Harnessing the Potential of Tidal Currents in Indus Delta Creeks for Making Sustainable and Green Pakistan

M. H. Arsalan[1], H. Fatima[1], A. Khalid[1], I. Zia[2] , I. Ahmad[3]

[1] *Geo-informatics and Sustainable Development Research Lab, Institute of Space and Planetary Astrophysics, University of Karachi, Karachi, Pakistan*
[2] *National Institute of Oceanography, Karachi, Pakistan*
[3] *City and Regional Planning Department, University of Engineering and Technology, Lahore, Pakistan*
[3]haamsafar@hotmail.com

Abstract- Pakistan is facing serious energy crises. Presently the energy supplies are primarily fulfilled by natural gas and imported oil. The energy deficit is a major constraint to economic growth. However, Pakistan is blessed with natural resources, which can be utilized to tackle the energy deficit. Compared to other renewable energy technologies, tidal energy is still not capitalized in Pakistan.

It was estimated that around 900 MW power can be generated from tidal currents in the Indus Delta Creek areas. Among all creeks Chan Waddo, Korangi, Paitiani, Kajhar and Khai creeks have the highest power potentials.

In this study, a GIS based approach was used to analysee the sustainable use of the estimated tidal current power potential. The proximity of power potential sites to power grid, urban area, built up land and road network for easy access demonstrate the sustainable use of this energy.

Results showed that energy generated at these potential sites can be utilized in many ways as Korangi creek, Chann Waddo creek and Phitti are close to Karachi, while there are several towns in the vicinity of Pitiani creek and Khai creek. Other potential sites are close to the planned city Zulfikarabad.

As the tidal current potential of the Indus delta creek system is encouraging, it can be considered in future energy policies and sustainable development strategies for a green and sustainable Pakistan. Therefore, it is highly recommended that further research and pilot projects should be commenced on priority basis.

Keywords- Tidal Energy, Tidal Currents, Indus Delta Creeks, Sustainability, Renewable Energy, Resource Mapping, GIS

I. BACKGROUND

Renewable energy has become a hot area of research these days. Its utilization is now considered as an important step in sustainable development. Sustainable development can be defined in many ways. However, the Landmark definition of the Brundtland (1987) is "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [i]. This goal can be achieved efficiently by utilizing renewable energy resources which give us unique opportunity not only to sustain natural capital, reduce greenhouse gas emission from conventional energy systems but also uplift economic conditions.

Technology associated life increased manifold global energy demands as well as increased knowledge of environmental issues that has made green energy a more favourable option for fulfilling global energy demands. Recent research [ii] showed a strong relation between the consumption of fossil fuels and the majority of global greenhouse gas emissions. Several countries around the world have integrated renewable energy policy in their sustainable development strategies. Green energy can be generated in form of Bioenergy, Direct Solar energy, Geothermal energy, Hydropower, Ocean energy and Wind energy.

Oceans cover about 70.8 % of the planet's surface. They not only provide heat and water to our atmosphere, but also they are potential resource of renewable energy [iii]. It has been estimated that if less than 0.1% of the renewable energy available within the oceans could be converted into electricity it would satisfy the present world demand for energy more than five times over [iv]. So far well-known ocean energy sources are waves, tidal range, tidal currents, ocean currents, ocean thermal energy conversion, and salinity gradients. All these sources have different origins and their distinct conversion technology. In comparison to other renewable energy technologies, Ocean energy systems are at an early stage of development, however, rapid advancement of ocean technologies still needs a number of pilot projects and intensive research [v].

Tidal power has more advantages than other renewable energy sources. It is highly predictable as compared to other resources like wind, solar, and wave power. The wind energy mills and tidal current turbines work on the same mechanism, although the high density of seawater, which is about 830 times denser than wind [vi], makes tidal power more efficient than wind power.

Tidal energy can be extracted in two ways: Tidal barrages; and Tidal current turbines. Tidal barrages systems utilize the potential energy of tides and convert it into a usable form that is electricity. The tidal barrages work on the same principle of hydroelectric generation. The tidal barrages consist of dam, turbine, sluice gates, embankments, and ship lock. The coming tides are trapped in reservoirs behind the dam and when the tides go back, the trapped water let out turning the turbine and generating energy [vii]. However, the tidal current turbines utilize the kinetic energy of the tides. Tidal currents are the horizontal movement of water accompanied by the rising and falling tides. The strength of these tidal currents also varies with the tidal range [viii]. Except tidal barrages, many ocean energy technologies are in the pre-commercial prototype stage [v].

Pakistan like other developing countries of the region is facing a serious energy crisis. The total primary energy demand in Pakistan estimated about 60 million tons of oil equivalent (TOE) in 2006-07. During the last ten years, annual growth of primary energy supplies and their per capita availability has increased by nearly 50%. The per capita availability now stands at 0.372 TOE, which is, however, very low as compared to 8 TOE for USA [ix]. According to World Energy Outlook 2011 about 38% population of Pakistan didn't have access to electricity in 2009 [x].

According to a report by the Energy Expert Group entitled "Integrated Energy Plan 2009-2022", during 2007-08 the share of natural gas in primary energy supplies was 47.5%, followed by oil 30.5%, hydroelectricity 10.9%coal 9.2.2%, nuclear electricity 1.2%, LPG 0.7% and imported electricity 0.1% as shown in Fig. 1.

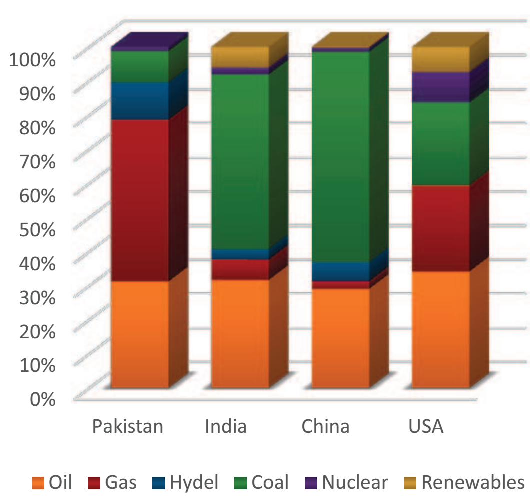

Fig. 1. Percentage of Energy Mix 2007-08 [xi]

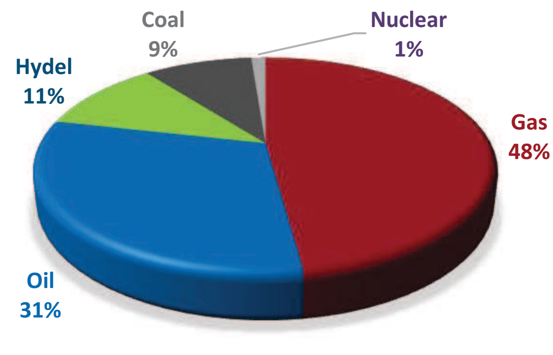

Fig. 2. Energy Mix 2008 [xi]

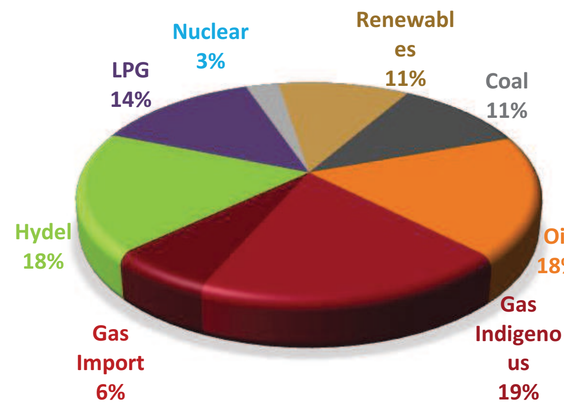

Fig. 3. Energy Mix 2022 [xi]

Pakistan's total primary energy demand is expected to increase from 62.9 MMTOEs (Million Tonnes of oil equivalent) in 2008 to 122.46 million TOEs in 2022[xi]. Figures 2 and 3 indicate the direction in which the Energy Expert Group expects to see the market grow in order to create greater self-reliance[xi]. The energy extraction from the renewable energy resources can help to achieve this expected renewable energy share in 2022 energy mix.

Pakistan's energy policies must be climate change concerned and energy secured. According to 2014 Key World Energy Statistics the net imports were 1.60 MTOE and CO_2 emissions were 0.20 Mt in year 2012 [xii] Table I. The renewable energy will reduce the proportional share of CO_2 emissions, if developed on a priority basis.

TABLE I
ENERGY INDICATORS FOR PAKISTAN YEAR 2012, (A) GROSS PRODUCTION + IMPORTS - EXPORTS -LOSSES, (B) CO2 EMISSIONS FROM FUEL BURNING [xii]

Energy Prod. (Mtoe)	Net Imports (Mtoe)	TPES (Mtoe)	Elec. Cons. [a] (TWh)	CO_2 emissions [b] (Mt of CO_2)
447	1.60	0.77	0.99	0.20

Pakistan is blessed with natural resources that can be utilized to generate electricity, such as Wind, Solar, Hydel, Biomass and tidal energy. The Government of Pakistan established the Alternative Energy Development Board (AEDB) in 2003 to promote investment from the private sector in renewable energy. "Government of Pakistan is putting greater emphasis on Renewable Energy and has set a target of 10% renewable energy or 2700 MW in the Country's energy mix by 2015" [xiii]. The Asian Development Bank (ADB) in its recent report titled '2011 Clean Energy Investments', pointed energy deficit as a major constraint on efficient economic growth in Pakistan [xiv], however this energy deficit can be overcome by utilizing renewable energy sources of Pakistan.

Pakistan has a coastline of about 990 Km [xv] with unique features of creeks in Indus delta. A network of creeks system formed over a period of time due to the flow of the Indus River into Arabian Sea. This creek system is spread over a distance of about 170 Km in the southeast of Karachi along the coast of Pakistan. These creeks meander about 50-69 Km inland where sea water flows into them with high velocity during flood and ebb tides, which is very favourable condition for the extraction of energy from tidal currents[xvi].

As compared to other renewable energy technologies, Tidal energy is still not working in Pakistan, however, the potential of tidal current energy of Indus delta creeks was estimated by Quraishee et al. [xvi] about 30 years ago. Since then the estimated potential has been cited several times, but no further research or pilot project has been initiated [xvii]. Throughout the world, several tidal power stations are working [xviii] say La Rance tidal power station in France, Annapolis Royal Generation Station in Canada, Kislaya Guba Tidal Power station in Russia, and Jangxia power station, China. The Indian state of Gujarat is also planning to host Asia's first commercial-scale tidal power station. British marine energy developer Atlantis Resources Corp. and Gujarat Power Corp. Ltd. signed a memorandum of understanding with the Gujarat government for the 50 megawatt tidal farm on India's west coast[xviii].

Now, it is the time for Pakistan to set its sustainable development goals higher than before and start capitalizing tidal power. If the estimated tidal current power is utilized it will uplift socioeconomic conditions of the coastal population of Pakistan as well as minimize environmental pollution. In this paper, we have highlighted the estimated tidal current power potential of the Indus delta creek system and have analysed its possible sustainable use.

Fig. 4. Indus Delta Creek System, Google Earth, 2014 [xiv]

II. Materials and Methods

A. Spatial Data Generation

Google Earth is a unique platform for base map creation. Its high resolution imagery is open access and free of cost for educational purposes, scholarly publications, and other non-profit uses. Its imagery can be easily captured and manipulated through the permission guidelines of Google Earth and Google Maps [xix] . We utilized images from Google earth to create base map and GIS data layers.

To assess the sustainable harnessing of energy from tidal currents, besides power generating potential many other physical, socioeconomic and environmental data were collected and analysed. To integrate the diversified nature of data layers, Geographical Information System (ArcGIS 10.2) was used. All the datasets were projected to Projected Coordinate System, UTM 1984 Zone 42N. The acquired data, their sources, and the processes involved are summarized in Table II.

TABLE II
COLLECTED DATA AND PROCESSING

Data Description	Type	Source	Processing
Shoreline	Physical	Landsat 7 (11 Apr, 2014), USGS, 2014, [xx]	Extracted in ArcGIS 10.2 using tasseled cap transformation [xxi, xxii]
Bathymetry		GEBCO, 2014, [xxiii]	GEBCO_08 Grid (a global bathymetric grid with 30 arc-second spacing) was extracted from GEBCO grid viewing and data access BODC software

Urban Area and built up land	Socioeconomic	Google Earth, 2014, [xix]	Digitized on Google Earth and processed in ArcGIS
Transportation lines		Google Earth, 2014, [xix]	
Fish Harbors		Google Earth, 2014, [xxiv]	
Ports		Google Earth, 2014, [xxv]	
Fairway and shipping lines		Google Earth, 2014 [xxvi-xxix]	
KESC Grid Station		Google Earth, 2014 [xix, xxx]	
HESCO Transmission lines		Google Earth, 2014, [xix, xxxi]	
Power Plants		Global Energy Observatory (GEO), 2014,[xxxii]	KML was downloaded and processed in ArcGIS

III. VISUALIZATION

Geographic Information system (GIS) provides a unique opportunity to visualize, query, analyse and interpret spatial data, conclude relationships, patterns, and trends. We utilized Visualization capability of GIS to map all input datasets and analysed outcomes in both raster and vector formats with their distinct attributes Fig. 5-14.

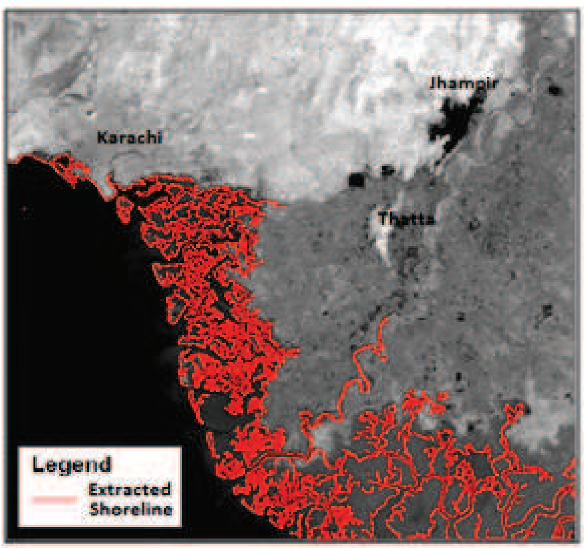

Fig. 5. Extracted Shoreline of Indus Delta

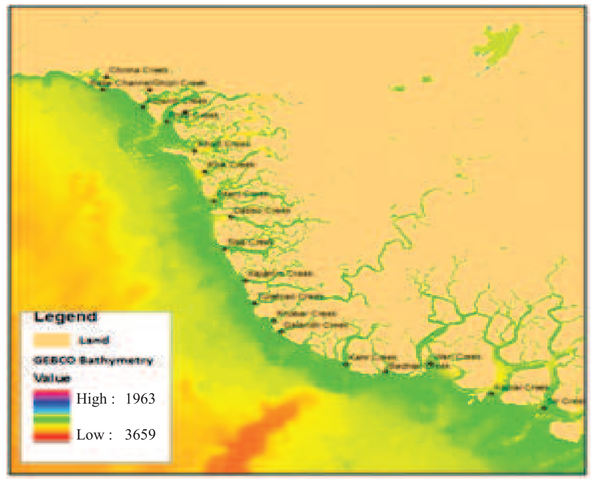

Fig. 6. GEBCO Bathymetry of Study area

Fig. 7. Fairway and Shipping Lines

Fig. 8. KESC Grid stations, Power Plants, and HESCO Transmission Lines

Fig. 9. Road Network

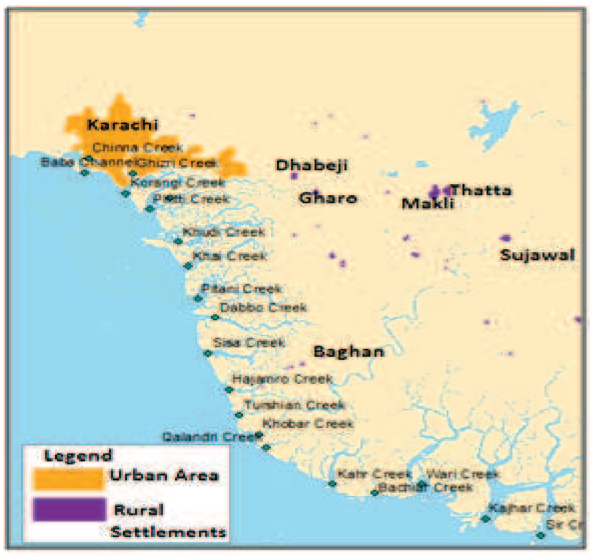

Fig. 10. Urban and Rural Settlements

Fig. 11. Ports and Fish Harbours

IV. Power Potential Analysis

The initial and critical step in tidal power generation is the reliable and comprehensive survey of temporal and spatial distribution of Tidal Energy along the coastlines. There is no regular tidal current monitoring program for creek areas of Pakistan. However a detailed project, named "Feasibility Studies for the extraction of Energy from current and Haliohydrogravity along Pakistan", was executed by [xvi]. It provides a sufficient Tidal power potential assessment for Indus Delta, Pakistan. As this project was the first of its kind and still there is not such a survey, the results of that survey is considered as Tidal power potential of Pakistan in this paper.

Reference [xvi] conducted an intensive survey of selected creeks through small boats. Galvanized Iron pipes and echo sounder were used for hydrographic and sounding purposes. Current velocities were measured in each creek at 0.5m below the surface, mid-depth and 0.5 m above the bottom with the help of Toho Deton and Ekman current meter. Tidal levels were computed by recorded tidal heights in the Khobar creek at Sajjan wari and Gharo creek at Pipri with the aid of tide poles [xvi].

As energy, extraction from current involves the installation of array of long bladed slow moving rotors. These rotors are appropriately designed depending upon various hydrodynamic and hydrographic parameters. Energy can be obtained from the rotation of rotors by the force of the flow of water. The maximum power that can be extracted from single rotor was calculated from this formula:

$$P_{max} = (16/27) * (1/2)\, \pi\, \rho\, V^3 R^2$$

Where,

P_{max} is the maximum power in megawatts

ρ is the average density of sea water in kg/m^3 (1027 kg/m^3)

R is Radius of the rotors in meters

V is the current velocity in Km/hour

16/27 is the Betz limits (max power coefficient for an open unrestricted environment). However, there are studies describing that the tidal turbines in a channel can theoretically have a power coefficient several times greater than 16/27 under certain circumstances[xxxiii].

The Research [xvi] proposed the diameter of the rotors of 1-3 m less than the depth of the creek (hence different radius of rotor for every creek) with a constant width of 0.5m. The number of rotors in one set was estimated for every creek, according to the average bottom width of that creek [xvi]. In this paper these proposed number of rotors Fig. 12 are considered and not calculated as it is out of scope of this paper.

D. Sustainable Use Analysis

Generally, the renewable power potential sites are far away from the users, hence for its utilization long-distance transmission infrastructure is needed. As Marine Current Turbine energy is highly dependent on the intensity of the current, it is difficult to regulate and conserve energy. Therefore, it will be economically efficient if the location is near to the electricity grid and the excess of generated energy will be distributed directly to the electricity grid[xxxiii].

For near shore locations (less than 10 km from the coastline), it is preferable to link individual Marine Current Turbine (MCT) transformer to an onshore transformer station using low voltage cable, although for offshore locations (more than 10 km from the coastline), it is preferable to link individual Marine Current Turbine (MCT) to an offshore transformer station[xxxiv].

After the preliminary engineering design of energy production and transmission, cost – benefit analysis can be determined. Nevertheless, Research [xvi] assessed the cost of production around USD 2.0/W at that time. Although it is the higher estimate of production in comparison with other ways of energy production, however, many studies suggest that the development timeframe and scale of projects have to be analysed in order to come up with the optimal entry point of cost and benefits [xxxv, xxxvi]. At large, small to medium-scale tidal projects are assessed more economically feasible due to experimental technologies. But new generations of technologies are gradually reducing the production cost as well as overall sustainability[xxxv, xxxvi].

To explore the sustainable use of the power potential of these sites, some spatial socioeconomic data of the study area was generated which is summarized in Table 2. The proximity of these power potential sites to national power grid, urban and built up land and road network for easy access is favourable. Along with tidal power potential these distances are important factors that are taken into account in site pilot project selection [xxxvii-xxxix].

V. Results and Discussions

Tidal energy is predictable as it is driven by gravity and not by the weather and it has less environmental impacts, hence it is gaining more and more attention these days. It is estimated that about 900 MW power can be generated from the Indus Delta Creek areas. It can be seen from Fig. 13 that Chan Waddo creek, Korangi creek, Paitiani creek, Kajhar creek and Khai creek have higher power potentials (i.e. 280 MW, 174 MW, 157MW, 127 MW and 58 MW respectively) while other creeks have power potentials below 20 MW.

Although Korangi creek, Chann Waddo creek and Phitti creek have great tidal potentials as well as they are close to Karachi- A populated city with enormous energy demand- they are navigational channels. Preferably a navigational channel should be avoided, but keeping these high potentials and energy crisis into account some engineering solutions are possible. If rotors are deployed in such a manner that rout of boat is not disturbed, then certainly they are the best which can be used for harnessing energy. Economically Chann waddo creek is the most feasible option, as energy generated here can be easily linked with national grid through Bin Qasim Power Plant. A pilot project in Chann Waddo creek is strongly suggested.

Fig. 12: Suggested No. of Rotors in one set

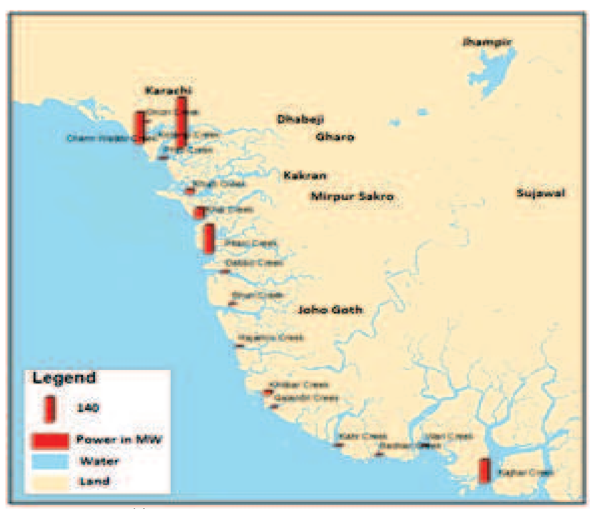

Figure 14 gives the sustainable use of analysis of energy with respect to the distances. It shows that within 20 – 30 km from the coastline favourable conditions exist in the form of HESCO transmission lines, KESC grid stations, power plants, road network, urban area, rural settlements and ports. The energy generated can be directly supplied to the national grid, neighbouring localities, to the warehouses at ports, to coast guards offices etc.

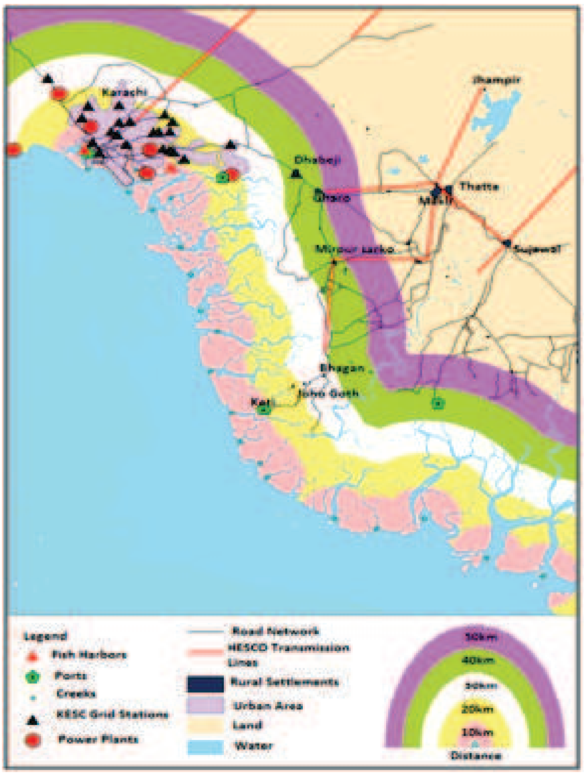

Fig. 14. Sustainable Use Analysis Map

Figure 15 show that some of the power potential sites (i.e. Pitiani creek, Dabbo creek, Bhuri creek, Hajamro creek, Khobar creek, Qalandri creek, Khar creek, Bachiar creek and Wari creek) are close to the planned city Zulfikarabad. Government of Sindh established Zulfikarabad Development Authority (ZDA) in 2010. ZDA is anticipated to facilitate the development of Keti Bandar, Kharo Chann, Shah Bandar and Jati (coastal sub-districts of District Thatta). These power potential sites should be taken into account for sustainable development of the city.

Fig. 15. Planned city Zulfikarabad

In future energy policies and sustainable development strategies tidal energy should be considered for a green and sustainable Pakistan. As the tidal current potential of the Indus delta creek system is encouraging and it can be utilized sustainability further research and pilot projects should be done.

VI. Conclusion

About 900 MW power can be generated from the Indus River Delta. Chan Waddo creek, Korangi creek, Paitiani creek, Kajhar creek and Khai creek have considerable tidal current energy potentials. Korangi creek, Chann Waddo creek and Phitti creek are close to Karachi and this proximity makes them more suitable for power production sites, but these are navigational channels, hence rotors may be deployed in such a manner that fairways are not disturbed. Further research is needed for this engineering challenge.

A pilot project in Chann Waddo creek is strongly suggested as it is economically most feasible. Energy generated here can be easily linked with national grid through Bin Qasim Power Plant.

Pitiani creek and Khai creek have good power potentials of 157 MW and 58 MW respectively, as well as they are close to Mirpur Sakro, Fatah M Kalmati, Kakran, and Lait. Bhuri creek has power potential of 12 MW and it is close to Joho Goth, Baghan, Dandari and Udasi. Kajhar creek has good power potential of 157 MW, but there is no settlement in its vicinity yet. However, Kajhar creek, Dabbo creek, Bhuri creek, Hajamro creek, Khobar creek, Qalandri creek, Khar creek, Bachiar creek and Wari creek are in vicinity of planned city Zulfikarabad. At least some of these sites should be considered in sustainable policies of this city. Besides the fair power potentials of these sites and their proximity to users, further research is needed to come up with optimized sites. So the optimized sites are utilized on priority basis.

While exploitation of tidal current energy in Indus delta is anticipated to contribute to sustainable development, the protection of a delicate mangrove ecosystem was equally vital, especially in the case of the largest mangrove forest in the country. An independent environmental impact assessment (EIA) should be done.

REFERENCES

[I] I. Burton, " Our common future: The world commission on environment and development," Environment: Science and Policy for Sustainable Development, vol. 29, pp. 25-29, 1987.

[ii] W. Moomaw, F. Yamba, M. Kamimoto, L. Maurice, J. Nyboer, K. Urama, et al., "Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change," Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press2011.

[iii] M. G. Gross, Principles of Oceanography, 7th ed.: Prentice Hall College Div, 1995.

[iv] Green Energy News. (1999, Dec). Oceans of Power. Available: http://www.green-energy-news.com/arch/nrgs1999/19990040.html

[v] A. Lewis, S. Estefen, J. Huckerby, W. Musial, T. Pontes, and J. Torres-Martinez, "Ocean energy," IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds.), Cambridge University Press, Cambridge, United Kingdom, 2011.

[vi] N. Sveinsson, "Profitability Assessment for a Tidal Power Plant at the Mouth of Hvammsfjörður, Iceland," 2011.

[vii] F. O Rourke, F. Boyle, and A. Reynolds, "Tidal energy update 2009," Applied Energy, vol. 87, pp. 398-409, 2010.

[viii] Nicky Satyadharma Aziz, "Tidal energy resources assessment in Indonesia a case study in Alas Strait," Masters, University of Southampton, 2009.

[ix] Pakistan Water and Power Development Authority, "Hydro Potential in Pakistan," 2008.

[x] International Energy Agency, "World Energy Outlook 2011," 2011.

[xi] Energy Expert Group, "Integrated Energy Plan 2009-2022," 2009.

[xii] The International Energy Agency, "2014 Key World Energy Statistics," 2014.

[xiii] CDM- Excutive Board, "UEP 99 MW Wind Power Project," 2014.

[xiv] Asian Development Bank, "2011 Clean Energy Investments," 2012.

[xv] Hira Fatima, Mudassar H. Arsalan, Anam Khalid, Kashif Marjan, and M. Kumar, "Spatio -Temporal Analysis of Shoreline Changes along Makran Coast Using Remote Sensing and Geographical Information System," in Fourth International Conference on Space Science and Technology (ICASE) 2015, Institute of Space Technology-Islamabad, Pakistan, 2016.

[xvi] Quraishee G. S, "Feasibility Studies for the Extraction of Energy from Current and Haliohydrography along Pakistan Coast," ed: NIO,, 1986.

[xvii] Nayyer Alam Zaigham and Zeeshan Alam Nayyer, "Prospects of Renewable Energy Sources in Pakistan," in Renewable Energy Technologies & Sustainable Develoment, Karachi, 2005, pp. 65-81.

[xviii] Energy Daily. (2011, Dec). India plans tidal power station. Available: http://www.energy-daily.com/reports/India_plans_tidal_power_station_999.html

[xix] Google. (2015, Dec). Permission Guidelines For Google Maps and Google Earth. Available: http://www.google.com/permissions/geoguidelines.html]

[xx] USGS. (2014, December). Data sets. Available: http://earthexplorer.usgs.gov/

[xxi] C. Huang, B. Wylie, L. Yang, C. Homer, and G. Zylstra, "Derivation of a tasselled cap transformation based on Landsat 7 at-satellite reflectance," International Journal of Remote Sensing, vol. 23, pp. 1741-1748, 2002.

[xxii] L. R. M. Joseph W. Scott, William M. Harris, and Matthew D. Reed, "Using the Landsat 7 Enhanced Thematic Mapper Tasseled Cap Transformation to Extract Shoreline," 2003.

[xxiii] General Bathymetric Charts of the Oceans (GEBCO). (2014, 2014). Available: http://www.gebco.net/

[xxiv] P. Fishing. (2014, October). Fishing Industry in Pakistan. Available: http://www.pakistanfishing.com/fishing-info/fishing-industry-in-pakistan

[xxv] Sea Rates. (2014, May). Sea Ports of Pakistan. Available: http://www.searates.com/maritime/pakistan.

html
[xxvi] K. Y. Club. (2014, October). Karachi Harbor. Available: http://www.karachiyachtclub.com/map.htm
[xxvii] Alan Jhons. (2008, September). Keti Bandar What? Who? Where? Available: http://www.pgfa.org/Articles/Keti_Bandar_Karachi_Sindh_Pakistan
[xxviii] Port Qaim Authority. (2012, December). Navigation Channel and Channel Aids. Available: http://www.pqa.gov.pk/navigation_channel.php
[xxix] Wikipedia. (2014, June). Shahbandar. Available: http://en.wikipedia.org/wiki/Shahbandar
[xxx] General Electro-mecanique (GEL). (2014, September). Installation, Testing & Commissioning Of 22 Nos 132/11kv, Conventional Grid Stations In Kesc Network Under Contract No.Pak-031 For Kesc 5th Power Project Available: http://www.gelpak.net/ProjectCompleted.aspx?categoryid=8
[xxxi] HESCO. (2014, June). HESCO transmission lines. Available: http://www.hesco.gov.pk/htmls/images/hesco1.gif
[xxxii] G. E. O. (GEO). (2014, 2014). Power Plants. Available: http://globalenergyobservatory.org/constructNetworkIndex.php
[xxxiii] R. Vennell, "Exceeding the Betz limit with tidal turbines," Renewable Energy, vol. 55, pp. 277-285, 2013.
[xxxiv] L. Myers and A. Bahaj, "Simulated electrical power potential harnessed by marine current turbine arrays in the Alderney Race," Renewable Energy, vol. 30, pp. 1713-1731, 2005.
[xxxv] J. Houde, "Cost-benefit analysis of tidal energy generation in Nova Scotia: a scenario for a tidal farm with 300MW of installed capacity in the Minas Passage in 2020," 2012.
[xxxvi] Y. Li and H. K. Florig, "Modeling the operation and maintenance costs of a large scale tidal current turbine farm," in OCEANS 2006, 2006, pp. 1-6.
[xxxvii] H. S. Tang, S. Kraatz, K. Qu, G. Q. Chen, N. Aboobaker, and C. B. Jiang, "High-resolution survey of tidal energy towards power generation and influence of sea-level-rise: A case study at coast of New Jersey, USA," Renewable and Sustainable Energy Reviews, vol. 32, pp. 960-982 %@ 1364-0321, 2014.
[xxxviii] Z. Defne, K. A. Haas, and H. M. Fritz, "GIS based multi-criteria assessment of tidal stream power potential: A case study for Georgia, USA," Renewable and Sustainable Energy Reviews, vol. 15, pp. 2310-2321 %@ 1364-0321, 2011.
[xxxix] N. S. Aziz, "Tidal energy resources assessment in Indonesia: A case study in Alas Strait," TU Delft, Delft University of Technology, 2009.