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Performance Evaluation of Hydrokinetic Energy: A Global Review

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INTRODUCTION

Reducing global warming is one of the biggest challenges facing the world today. The urgent need to address this challenge has led to various international initiatives to promote the use of renewable energies. Among various forms of renewable energy, ocean / tidal energy, wind energy and solar energy bear at most importance (Lee, 2010).

Demand for modern renewable energy grows remarkably, but different types achieve greater or lesser penetration such as hydropower accounts for more than 60 % of electricity generation in Latin America, while wind power accounts for nearly 20 % of generation in the European Union.

Global carbon dioxide levels today exceed 400 parts per million, of which 91 % is accounted from fossil fuel emissions (co2.earth, 2017). In 2010, carbon emission accounted to 30.4 gigatonnes; this is 5 % higher than in 2009. If carbon dioxide and other greenhouse gases continue to pour into the atmosphere unchecked, the world may warm rapidly. Thus governments around the world meet regularly to discuss what can be done to reduce these greenhouse gases emissions. As each country evaluates its resources, many have recognized hydrokinetic energy as a significant contributor to its renewable energy portfolio (Laws and Epps, 2015).

Hydrokinetic energy such as ocean wave, current tidal, and in-stream current energy resources, is one such promising candidate for augmenting the needed supply of carbon-free energy sources (Wellington, Pederson, and Morenoff, 2008).

Hydropower is the world's largest, most mature application and cheapest source of renewable energy (Timmons, Harris, and Roach, 2014) and plays an important part in global power generation. Moreover, hydropower is an extremely flexible technology for power generation (Oprea, 2012). According to IEA (2010), water power generates about 16 % of global electricity in 2008 or equivalent to 3,288TWh worldwide.

China is the world's largest energy consumer at the same time largest producer of hydroelectric power, followed by the United States, Brazil, Canada and Russia (IEA, 2011). For Brazil and Canada hydro represents a very large share of national power generation, roughly 80 % and 60 %, respectively, depending on weather conditions. Furthermore, hydrokinetic source potential and technology analyses are mostly practiced by USA, UK and Canada (Yuce and Muratoglu, 2015).

In the Philippines, the electricity production is dominated by thermal resources, such as natural gas and coal, although hydropower is by far the largest renewable energy source accounting to 20 % of actual total share (Andritz, n.d.).

REVIEW OF RELATED LITERATURE

Renewable energy technology exists in many forms and the largest source of it comes from hydropower. Hydropower is renewable because it draws its essential energy from the sun which drives the hydrological cycle which, in turn, provides a continuous renewable supply of water (Oprea, 2012).

Furthermore, hydropower provides an option to store energy to optimize electricity generation.

Demand for electricity grows steadily and projected to grow by more than four-fifths between 2009 and 2035. World electricity demand is projected to increase from 17200 TWh in 2009 to over 31700 TWh in 2035, an annual growth rate of 2.4 % driven by economic and population growth. China and India account to half of this increase. Globally, industry remains the largest consuming sector, followed by the residential and services sectors.

Electricity demand by region and scenario shows in Table 1 reveals that global electricity demand doubles in the Current Policies Scenario and increases by almost two-thirds in the 450 scenario.

Table 1 Electricity Demand by Region and Scenio (TWh)

			New Policies Scenario		Current Policies Scenario		450 Scenario	
	1990	2009	2035	2009 - 2035	2035	2009 - 2035	2035	2009 - 2035
OECD	**6 593**	**9 193**	**12 005**	**1.0 %**	**12 554**	**1.2 %**	**11 343**	**0.8 %**
Americas	3 255	4 477	5 940	1.1 %	6 119	1.2 %	5 612	0.9 %
US	2 713	3 725	4 787	1.0 %	4 898	1.1 %	4 505	0.7 %
Europe	2 321	3 088	4 028	1.0 %	4 244	1.2 %	3 802	0.8 %
Asia Oceania	1 017	1 628	2 037	0.9 %	2 191	1.1 %	1 930	0.7 %
Japan	759	950	1 158	0.8 %	1 225	1.0 %	1 075	0.5 %
Non OECD	**3 492**	**8 024**	**19 717**	**3.5 %**	**21 798**	**3.9 %**	**16 978**	**2.9 %**
E. Europe / Eurasia	1 585	1 280	1 934	1.6 %	2 238	2.2 %	1 742	1.2 %
Russia	909	791	1 198	1.6 %	1 401	2.2 %	1 057	1.1 %
Asia	1 049	4 796	13 876	4.2 %	15 334	4.6 %	11 666	3.5 %
China	559	3 263	9 070	4.0 %	10 201	4.5 %	7 447	3.2 %
India	212	632	2 463	5.4 %	2 590	5.6 %	217	4.8 %
Middle East	190	600	1 393	3.3 %	1 525	3.7 %	1 264	2.9 %
Africa	263	532	1 084	2.8 %	1 152	3.0 %	1 000	2.5 %
Latin America	404	816	1 430	2.2 %	1 550	2.5 %	1 306	1.8 %
Brazil	211	408	750	2.4 %	792	2.6 %	675	2.0 %
World	**10 084**	**17 217**	**31 722**	**2.4 %**	**34 352**	**2.7 %**	**28 321**	**1.9 %**
European Union	*2 227*	*2 793*	*3 530*	*0.9 %*	*3 716*	*1.1 %*	*3 351*	*0.7 %*

Around 80 % of the growth in electricity demand in non-OECD countries, with China and India accounting for two-thirds of it.

Worldwide carbon dioxide emissions from the power sector increase by one-fourth between 2009 and 2035, growing slowly than demand this is the result of the increased use of renewables and improved plant efficiency that reduce the carbon dioxide emission (OECD/IEA, 2011).

Global electricity generation by plant type and scenario is presented in Table 2 showing an increase by 2.3 % per year on average from 20000 TWh in 2009 to more than 36000 TWh in 2035.

Table 2. Electricity Generation by Plant and Scenario (TWh)

			New Policies Scenario		Current Policies Scenario		450 Scenario	
	1990	2009	2020	2035	2020	2035	2020	2035
OECD	**7 629**	**10 394**	**11 997**	**13 304**	**12 143**	**13 939**	**11 743**	**12 541**
Fossil Fuels	4 561	6 306	6 649	6 165	6 993	7 713	6 133	3 285
Nuclear	1 729	2 242	2 445	2 779	2 389	2 472	2 495	3 463
Hydro	1 182	1 321	1 476	1 592	1 461	1 547	1 505	1 683
Non hydro renewables	157	525	1 427	2 768	1 300	2 208	1 610	4 110
Non OECD	**4 190**	**9 649**	**15 884**	**22 946**	**16 426**	**25 429**	**15 092**	**19 683**
Fossil Fuels	2 929	7 139	10 944	14 327	11 764	18 463	9 702	7 481
Nuclear	283	454	1 130	1 879	1 105	1 582	1 246	2 932
Hydro	962	1 931	2 904	3 926	2 793	3 597	3 042	4 369
Non hydro renewables	15	125	905	2 814	764	1 787	1 102	4 900
World	**11 819**	**20 043**	**27 881**	**36 250**	**28 569**	**39 368**	**26 835**	**32 224**
Fossil Fuels	7 490	13 445	17 593	20 492	18 757	26 176	15 835	10 765
Nuclear	2 013	2 697	3 576	4 658	3 495	4 053	3 741	6 396
Hydro	2 144	3 252	4 380	5 518	4 254	5 144	4 547	6 052
Non hydro renewables	173	650	2 332	5 582	2 063	3 995	2 712	9 011

Table 2 shows that coal is the largest source of electricity generation globally. However, hydro maintains relatively constant shares of electricity generation throughout the period of 16 %.

Hydropower System

Hydropower has already been developed extensively in many OECD countries and there is limited remaining potential, given the costs and environmental constraints (OECD/IEA, 2011). Table 3 shows the investment in new power plants globally.

In constructing a hydropower system, an artificial water head is created so that water can be diverted through a pipe (penstock) into a turbine where it is discharged usually through a draft tube, or diffused back into the river at a lower level. Various types of turbine have been developed to cope with different sizes of head and flow.

Water turbines are used to convert the energy of falling water into mechanical energy (Oprea, 2012). The principal types of turbines are impulse and reaction. Impulse turbines are used for high heads, in which entire pressure of water is converted into kinetic energy in a nozzle and the velocity of the jet drives the wheel. On the other hand, reaction turbines are used for low to medium heads, in which water enters the runner partly with pressure energy and partly with velocity head.

Hydropower plants have benefits such as facilitating irrigation, providing drinking water and flood control (Zhang, Xu, Yu and Li, 2014). It is a renewable power source which does not pollute the air like power plants that burn fossil fuels, such as coal or natural gas. However, disadvantages of this system include obstruction of navigation, obstruction of fish migration, modification of aquatic habitats and possible pollution of the water due to materials used in the system, methyl mercury (Okot, 2013). Further, construction of new hydropower facilities impacts the local environment and may compete with other uses for the land.

Hydrokinetic Technologies

Hydrokinetic electric power, is a promising new, vast, and renewable resource (Mangold, 2013), generated by turbines capturing the energy of naturally flowing water without impounding the water. Hydrokinetic turbines are renewable energy harnessing devices that convert kinetic energy of flowing water in the form of current and waves into electricity (Muratoglu and Yuce, 2015).

The technologies developed to generate energy from waves and currents, called hydrokinetic energy conversion devices, are generally categorized as either wave energy converters or rotating devices. Wave Energy Converters basically creates a system of reacting forces in two or more bodies relative to each other (Bedard, 2005). Rotating Devices, on the other hand, capture the kinetic energy of a flow of water as it passes across a rotor. Some rotational device designs rotate around a horizontal axis while other, more theoretical concepts are oriented around a vertical axis (Union of Concerned Scientists, 2009).

The hydrokinetic turbines fall under reaction type turbine and they have similar working principles as wind turbines which are to convert the hydrokinetic power into mechanical power in the form of rotating blades (Alam, 2009). Hydrokinetic turbines or water stream turbines are commonly used in river flow, canal flow, irrigation flow, and tidal current. There are two areas from which hydrokinetic power can be derived: marine and river power. Marine hydrokinetic power deals with extracting energy in the ocean from tides and currents. Whereas hydrokinetic power extracted from the river comes from kinetic energy of the flow.

There are different existing hydrokinetic turbines designs to accommodate variety of locations such as hydrovolts turbines, portable turbine, waterfall turbine, and other hydrokinetic turbines.

Generally, there are two types of turbines used to harness the power of the water's kinetic energy: horizontal and vertical axis turbines. These are used for extracting power from both wind and water. The horizontal axis turbine has its axis in line with the flow while the vertical axis turbine has its axis of rotation orthogonal to the flow.

However, a relatively new rotor was designed, a Gorlov Helical Turbine. This turbine is composed of two or more helical blades rotated like a screw thread welded between two discs. It allows large volumes of water to flow through and can be assembled vertically and horizontally (Gorlov, 2010).

Hydrokinetic energy extraction begins where moving water meets turbine blades. Turbine blades are made up of hydrofoil section profiles (Laws and Epps, 2015).

The Department of Energy (DOE), Pacific Northwest National Laboratory (PNNL), and Electric Power Research Institute (EPRI) are funding and implementing several studies regarding environmental impact of hydrokinetic turbines. One of which is the risk evaluation process that can be used to calculate the impact at different locations of the hydrokinetic turbine (Arango, 2011). Another study is the impact of the hydrokinetic turbine on the fish survivability in the Mississippi River (Kessler, 2010).

An impact comparison was made between hydrokinetic and solar energy, one of the most popular and well-known clean energy resources. According to the study conducted by Devlin (2012), a 5 kW solar system with no tax credits is currently estimated to cost between $ 25,000 and $ 35,000 with an estimated Return of Investment of roughly 20 years. This is more expensive than hydrokinetic turbines with Return on Investment of 7.6 years and at the same time the hydrokinetics has potential to be more efficient and cost-effective than the leading renewable energy sources. This claim of hydrokinetic technology is more economical compared to solar power system is further validated by Kusakana and Vermaak (2012).

International Agreements / National Policies and Regulations

The United Nations Framework Convention on Climate Change (UNFCCC), formed in 1992 by 196 parties, set the ultimate objective to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

In 1997, the Kyoto Protocol was adopted at the third Conference of the Parties to the UNFCCC which shares the objectives and institutions of the convention. It was designed to assist countries in adapting to the inevitable effects of climate change and facilitates the development of techniques that can help increase resilience to climate change impacts. Under the Protocol, 37 industrialized countries and the European Communities have committed to reducing their emissions by an average of 5 percent against 1990 levels over the five-year period 2008 – 2012.

In 2009, the Copenhagen climate change conference produced the Copenhagen Accord and was expanded and formally adopted in 2010 as the Cancun Agreement where countries committed to reducing their emissions by 2020.

On December 12, 2015 an international agreement was adopted by different countries known as the Paris Agreement on Climate Change. The agreement requires all countries to make significant commitments to address climate change. It includes a stronger transparency and accountability system for all countries that requires reporting on greenhouse gas inventories and projections (FCCC, 2015).

The Senate and House of Representatives of the United States of America enacted the Energy Policy Act of 2005 which encourages the production of renewable energy from both hydroelectric power and ocean energy, and set requirements for the federal government to purchase not less than 7.5 % of its electricity from renewable sources by 2013 and each year thereafter (US-EPA, 2017).

The South African Government give push to renewable energy and integrates it into the mainstream energy economy by setting a target of 10000 GWh renewable energy contributions to be produced mainly from biomass, wind, solar and small-scale hydropower by 2013. (DEM, 2003).

In the Philippines, the Senate and House of Representative enacted the Republic Act No. 9513 known as the “Renewable Energy Act of 2008”. The act encourages the development and utilization of renewable energy resources as tools to effectively prevent or reduce harmful emissions and thereby balance the goals of economic growth and development with the protection of health and the environment (Section c). This policy was created to define substantive feed-in tariffs for hydroelectric power.

Republic Act 7156 is another act enacted in the Philippines' congress in September 1991 granting incentives to mini-hydroelectric power developers. One of the objectives of the framework is to encourage entrepreneurs to develop potential sites for hydroelectric power existing in their respective localities. Mini-hydro systems are those installations with size ranging from 101 kW to 10 MW. By inference, micro-hydro systems refer to installations with capacity of 100 kW or less.

Global Researches and Development

REN21 provides annual renewables global status report. In the 2016 annual review, the secretariat mentioned that an estimated 148 GW of renewable power capacity (largest annual increase ever) was added in 2015 of which approximately 28 GW is from new hydropower capacity. This brings an increase of 1,064 GW total global capacities. The report also reveals that China is leading in the investment in renewable power and fuels as well as in renewable power capacity and generation. The 16 GW of new hydropower projects was commissioned by China. Other countries with substantial increase in 2015 include Brazil, Turkey, India, Vietnam, Malaysia, Canada, Columbia and Lao PDR. Furthermore, it was reported that, in 2015 more than 600 micro-hydro plants were providing electricity off-grid to rural areas of Indonesia, around 1,300 micro-hydro plants in Nepal, and 1,600 pico hydro systems were in operation for a combined capacity of 27.7 MW.

Globally, the technical hydropower potential is estimated around 15000 TWh. However, in most developed regions such as Europe, a significant fraction of these potential is already exploited, though about 50 % of these estimates is still untapped. The most untapped region is Africa having 92 % of its total potential has not yet been developed (IEAETSAP and IRENA, 2015).

Kaur and Saini (2016) conducted a study on the development of an efficient hydrokinetic turbine. Based on the experimentation, the maximum power output of 37.47 Watts was obtained at a velocity of 2.25 m/s. The maximum power coefficient (0.372) and torque coefficient (0.525) was also obtained at a tip ratio of 0.709 indicating an efficient hydrokinetic turbine was developed. The study suggested for further analysis on the reliability and sustainability aspects of the technology.

In India, Verma and Saini (2015) conducted a review on the efficiency measurement techniques for evaluation of performance of hydrokinetic turbines. The study revealed that hydrokinetic turbines are considered the suitable turbines to the tap the hydro potential available in velocity of flowing streams in India.

According to the report of IRENA (2014), China has become a global leader in renewable energy and installed more new renewable energy capacity than all of Europe and the rest of the Asia Pacific region. To date, China has the world's largest installed capacity of hydroelectric power. Zhou, Tian, Zhang, and Wei (2005) mentioned in their research that more than 290 GW economically exploitable hydro power potential ranks China number 1 in the world in hydro power resource. The total small hydro power resource is about 128 GW and 75 GW is technically exploitable. However, in 2001 Canada is the largest producer of hydroelectric power in the world (Gürbüz, 2006).

The hydrokinetic river turbines are used to power remote communities that do not have access to electricity. However, these turbines face significant challenges with debris (Mangold, 2012), which clogs the rotors and generate the need for repairs and maintenance (Bavar, 2014) and resulting in power loss (Anyi and Kirke, 2010; Khan, Bhuyan, Iqbal, and Quaicoe, 2009).

A study conducted by Romero-Gomez and Richmond (2014) provides insight to fish interactions with marine hydrokinetic tidal devices. The study shows turbine blades do not pose direct threat to the fish and that the fish mortality rates is less than 4 % which is lower than the rates for conventional turbines. Another first and only direct fish survival study was carried out by Kessler (2010) at Hydro Green's hydrokinetic turbine on the Mississippi River in Hastings, Minnesota showing that out of 402 fish only one was exposed to direct physical harm.

Mangold (2012) conducted an analysis on the efficiency and potential of hydrokinetic power in the Roza and Kittitas Canals. The results of the study reveal that the turbine performed above the expectations during the sampling timeframe at the Roza Canal which provided 3 kW higher than expected. Similarly, in the case of Kittitas Reclamation District, turbines produce a large amount of clean energy with a Return on Investment of less than half the turbine's lifetime. Aside from these benefits, hydrokinetic turbines can be installed easily and produces consistent power output.

According to the report on Hydro in Europe by RESAP (2011), hydropower plants is the most efficient renewable energy that converts more than 95 % of moving water's energy into electricity as compared with 60 % efficiency of the best fossil fuel plants. Moreover, it demonstrates the best performances when it comes to greenhouse gas emissions as measured on a life-cycle basis with only 4g Carbon Dioxide per kWhe as compared with 1001g Carbon Dioxide per kWhe coal (fossil fuels). This is based on the review conducted on the same year by the Intergovernmental Panel on Climate Change.

In 2010, Ortega-Achury and colleagues reviews the existing US literature and databases of information on hydrokinetics and explore the effects of energy extraction using hydrodynamic calculations. It was reveals that the hydrokinetic power generation offers a significant contribution to US electricity needs by adding as much as 20,000 to 30,000 MW to the present capacity with less visual aesthetic impact. However, possible effects of the installation of such technologies on navigation include increased risk of waterborne vessel accidents and environmental effects that impinge on navigation projects' safety, sustainability, and effectiveness. The United States Department of Energy assesses and mapped the potential off-shore ocean current hydro kinetic energy resources along the U.S. coastline, excluding tidal currents, to facilitate market penetration of water power technologies (Neary, 2012).

The Australian Government gets hydropower from wastewater (Patel, 2010). An Australian 4.5 MegaWatt hydroelectric sewage plant use treated wastewater falling down a 60 meters shaft to produce its own power. This is one of the three units the New South Wales government installed in Sydney Water's water and sewerage networks.

In California, USA, the 225 kW system Los Angeles wastewater treatment plant was built to support the 19 % electricity requirement for treating and distributing water and wastewater (Patel, 2010).

Johnson and Pride (2010) outline the status of hydrokinetic power generation technology in Alaska. As cited in the study, Alaska is well positioned to use hydro kinetic turbines as a replacement for fossil fuels. It was concluded that hydro kinetic turbines are a viable method of generating power in Alaska. However, there are challenges facing the development of commercial hydro kinetic industry in the area such as determining the technological, operational, and economic viability of hydro kinetic turbines, meeting permitting requirements, and gaining stakeholder acceptance. Further, coinciding with the claim of Bavar, the study also reveals that hydro kinetic technology can be affected by debris.

Kassam (2009) conducted a study to demonstrate the viability of river hydro kinetic power in cold climates. This research project was deployed in Winnipeg River in Canada. The study found out that the turbine performed well during the winter as long as it is not froze in and cold climate did not affect power production. Thus, kinetic turbine technology has proven potential to extract electric powers that flow through rivers and has potential to provide reliable and consistent power in remote locations.

The study conducted by Previsic, et.al. (2009) on the hydro kinetic energy in the United States reveals that the recoverable potential to provide electricity from hydro kinetic energy resources is estimated to be about 10 % of the electric consumption in the United States. Initial studies suggest that given sufficient deployment scale on these technologies, it will be commercially competitive with other forms of renewable power generation.

Meanwhile, France is the European Union's largest producer of hydroelectricity. In 2001, generation capacity of hydropower was about 25,000 MW (Balat, 2006). According to Gürbüz (2006), in 2001 Norway derived 99 % of its power from hydroelectric plants and in the same year, 100 % of the electricity used in Democratic Republic of the Congo and 83 % in Brazil is provided by hydroelectric power.

Kusakana and Vermaak (2012) investigated the possibility of using and developing hydro kinetic power suitable to supply electricity to rural and isolated loads in South Africa and found out that proposed hydrokinetic system meet the load energy requirement of the area during the worst months. The result of the study further reveals that hydro kinetic is the best supply option compared to solar and diesel generator. Moreover, apart from being very cheap to operate and maintain, the hydro kinetic system contributes to the reduction of the carbon dioxide and green house gases in the atmosphere.

According to SATMP, the Inarihan Mini-hydro power plant was the first project to avail of the RA 7156 incentives for mini-hydro project. It was launched in 1996 at Naga City, Bicol and was completed after two years. The system has a capacity of 960 kW of power and generates an estimated 5.30 MW-h annual electricity.

Several studies have been concluded that employing hydrokinetic turbines is most suitable and cheap way of supplying clean reliable electricity to remote and less developed countries which are off-grid areas where transmission lines do not exist (Yuce and Muratoglu, 2015; McGlynn, 2014; Kusakana and Vermaak, 2013; Balat, 2006).

CONCLUSIONS AND RECOMMENDATIONS

Hydrokinetic power generation avoids greenhouse gas emissions and other air pollution associated with fossil fuel. It does not change the river flow regime, no destruction of nearby land as well as reduction of flora and fauna destruction. It further significantly contributes to climate change mitigation.

Hydrokinetic turbines are a promising source of clean renewable energy notable for their minimal negative environmental effects; the technology is safe for fish. It also does not produce any audible noise that could harm the human health.

Although hydrokinetic power generation is flexible in terms of locations where it can be used, it is dependent on weather conditions. Further, it produces consistent power output; it is most suitable in remote communities.

Since hydrokinetic technology is a very new renewable energy technology, it needs further studies particularly on its feasibility, efficiency, environmental and social impact and reliability. More so, mitigation of debris issues must be considered in developing the technology.

Conduct further study on the rural electrification by considering the hydrokinetic energy as the main source.

Furthermore, long-term performance evaluation of hydrokinetic turbines in various situations is recommended to test the reliability as well as the quality of the turbine designs and projected power outputs.

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