Ocean energy in combination with land-based renewable energy sources: appropriate technology for smaller electricity grids in Africa?

L. Hammar[1], J. Ehnberg[2], M. Gullström[3], S. Molander[1]

[1] Chalmers University of Technology,
Environmental System Analysis,
SE-412 96 Göteborg,
Sweden.

[2]University West,
Engineering Science,
SE-461 86 Trollhättan,
Sweden.

[3]Stockholm University,
Systems Ecology,
SE-106 91 Stockholm,
Sweden

Abstract

The rapid development within ocean energy includes a numerous set of different energy converters differentiated both regarding technical scale and resource requirements. While many of the developers focus on resource hot-spots and commercialization in industrial countries, some technologies may benefit from shifting into niche markets in developing countries. Prerequisites for future sustainable implementations of small-scale ocean energy for electrification of rural communities in low latitude developing regions are reviewed using African countries as case study. To meet the ubiquitous need of power generation at village level in remote areas renewable energy systems, often based on solar photovoltaic, are becoming more frequently implemented. Despite choice of energy source, several small rather than fewer large generators may be preferable since development of distribution grids is generally very slow. This paper discusses ocean energy converter concepts in the perspective of appropriate technology for developing country implementation, and its potential benefits of combination with other sources in small grids.

Keywords: Developing countries, renewable energy, small-scale, ocean energy, electrification

1 Introduction

The harnessing of renewable energy sources (RES) has been pointed out as necessary for a sustainable development since threats to climate change must be met simultaneously with the provision of reasonable amounts of energy to developing societies. Furthermore the concomitant limitations of finance, competence and institutional support severely affect the spread of RES-based technologies (RET) for electrification in rural areas of developing countries [1].

There are several ways to secure energy availability in rural areas of developing countries but the authors believe that grid extension is, at least at current speed, not a suitable solution. Small autonomous systems are therefore an appropriate first step to secure the availability of energy. However, small autonomous systems require a variety of sources to secure continuation in availability [2]. Small-scale energy systems may also be of preference from an environmental perspective since ecological values are of great importance in communities where local population are certainly dependent of ecosystem services.

In order to obtain an integrated assessment of social, technical and ecological prerequisites and consequences for RES-based electrification in South-East Africa, a region with reasonably availability of RES, a huge need for electric power and a very low rate of electrification, the STEEP-RES (Socio-Technical-Ecological Evaluation of Potential Renewable Energy Sources) research program has been initiated. In collaboration with local research institutions the program further includes a comparative assessment of RES availability in the region.

As a result of governmental and donor organizations, and with the support of CDM (Clean Development Mechanism) or subsequent post-Kyoto-protocol programs, appropriate RET are offered an

© Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden, 2009

alternative market in developing countries [3,4]. If RET, including ocean energies, can be found viable not only on large scale national level but also for rural electrification purposes on small scale community level, the market for appropriate technologies may become vast.

As an example, global overviews of the tidal energy potential [5], shows substantial tidal ranges in several developing regions. Potential for prominent semidiurnal tides is found in north western Latin America (e.g. Colombia, Panama, Ecuador), in southern Argentina, in East Asia (e.g. Philippines) and in East Africa (Mozambique, Tanzania, Madagascar). Potential for high diurnal tides is found in South East Asia (China, Indonesia). Significant wave energy potential is indicated for e.g. South Africa, Namibia, Chile, Indonesia and several remote oceanic islands [5].

The long coastlines of South-East Africa are characterized by a large and geographically dispersed population in need of electrical power, along with a significant, though not immense, tidal range. In contrast, South-West Africa holds a considerable exposure to waves

This paper gives a brief introduction to the challenges posed by the preconditions of developing countries and the need of adaption of different technologies from a developing country perspective.

2 Special preconditions of developing regions

Implementation of renewable energy sources in developing countries need to take into account the certain conditions of developing countries compared to implementation in the industrial part of the world. In general, resource availability as well as economical, social and ecological sustainability needs consideration just as in industrialized countries, while several specific, technical, solutions must be adopted specially for developing countries [2]. The particular problems of technology implementation in developing countries are thoroughly discussed in literature [2,6-8] and several preconditions of developing countries need special attention.

In developing countries long-term hydrological and meteorological data are often lacking. Such data is needed for determining suitable locations of advanced renewable energy systems like wind turbines, mini-/micro-hydropower and solar power installations. This implies that long term observations of the actual resource availability often need to precede constructions even for light implementation of RET [6]. For instance, in Tanzania and Mozambique site specific data of solar, wind and tidal power have been collected by independent researchers and by the national meteorological institutes. However, the measurements often lack continuity, are of low geographical resolution [6], and/or cover only a short period of time [9]. As an example, even though Mozambique apparently have a high tidal range, a good coastal wind climate [10], and a promising insolation [11], renewable energy resource assessments are predominantly referring to data from few sites at population centres. Collection of more extensive data sets from more locations is not necessary expensive but may suffer from difficulties in logistics and field measurement continuity.

A frequent obstacle for rural electrification, irrespective of the source of power, is the lack of trained personnel to operate and maintain even uncomplicated energy systems [6]. This is a specific setback for ocean technologies which often have complicated maintenance requirements [5]. Technically trained personnel can often be found in urban areas but their skills are also required in rural developing areas. Furthermore a weak transport infrastructure increase travel time and costs. Transfer of personnel for the construction and the building phase is an option, and in the case of import, local construction can be minimized which may be favourable from a labour capacity point of view. However, social acceptance of a new technology is strongly associated with local participation [12]. One solution to combining local acceptance with professional maintenance support is a solution where the power systems are rented from local contractors who also carry out practical works, as proved successful on e.g. solar home system campaigns in Zambia [13].

Underdeveloped business organisation may lead to a lack of locally available spare parts [2,6]. Insufficient roads make transports of equipment, fuel and spare parts very slow and costly [8] and local production of utensils is rarely a viable option [6]. Insufficient grid infrastructure also complicates transport of produced electricity. Extension of the national grid is a slow and very costly process [4]; therefore local production of electricity can be a viable option. Since power systems in small self-contained power grids are autonomous the generation reliability has to be thoroughly considered and the combination of different RET's for electricity generation may be important for the total availability and reliability of the autonomous grid. E.g. wind and wave energy systems are weather dependent and may be considered unreliable as solitary sources. Solar and small scale tidal energy systems are more predictable, but the given null-production hours has to be deeply considered if being used in solitary systems.

Theft and vandalism are unfortunately also factors to consider when choosing and designing electric power systems [6,8]. The problem is so large in Tanzania that rewards have been launched to reduce it [14]. Among means to prevent vandalism and theft are social acceptance and development on local stakeholders' initiative. In addition the technology itself may work to either ease or impede acts of damage.

In developing countries the rural population is often directly dependent of local ecosystem services, making them more vulnerable to environmental disturbance than would be expected in industrialised countries. Regarding some energy sources, like hydro power [7], use of the resource for electricity production may consequently come in conflicts with local livelihoods, e.g. fishery. Tidal barriers may also impact local marine and estuarine ecosystems, posing risks for e.g. mangroves, seagrass meadows and in turn for biodiversity.

3 Criteria of appropriate technology

The severity of these implementation obstacles can be reduced by the use of "appropriate technology" - a technology that is chosen or adapted to suite local specific requirements in terms of simplicity, robustness, competence of personnel, effect dimension, ecological impacts, social acceptability and institutional support.

For employment of small-scale renewable energy in remote areas of developing countries appropriate technology may imply electricity converters with no need for transported fuel (which is the case for renewable energy technologies in general), low installation efforts, and daily operation and maintenance duties that can be performed by personnel with very basic skills. Further, it is beneficial with technical systems that do not contain essential parts possible to pinch. To secure availability of the energy the source should rather be a power source than an energy source. In many settings of developing regions it is also of certain importance that the resource extraction does not infer with local livelihood ecosystem services.

Appropriate technology will hardly be a large high-effect installation, but a scalable solution on the lower range of installed effect. However, in order to enhance chances of successful technology transfer it is indicated that the generated electricity should not be too low either, as in the case of solar home systems [15].

4 Appropriate renewable energy conversion systems

In this section different solutions on renewable energy with a focus on ocean energy will be discussed from the appropriate technology perspective.

Wave energy and tidal energy, including tidal stream and tidal potential, are ocean energy sources which may possess a potential for employment in the context of rural electrification in developing countries. Here, ocean current converters, large tidal barrages and thermal exchangers are excluded since these are bound to deep waters and large-scale employments. We argue that appropriate technology may preferably be energy systems employed on near-shore sites, which facilitates installation, ease maintenance and reduce costs of sub-marine cables. Moreover, a common obstacle for small-scale ocean energy is the sensitivity to extreme weather conditions; geographical regions with cyclone climate may consequently be directly inappropriate.

Wave energy

Among the approximately 100 identified wave energy prototypes [16], most concepts allow some kind of floating device, which is firmly anchored, to follow the movement of the surface. Either coastal water waves or ocean swell is utilized. Electricity is created by allowing the water movement to create a drag or a compressed flow to propel the generator. Examples are attenuator concepts, like *Pelamis* (Pelamis wave Power) [17], *Swell Fuel* (Swell Fuel) and *Ocean Treader* WEC (Green Ocean energy Ltd), or the more common point absorber concepts like *Aquaboy* (Finavera Renewables), *WET EnGen* (Wave energy Technologies Inc.) and *Seabased WEC* (Seabased AB) [18] where the generator is submerged. Also several oscillating water column (OWC) devices use a floating concept. In opposite, oscillating wave surge converters like *Waveroller* (AW-Energy) [19], *Oyster* (Aquamarine Power) and *BioWave* (BioPower systems) works fully submerged in shallow water.

Submerged technologies may have benefits from low access for theft and vandalism, and will in many cases have a limited effect on other economical interest in the area. However, since the moving parts, that need maintenance, are located below the surface the need of frequent UW works constitute a dreadful setback for use in remote developing regions.

Floating devices with the generator located at the surface implies that maintenance will be to some extent eased although the exposure of technology may motivate certain precaution against vandalism.

The offshore possibility of installation directly from sea, reducing land transports, is a strong advantage in areas with low infrastructure.

Some oscillating water column devices, like the *Pico OWC* (Instituto Superior Tecnico) and the *Limpet* (Wavegen) are installed on land utilizing energy from the breakwater as the incoming waves compress locked-in air that drive a generator. This concept may be more difficult to install in remote areas, but gain significant benefits from facilitated maintenance.

Finally and evidently, the wave energy generation reliability is low in most near-shore locations since the source is weather (wind) dependent. As remote developing regions often lack access to a larger electricity grid this implication becomes large, and motivates use of multiple sources (e.g. solar energy).

Tidal energy

Utilization of tidal energy will give higher generation reliability due to its regularity which may be certainly attractive for remote developing regions (or islands) with substantial tides. The principle for tidal stream converters have similarities to that of wind power, but operating below the water surface where much lower speeds can be utilized due to the higher power density of water compared to air [20]. Among about 50 identified prototypes [16] different concepts are used, like horizontal axis turbines (including venturi effect), vertical axis turbines, and oscillating hydrofoils, to generate electricity at substantial water currents (in general a mean maximum spring speed 2.5 m/s [5]). Examples on developing prototypes are the floating *Kobold Turbine* (Ponte di Archimede) and *Ocean Turbine* (Blue Energy) and the fully submerged *Stingray* (IHC Engineering Business Ltd).

Additionally, several large scale devices are piled to the sea floor.

The remote developing region issues of submerged or offshore tidal energy are similar as for wave energy generators, with most importantly complications of maintenance but also benefits from possible sea-based installations.

Another approach of tidal energy is to erect an enclosure, independent or in conjunction with natural rock, which is filled during flood and emptied slowly during ebb tide, allowing water to pass through generators. The same system can be arranged to let water pass through generators on the inflow, consequently producing electricity during tidal flow in both directions. This technology concept has previously been used only for large scale installations, enclosing entire bays or river mouths, which entails large environmental effects from water allocation [9]. A modern solution to this is approaches of smaller "tidal lagoons" rather than barrages, as presented by Tidal Electric which is currently projecting a 60 MW lagoon in British waters but also argues for scalability down to installations on kW levels, which may be more appropriate for meeting power demands and ecological sensitivity of coastal developing regions. This concept can be implemented on intertidal flats or at natural rock and include few moving parts, which is favourable due to maintenance. The technology of the turbines is rather mature and has in principle been in service since the 1960s [21]. A setback for remote locations is the effort consuming construction of the impoundment, even though natural rock can serve as part of the wall.

Moreover, Woodshed Technologies has suggested a tidal energy approach, *TidalDelay*, where the potential energy of water level differences on opposite sides of a narrow peninsula is tapped by turbines installed in connective pipes. This concept has several advantages as being land based and relatively easy constructed and maintained, however appropriate sites may be very sparse. The predictability of tidal energy is an advantage in comparison with weather dependent sources and short term storage of energy may work to ease synchronization with load in solitary grids. However, multiple source grids will be beneficial also for tidal energy systems.

Land-based RES

Land-based renewable energy technologies are generally more mature and are increasingly discussed from a developing country perspective. Since this paper only discusses small-scale electricity sources geothermal energy as well as thermal solar power systems is not further considered. Bio-energy electricity conversion may be of interest where the harvest can be done locally and does not cause deforestation or compete with food production.

Wind power, as being a rather mature energy source, is of interest from a developing country perspective if wind speeds are prominent all year round. However, there has not been any substantial boom for wind power in many developing countries, with true exceptions of economically expanding countries like China and India. Lack of local responsibility and competence for wind mill maintenance at community level [12], and lack of successful measures against theft and vandalism [14], has been reported as major impediments for successful technology transfer in Tanzania. Another concern with wind energy is the stochastic behaviour of power production, an issue that to some degree can be counteracted by using designs that utilises lower wind speeds to a higher extent, as proposed by Khan *et al.* [22]. Another interesting solution for wind energy is to combine it with other more regularly used sources like solar [2].

Solar power can be seen as a very promising solution since the resource is available in many developing countries of low latitudes [23] and the generation is often regular. Subtropical regions may offer certainly good conditions for solar power while clouds are very frequent in coastal tropical regions, somehow reducing its potential here. The systems can be scaled to any size and to be placed out of reach to prevent theft and vandalism. Disadvantages with smaller solar photovoltaic systems are the relatively low effects obtainable and the installation costs.

Need of adaption

In Table 1 the need of adaption before implementation of above discussed energy conversion technologies are summarized. The table highlights discussed needs of technical adaptation associated with technology transfer in developing countries; however this discussion does not include the economic and social prerequisites for technology absorption.

Table 1. The table summarize how different concepts of discussed RET meet issues of appropriate technology from a developing country perspective. The magnitude of need for adaption is estimated as Adaption Needed (**AN**) and Minor Adaption Needed (**MAN**). No Specific (**NS**) adaption needed indicates that the authors cannot foresee particular technical adaption for implementation in developing countries. For the land-based energy conversion systems the water allocation is not relevant (**nr**).

	Generation reliability	**Transport and installation**	**Maintenance**	**Vandalism and theft**	**Water allocation**
Wave Energy; submerged	MAN	AN	AN	NS	NS
Wave Energy; surface	MAN	MAN	MAN	MAN	MAN
Wave Energy: land	MAN	MAN	MAN	AN	MAN
Tidal Stream: submerged	NS	MAN	AN	NS	NS
Tidal Stream: surface	NS	AN	MAN	MAN	MAN
Tidal (range) Potential	NS	AN	MAN	MAN	AN
Wind Power	MAN	MAN	MAN	AN	nr
Solar Power	MAN	NS	MAN	MAN	nr

5 Combinations of appropriate RES

As emphasized in Table 1 the weather dependent RES offer complications with generation reliability and therefore a combination of sources are needed. Therefore autonomous systems are normally combined with sources of high generation reliability, for example a diesel generator [24]. However, during later years other combinations have been developed due to technical progress, like combinations with fuel-cells [25]. Here, technologies are still in under development. When utilizing tidal energy the availability is of concern. Electricity from the predictable tide can be used to supplement parallel technologies with lower generation reliability; the total reliability will then increase significantly as shown by Ehnberg [2].

The control of a system with a combination of sources is more complicated than if only a single source is used. The control method also needs to be adapted to the combination of sources in order to maximise the energy use of the system. In case of combinations of sources with low generation reliability such as wave or wind power, or technologies without storage possibilities, it has been shown that a load based control system can be favourable [2]. In the case of tidal potential power (e.g. the "tidal lagoon" concept) the built-in storage in the lagoon can be used like storage as in hydro power systems. However, a significant difference is that the water can only be stored until the next flood when unexploited potential has to be wasted to create a new, reverse, potential. The relatively long (hours) lag time between flood and ebb tide, like other sources with variable generation, motivates that also this control method benefits from combination with flexible industrial activity in order to maximise the use of the installation and minimise the problem with availability.

6 Conclusions

Even though the ocean energy technologies are mainly being developed for the industrialized part of the world, some concepts are likely to benefit from further adaption towards the market of developing countries. This way of rural electrification can be supported by CDM or subsequent post-Kyoto-protocol programs.

Installations of ocean energy conversions systems will probably be most interesting as combinations with more mature land-based technologies like solar, in order to increase the generation reliability. The regular tide makes tidal energy conversion systems a certainly interesting component for autonomous power systems based renewable in developing regions, especially for the aspect of generation reliability. However, difficulties on maintenance are of great importance and must, together with social acceptance and ecological considerations, be addressed thoroughly in parallel to any system design.

Furthermore, it is of importance that RET-concepts are scalable, in terms of installed power, in order to be appropriate for markets covering large spans of demand, which can be expected in developing countries.

Acknowledgements

The authors would like to thank the Futura Foundation for financial support.

References

[1] Murphy, J. T. (2001). "Making the energy transition in rural east Africa: Is leapfrogging an alternative?" *Technological Forecasting and Social Change* 68(2): 173-193

[2] J. Ehnberg, *Autonomous Power Systems based on renewable – on generation reliability and system control*, PhD thesis, Chalmers University of Technology, Göteborg, 2007.

[3] H. Doukas, C. Karakosta, J. Psarras. RES technology transfer within the new climate regime: A ‘‘helicopter’’ view under the CDM. *Renewable and Sustainable Energy Reviews* 13: 1138-1143, 2009.

[4] N. Duic, L.M. Alves, F. Chen, M. de Graca Carvalho. Potential of Kyoto Protocol Clean Development Mechanism in transfer of clean energy technologies to Small Island Developing States: case study of Cape Verde. *Renewable and Sustainable Energy Reviews* 7: 83–98, 2003.

[5] EPRI Electric Power Research Institute. Ocean Tidal and Wave Energy – Renewable Energy Technical Assessment Guide. Report, 2005.

[6] M. Sheya and S. Mushi, The state of renewable energy harnessing in Tanzania, *Applied Energy*, 65: 257-271, 2000.

[7] R. Kadigi et al. Water for irrigation or hydropower generation? – Complex question regarding water allocation in Tanzania, *Agricultural water management*, 95: 984-992, 2008.

[8] J. Ehnberg, Study trip to Tanzania in February 2005, Technical report, Department of Energy and Environment, Chalmers University of Technology, Sweden, 2006.

[9] A. Dubi, Tidal Power Potential in the submerged Channels of Dar es Salaam Coastal Waters, Western *Indian Ocean J. Mar, Sci.,* 5: 95-104, 2006.

[10] B.C Cuamba, R. Uthui, M.L. Chenene et al., Identification of areas with likely good wind regimes for energy applications in Mozambique, Eduardo Mondlane University, Unpublished report.

[11] B.C Cuamba, M.L. Chenene, G. Mahumane et al., Solar energy resources assessment in Mozambique, Eduardo Mondlane University, Unpublished report.

[12] STEEP-RES, Field report on renewable energy discussions in East Africa, Chalmers University of Technology, 2009.

[13] M Gustavsson, *Solar Energy for a Brighter Life – A Case Study of Rural Electrification through Solar Photovoltaic Technology in the Eastern Province, Zambia*, Dissertation, University of Gothenburg, 2008.

[14] Tanesco Ltd, *TANESCO LOSES TSH 796 MILLION OIL TO VANDALS* [Electronic] Dar-es-salaam Available: <http://www.tanesco.com> [2009-04-13]

[15] J. T. Murphy, Making the energy transition in rural East Africa: Is leapfrogging an alternative? *Technological Forecasting and Social Change* 68: 173-193, 2001.

[16] EMEC The European Marine Energy Centre Ltd. Available <http://www.emec.org.uk> [2009-04-19]

[17] D. Kerr, Marine Energy, *Phil. Trans. R. Soc. A,* 365: 971-992, 2007.

[18] M. Leijon *et al.*, An electrical approach to wave energy conversion, *Renewable Energy*, 31: 1309-1319, 2006.

[19] AW-energy, WaveRoller Concept, [Electronic] Vantaa Available: <http://www.aw-energy.com> [2009-04-19]

[20] M. Khan, River current energy conversion systems: Progres, prospects and challenges, *Renewable and Sustainable Energy Reviews*, 12: 2177-2193, 2008.

[21] I. Usachev et al., Performance control of a marine power plant in the Russian arctic coast and prospects for the wide –scale use of tidal energy, *Power Technology and Engineering,* 38: 188-193, 2004.

[22] A. Khan *et al.* On adapting a Small PM Wind Generator for a Multiblade, High Solidity Wind Turbine, *IEEE Transaction on energy conversion*, 20: 685-692, 2005.

[23] L. Diabate et al., Solar radiation climate in Africa, *Solar Energy*, 76: 733-744, 2004.

[24] N. Lipman, 'Overview of Wind/diesel systems', *Renewable Energy*, 5: 595-617, 1994.

[25] E. Kasseris *et al.* 'Optimization of a wind-power fuel-cell hybrid system in a autonomous electrical network environment', *Renewable Energy*, 32: 57-79, 2007.