General Feasibility Study on Applicability of Sea Wave Energy Technology in a Sri Lankan context

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Abstract

Sri Lanka being a developing country with a rapidly increasing energy demand is in a need to utilize its untouched renewable energy potential in the near future. As no fossil fuel resources areavailable in the country and conventional renewable sources like hydro energy has been fully utilized, the government is paying attention to developing non-conventional energy (NCRE) sources. Small hydro wind and solar technologies have already been introduced and developed to certain extents but no single wave energy plant has been developed. Wave power is more reliable than solar and wind due to its24x7 availability and lowereffects ofgrid voltage fluctuations.

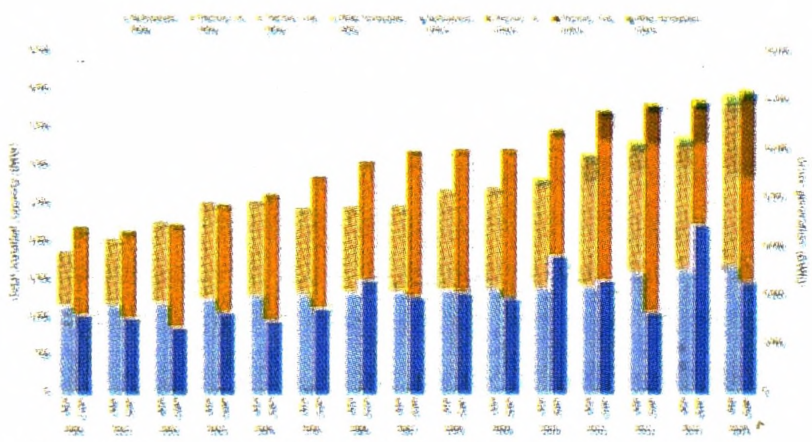
Some research, basically model/pre-feasibility studies at selected locations,has been done by the University of Peradeniya. Our study is based on the local and international literature sources and secondary data.The paper discusses the practical possibility of developing wave energy in Sri Lanka in general considering technical, economic, social and environmental factors as appropriate. Different wave power generation technologies have been compared to select the most appropriate technology. The selected technology is compared with the existing NCRE technologies.

While a wide range of wave energy technologies have been invented all over the world, only a handful of them have been practically implemented.In the recent past, most of the countries have not been interested in implementing wave power plants, though they have enough resources due to the high levelized, cost but learning curves and technological development has brought down costs making itcompetitiveagainst other renewable energy technologies.

The study has found that the main challenge to develop wave energy in Sri Lanka is the comparatively low height of the waves which may increase the per MW investment for such a project.However the latest Israeli technology can lead to recovery of the cost of investments within four years according to the current feed-in-tariff structure in Sri Lanka.

Introduction

Sri Lanka being a developing country has experienced a rapid growth in its electricity consumption over last few decades due to the opening of its economy in 1977. Until late 90s, power generation heavily relied on conventional hydro power sources. After the significant power shortage in 1996, the government started purchasing power from private owned thermal power stations. As a result, the contribution from thermal plants gradually increased and it accounts for more than 50% at the moment as shown in Fig, 1. It is not a healthy situation for a country like Sri Lanka which does not have any fossil fuel reserves. On the other hand, government opened the electricity market for Non-Conventional Renewable Energy (NCRE) producers. Accordingly, first private owned mini hydropower plant was connected to the national grid in 1997.



. **Fig. 1.** Growth of electricity demand in Sri Lanka

Two World Bank funded projects ESD (Energy Services Delivery Project) and RERED (Renewable Energy for Rural Economic Development) played a key role in the development of renewable energy sector of the country. Mini hydro and wind power industries have significantly established while solar and biomass are still emerging as shown in the (Table 1.).

	2,010	2,011	2,012	2,013	2,014
Hydro	**646**	**601**	**565**	**908**	**902**
Wind	50	89	144	232	270
Biomass	33	32	22	26	41
solar	-	1	2	2	1
Sub Total SPP	728	722	733	1,169	1,215

Table 1. Growth of NCRE generation in Sri Lanka in the last five years[3]

As far as hydro and wind power technologies are concerned, there is a seasonal variation of generation and therefore it cannot be identified as a sustainable solution for the power crisis of the country. Solar power is a comparatively reliable source but still the generation is limited only to the day time which is not the critical duration of the day in Sri Lankan context

Therefore sea wave power can be promoted as reliable source as it will be available during 24 hours on 365 days of the year with minimum variation.

The subsequent chapters are focussed on the following points

- Technical feasibility of developing sea wave power in Sri Lanka
- Whether sea wave power is competitive with other NCRE technologies
- Review and comparison of different methods of harnessing sea wave power

Technical Feasibility - Wave Power in Sri Lanka

So far no wave power project has been implemented in Sri Lanka but some efforts have been made by foreign and local developers which have not been successful. Only a limited number of research studies have been conducted on the technical feasibility of wave power in Sri Lankan context. A pre-feasibility study done by University of Peradeniya in collaboration with Uppsala University, Sweden concludes that a 10MW wave power plant would be electrically feasible for a set of selected sites in the southern coast of Sri Lanka. Still that study has been based on a set of estimated data in the absence of actual data on wave heights.

The global Wave Power Resource availability is 3TW. Due to the high cost of harvesting, very few resources have been recovered from this availability. Demand supporting policies such as feed – in tariff leads to improved research in the field. Presently, Wave Power generation technologies are more competitive against the other Renewable Energy Generation Technologies due to continuous technological improvements and learning curves. world wide

Wave Resource Availability is shown in Fig. 2.

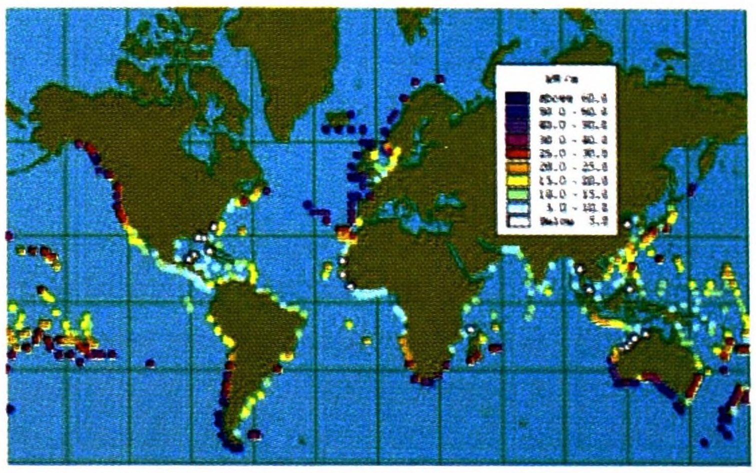


Fig. 11. Worldwide Wave Resource [6,7]

Source: Roger Beard, "Economic and Social benefit form Wave Energy Conversion Marine Technology

Sri Lanka is affected by two monsoon periods, north east and south west. Waves in the southern coastline are affected by both monsoons. Therefore, the southern coastline is the most suitable coastal belt for Wave Energy Power Plants. Based on the RERED Final Report of 2005 and CCD_GTZ final report, the annual average wave power availability is 14kW/m. According to

Fig. **11**, it is between 15kW/m and 20kW/m. According to **Error! Reference source not found.** estimation of annual average wave power availability in Galle area is around 15 kW/m

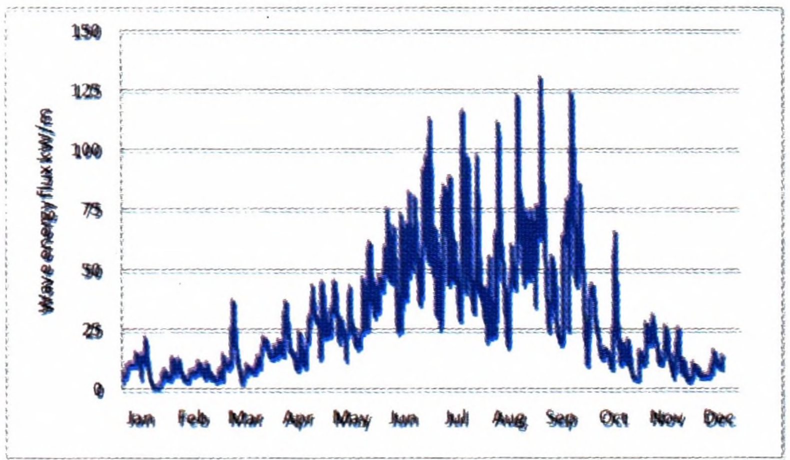


Fig. 3. *Seasonal Wave Energy Flu –Estimated in Galle[8].*

Wave Power and Other NCRE Sources

It is vital important to analyse and determine the economic feasibility of each NCRE source used in Sri Lanka compared with sea wave energy sources. The capital expenditure, fixed O&M cost, and variable O&M cost of the following NCRE sources were investigated: 1MW commercial power plant. Mini hydropower, Wind (on shore), Solar (Photovoltaic), and sea wave (ECO Power – Invention.)

NCRE Source	Average Capital Cost per 1 MW plant (USD)	Capital cost (USD/Kw)	Fixed O&M Cost (USD/kw-yr)	Variable O&M Cost (USD/Mwh)
Mini - Hydro	1,659,259.26	1,659.26	37.80	4.47
Wind (On shore)	2,213,000.00	2,213.00	39.55	No cost
Solar (Photovoltaic)	3,873,000.00	3,873.00	24.69	No cost
Sea Wave (ECO POWER - Invention)	1,200,000.00	1,200.00	28.54	No cost

Table 2. Capital expenditure, Fixed O & M cost, and Variable O & M cost of NCRE sources[9]

Data used for the analysis

Construction, installation, commissioning, operation, and maintain of capacity of 1MW commercial type plant is considered as a pilot power plant only for the purpose of analysis. Performance information on commercial plants was abstracted from a study done by the U.S. Department of Energy[9] whereas sea wave plant detail was provided by Israel based Eco power, on their experimental plant performance.

Biomass sources has not been considered as NCRE sources in the above analysis because the biomass plant concept comprises of a more conservative environmental protection aspect which demands high cost of capital, etc. whereas performances significantly differs depending on type of input used e.g. solid wood, liquid biofuels, and biogas.

Moreover, Plant factors are important key criteria to calculate physical/actual production capacity of each type of plant. Plant factors as shown below were abstracted from an article published in 2011 by the Public Utilities Commission of Sri Lanka (PUCSL).[10]

The PUCSL announced a flat tariff for purchasing electricity to the national grid on a standardized power purchased agreement.

Table 3. Average Plant Factors of NCRE sources[10]

NCRE Source	Average Plant Factor
Mini - Hydro	35%
Wind (On shore)	37%
Solar (Photovoltaic)	70%
Sea Wave (ECO POWER - Invention)	40%

Table 4. Feed-in tariff declared by PUCSL for different NCRE sources10

NCRE Source	PUC Flat Tariff - Rate in SPPA (Rs/Kwh)
Mini - Hydro	17.15
Wind (On shore)	21.22
Solar (Photovoltaic)	25.09
Sea Wave (ECO POWER - Invention)	25.09

Outcome of Economic analysis

The analysis of payback period for each source is done as per actual performance data abstracted in above information. It is assumed that the whole process of construction, installation, commissioning, for commencing operation will take a year and from the second year onwards, operation and maintenance work begins.. The payback period is measured starting from the day of commencement of operation. The highest payback period is recorded by mini hydro source which is 6 years and 5 months whereas the lowest, 2 years and 2 months, is shown by Sea Wave (Eco Power – Invention)

In addition, Break even analysis shows the really interesting fact that the Sea wave (Eco Power – Invention) required the minimum number of units, 7,628 Mwh, to reach break-even point. Further, its low capital cost and 40% plant factor contribute to a healthy break-even point.

Although the highest Net Present Value (NPV) analysis is shown by Solar (Photovoltaic) which is 3,361,323 USD for 15 year at a flat interest rate of 10% for the whole 15 years period of time, Sea wave (Eco Power – Invention) had the second highest NPV at 2,860,701 USD on the same basia

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Table 5. Pay Back and Break Even Analysis Outcome for NCRE Sources

NCRE Source	Average Capital Cost / 1MW Plant (USD)	Units (Mwh) produced /yr	Pay Back Period	Break even Point (Units Mwh)	NPV at 10% (USD)
Mini-Hydro	1,659,259.26	3,066	6 y 5 m	19,574	255,311
Wind (On shore)	2,213,000.00	3,234	5 y 10 m	18,812	597,662
Solar (Photovoltaic)	3,873,000.00	6,093	3 y 11 m	24,032	3,361,328
Sea Wave (EcoPower)	1,200,000	3,504	2 y 2 m	7,628	2,860,701

Technologies for Harnessing Wave Power

Many technologies have been developed for harvesting wave energy. The selection of a suitable device has to be made using criteria such as resource availability, energy conversion efficiency, grid availability etc. However, the most important parameters are location and the operating principle. The developed technologies are described below.

Oscillating Wave Column (OWC)

The water column is moving up and down when waves are passing through the OWC. Then pressurized air is passing through a turbine, hich is connected to the suitable generator to generate the electricity. Due to low conversion efficiency, the technology is suitable for high power waves[11]. A 500 kW grid connected plant developed by Energetech is being operated in Australia[12-14].

The Pelamis

This device is a long multi-segment floating or semi-submerged cylindrical structure composed of several sections connected by hinged joints. When waves pass, the segments move with the waves, but are resisted somewhat by hydraulics. The movement of the hydraulics pressurizes oil, which is pumped into hydraulic motors that power electric generators. The technology is suitable for high power waves[12-14].

The Wave Dragon

The Wave Dragon overtopping device elevates ocean waves to a reservoir above sea level where water is spilt out through a number of low head turbines to generate electricity. The technology is suitable for high power waves[12-14].

AWS Device

The submerged wave power buoy reacts to changes in sub-sea water pressure caused by passing waves and converts the resulting motion into electricity *via* a direct-drive generator. The system is suitable for deployment in water depths in excess of 25 m and can be configured for ratings between 25 kW and 250 kW by selecting the appropriate scale[12-14].

The McCabe Wave Pump

The wave pump has three pontoons which are linearly hinged together and pointed parallel to the wave direction. The center pontoon is fixed relative to the forward and afterward pontoons. The hydraulic pump is connected between the center pontoon and the afterward pontoon. The pressurized hydraulic fluid is used to drive the motor generator [12-14].

The Power Buoy and Aqua Buoy

The device is floating on the surface of the water, held in place by cables connected to the seabed. The rise and fall of the Buoys drive hydraulic pumps and generate electricity [12-14].

Cost Comparison of different technologies

Table 6. Cost Comparison of different technologies

Technology	Capital Cost USD/kW	O&M Cost USD/kW
OWC	3131.00	144.73
Pelamis	1860.00	86.67
Wave dragon	3200.00	66.54
AWS device	3595.00	n/a
McCabe Wave Pump	n/a	n/a
The PowerBuoy	1500.00	n/a
The AquaBuoy	3000.00	n/a
Sea Wave (EcoPower)	1200.00	28.54

n/a – Not available

The study has confirmed that the technology developed by Eco Power is more economical as well as technically feasible subjected to the availability of required type of waves.

Conclusions

It is concluded that sea wave is revitalized by this new invention (Eco Power – Invention) which stretches the conventional boundaries of an NCREd industry

. Further sea wave (Eco Power – Invention) has been shown to have a healthy economic feasibility by maintaining satisfactory margins compared with other NCRE sources such as Mini-hydro, wind and Solar which are widely available in Sri Lanka.

The main challenge in developing wave energy generation in Sri Lanka is the comparatively low height of our waves which may downsize the production rate per unit time. Moreover, the degree of environment impact and obstruction to aesthetic landscape of natural beauty will be another challenge in the Sri Lankan context as feasible waves are generated in the southern coast beaches where the tourism industry is dominant and flourishing.

Since the energy crisis has become a national topic in Sri Lanka after the power-cuts experienced during March-April this year. Sea wave energy which has no environment pollution, no operational cost, less capital requirements, less maintenance charges and more importantly is available 24 x 7 all around the island throughout the year could provide a strategy to overcome energy shortfall in the island.

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