to use the resources optimally to generate power.

Thus concerning all these facts together "Resource potential identification" was considered as the first step in technology road mapping process.

- **International Technology Transfer & Cooperation**

There are two ways in which a country can acquire the technology. Either develops the technology in-house of transfer already developed technology in other part of the world. Concerning current technological capabilities in the renewable energy sector of the country, experts claim that the next stage of the technology roadmap should be the effective transfer of technologies.

The Intergovernmental Panel on Climate Change (IPCC) provides a frequently quoted definition of climate change technology transfer as 'a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations, and research or education institutions' [10].

Literature claims that the technologies can be transferred through several channels, mainly trade, foreign direct investment (FDI) in the form of either wholly owned subsidiaries or joint ventures, licensing agreements, official development assistance (ODA), hiring of foreign human resources, and person-to-person pathways such as training programmes, conferences or scientific exchanges.

A careful study of existing successful renewable energy technologies in the country such as hydro power sector provides us evidence of technology transfer in its initial stages. Local hydro power sector initiated with international trade in which turbines were imported from foreign sources. But today technology transfer mechanisms in the hydro power sector have extended to technology licensing and even to in-house R&D. However in commercial scale solar power sector, technology transfer mechanisms are only limited to international trade. Booming technologies such as wind power sector still depends on international trade. Technology licensing agreements could also be seen in the wind power sector.

However experts claim, that Sri Lanka still lacking with the expertise in the core engineering of renewable energy sector. Experts further claim the technology transfer needs to be carried out gradually in order to transfer the technologies sustainable. Example drawn from China and India claim that these countries did not transfer the renewable energy technologies overnight. Years of technology transfer process have strengthened the production capacities of these emerging countries to compete with many developed nations.

- **Local Technology value addition**

The technology transfer does not guarantee that the country will develop the capabilities to manufacture technologies in-house just after acquiring the technology. But small steps like local technology value addition and technology adoption will enable the country to reach the said destination. Under technology value addition, authorities should take appropriate measures to initially transfer and develop operation and maintenance capabilities. Such measures will help the country to continue and retrain the existing transferred technologies from foreign sources. In addition most of such imported technologies comprises with many small units (such as outer casing, wire mesh, etc…) which can be manufactured in-house. Such small steps in local technological value additions will enable us to gradually step towards more advance technologies to develop renewable energy technologies in-house.

- **Local Technology Adoption**

Most of the time the technology acquired to the country does not suit as it is not to local climatic and environmental condition. For example in the biomass sector gasification was used in many part of the world to generate power. But in the Sri Lankan context the technology needs to be adapted to suite local conditions such as humidity, particle size and so on. Thus these technologies are subjected to technology adoption to suite local conditions. Thus in the projected technology roadmap we propose to conduct technology adoptions in parallel to the technology value addition activities.

- **Technology diffusion**

The effective diffusion of these transferred technologies within the country is a very important step in technology roadmap. Experts believe that the government bodies such as the Sustainable Energy Authority in Sri Lanka (SLSEA) could play a prominent role in this respect. For example SLSEA could perform as the intermediate in between the end users and the technology providers. Such measures could be combined with the existing measures taken by the SLSEA. For example SLSEA already have a technology transfer division which already conducts regular workshops and seminars to educate general public. The information that disseminates to the general public also varies with the respective technologies as well. For example while SLSEA educate the rural households on biomass applications, the urban households were also educated on net-metering solutions. Hybrid systems such as combined solar and biomass applications were promoted as direct heat energy applications for the fuel switching program. In parallel to such measure the authorities should also engage in knowledge transfers to local components manufactures to sustain the transferred knowledge that were transferred from foreign sources..

- **Manufacturing**

This is the final destination the country should reach by year 2030. In other words country should be able to develop its own technologies by the stated time period. In doing so, the country should capitalize on the already established renewable energy solutions to reach the said target. Hydro power sector is one of such successful case in Sri Lanka.

The experience gained in the major hydro power sector has strengthened the small hydro power sector in many ways. For example 'VS Hydro' one of the leading firms in the small hydro power sector of Sri Lanka presently provides services as a one stop shop for this sector.

Starting from civil construction, followed by manufacturing of turbines, installation of plant and equipments, surveys and even operation and maintains are done by this local firm. The services of this firm has now even been extend to foreign countries, in which VS Hydro now transfer their technological assistance to number of small hydro power projects in Africa.

Similar examples could also found in direct energy application in the rural sector of the country. For instance SLSEA along with many NGOs have facilitated technology innovation opportunities such as cooking stoves. The cooking stoves are mainly used in the rural households as a very efficient biomass application in domestic cooking and so as an extended version that were used industry biomass heating purposes as well.

The experts believe that government institutes such as 'National Engineering Research & Development Center of Sri Lanka" or NERD center, can also play a prominent role by providing their technological capabilities. The fact that the NERD center has already engaged with a number of small scale renewable energy power projects throughout the country is an opportunity that we should excel in the future. For example biomass power plants, which operates from the strong and sustainable fuel food supply from the users of the technology, micro hydro power systems, and small scaled (100W) two blade wind turbine developed in a village in Nikawaratiya to charge batteries are some examples.

5. Conclusion

Scenario planning and technology road mapping are strong technology foresight approaches that have been widely used in the world renewable energy sector. However each of these approaches has their own limitation when applying in real life business scenarios. By combining scenario planning with technology road mapping, we will be able to overcome unique weaknesses of these two methods. This study has attempted to combine both the techniques and have overcome the critical limitations of each of these tools. For example the four scenarios developed in this study were used to describe the future circumstance of Sri Lanka's renewable energy sector. Thus the scenario alone will not give pathways into the desired scenario. By combining road map we have connect the future with the present and informed that action to reach the said destination. On the other hand scenario planning has also contributed in overcoming the limitations that we face in road mapping process.

The roadmap alone is more target oriented, and it suggest linear and isolated thinking. Thus roadmap alone is more difficult to communicate to a non-participant of the process as the results are too technical. The combination of scenario into the technology road mapping process opens up critical thinking and its highly participative and interactive nature makes the process more reachable even to a non-participant of this process.

Finally, it shall be highlighted that neither road mapping nor scenarios provides a silver bullet to the struggling renewable energy issues of Sri Lanka [18]. Scholars such as Saritas and Aylen, have argued that the road mapping process does not end with the roadmap itself. The true value of road mapping lies in an on-going process [13]. The authors fall in line with this advice, and we believe the linking scenarios to road mapping processes should be followed up as an on-going process, understanding that it is a learning process that usually reveals more questions than answers.

References

[1] Bagheri Moghaddam, N., Mousavi, M., Moallemi, A. and Nasiri, M, "Formulating directional industry strategies for renewable energies in developing countries: The case study of Iran's wind turbine industry", *Renewable Energy*, 39 (1). 299-306. 2012.

[2] SLSEA, *Sri Lanka Energy Balance 2012: An Analysis of Energy Sector Performance*, Sustainable Energy Authority of Sri Lanka., Colombo, 2013.

[3] Ceylon Electricity Board, *Long Term Generation Expansion Plan*, CEB, Colombo, 2011.

[4] RAM, *Sri Lankan Power sector-Firing the rain*, RAM Rating (Lanka), 2012. [E-book] Available: http://lra.com.lk/reports/power_sector_update.pdf.

[5] Abeygunawardana, A., "Feed - in - tariff in Sri Lanka", Energy Forum, Colombo, 2012.

[6] Streeter, A.L.E., and Jongh, D., "Factors influencing the implementation of clean energy interventions in low-incomeurban communities in South Africa," *Journal of Global Responsibility*, 4(1). 76-98. 2013.

[7] Ranasinghe, D.M.H.S.K., "Climate Change Mitigation Sri Lanka's Perspective," *International Forestry and Environment Symposium*, 15. 290-296.

[8] Ratnasiri, J., "Alternative energy - prospects for Sri Lanka", *Journal of the National Science Foundation of Sri Lanka*, 36(Special Issue). 89-114. 2008.

[9] Ming, W.X., and Xing, Z., "A new strategy of technology transfer to China", *International Journal of Operations & Production Management*, 19(5/6). 527-37. 1999.

[10] IPCC, *Special report on emission scenarios*, Intergovernmental panel of climate change, Cambridge University press, Cambridge, 2000.

[11] Shell, *Executive summary of the Shell Global Scenarios to 2025*, 2005, [E-book] Available: http://www.shell.com/content/dam/s hell/static/future-energy/downloads/shell-scenarios/shell-global-scenarios2025summary2005.pdf. [Accessed Jan. 5, 2015].

[12] Lizaso, F. and Reger, G. "Scenario-based roadmapping--a conceptual view", *EU-US Scientific Seminar on New Technology Foresight*, Forecasting & Assessment Methods, 2004.

[13] Saritas, O. and Aylen, J. "Using scenarios for roadmapping: the case of clean production", *Technological forecasting and social change*, 77(7). 1061-1075. 2010.

[14] Rikkonen, P. and Tapio, P. "Future prospects of alternative agro-based bioenergy use in Finland—constructing scenarios with quantitative and qualitative Delphi data", *Technological Forecasting and Social Change*, 76(7), 978-990, 2009.

[15] Organization For Economic Co-Operation And Development (OECD) and International Energy Agency(IEA), Energy to 2050: Scenarios for sustainable future, France, 2003.

[16] Hirsch, S., Burggraf, P., and Daheim, C. "Scenario planning with integrated quantification–managing uncertainty in corporate strategy building", *foresight*, 15(5), 363-374, 2013.

[17] UNIDO, *Technology Foresight Manual – Volume 01*, 2005. [E-book], Available: https://www.unido.org/foresight/registration/ dokums_raw/volume1_unido_tf_manual.pdf .

[18] Ricard, L. and Borch, K.., "From Future Scenarios to Roadmapping: A practical guide to explore innovation and strategy", *The 4th International Seville Conference on Future-Oriented Technology Analysis (FTA)*, May 12-13, 2011, 2012.

[19] Overland, E. "The Importance of Developing Long-Term Visions for Countries. The Norway2030-Vision: Lessons for Turkey", *Istanbul Forum*, 2003.

[20] Heinimö, J., Ojanen, V. and Kässi, T. "Views on the international market for energy biomass in 2020: results from a scenario study", *International Journal of Energy Sector Management*, 2(4), 547-569, 2008.

[21] dos Santos, M.F.R.F., Borschiver, S., and Couto, M.A.P.G. "The Application of Technology Roadmapping Method Related to Sustainable Energy: Case Study in the World and Brazil", *Chemical Engineering and Science*, 1(4), 67-74, 2013.

[22] Phaal, R., Farrukh, C.J.P., and Probert, D.R. "Technology roadmapping—a planning framework for evolution and revolution", *Technological forecasting and social change*, 71(1), 5-26, 2004.

[23] Kappel, T. "A. Perspectives on roadmaps: how organizations talk about the future", *The Journal of Product Innovation Management*, 18, 39-50, 2001.

[24] SLSEA, *A Guide To The Project Approval Process For On-Grid Renewable Energy Project Development*, Sustainable Energy Authority of Sri Lanka, Colombo, 2011.

[25] Ceylon Electricity Board, *Long Term Generation Expansion Plan 2013-2032*, CEB, Colombo, 2013.

[26] Loveridge, D. "The STEEPV acronym and process-a clarification", *Ideas in Progress, Paper*, 29, 2002.

[27] Fogg, B.J, *Persuasive technology: using computers to change what we think and do*, Morgan Kaufmann Publishers, Boston, 2003, 30-35.

[28] Hirsh, H., Coen, M.H., Mozer, M.C., Hasha, R. and Flanagan, J.L, "Room service, AI-style," *IEEE intelligent systems*, 14 (2). 8-19. Jul.2002.

[29] T. Eckes, *The Developmental Social Psychology of Gender*, Lawrence Erlbaum, 2000. [E-book] Available: netLibrary e-book.