

South Korea's Plans for Tidal Power: When a "Green" Solution Creates More Problems

Recommended Citation

Yekang Ko and Derek K. Schubert, "South Korea's Plans for Tidal Power: When a "Green" Solution Creates More Problems", NAPSNet Special Reports, November 29, 2011, <https://nautilus.org/napsnet/napsnet-special-reports/south-koreas-plan-for-tidal-power-when-a-green-solution-creates-more-problems/>

By Yekang Ko and Derek K. Schubert

November 29, 2011

Nautilus invites your contributions to this forum, including any responses to this report.

CONTENTS

[I. Introduction](#)

[II. Report by Yekang Ko and Derek K. Schubert](#)

[III. References](#)

[IV. Nautilus invites your responses](#)

I. Introduction

Yekang Ko, a Ph.D. candidate in Environmental Planning at UC Berkeley, and Derek K. Schubert, a

Landscape Architect at John Northmore Roberts & Associates and President of SAVE International, respond to "[Case Study of Green Economy Policies: Korea](#)" by Sun-Jin Yun and Myungrae Cho (Nautilus Institute Special Report, September 13, 2011). Yun and Cho argue that the center of South Korea's Green Growth clearly favors economic growth, national industrial competitiveness, and an energy portfolio emphasizing nuclear power, but puts little effort toward promoting energy democracy and justice for decentralized renewable energy systems and local communities. As a complementary study to Yun and Cho's report, the authors introduce a fierce controversy between large-scale tidal power and the local efforts toward preserving wetlands and fisheries in Incheon, South Korea.

The views expressed in this report do not necessarily reflect the official policy or position of the Nautilus Institute. Readers should note that Nautilus seeks a diversity of views and opinions on significant topics in order to identify common ground.

II. Report by Yekang Ko and Derek K. Schubert

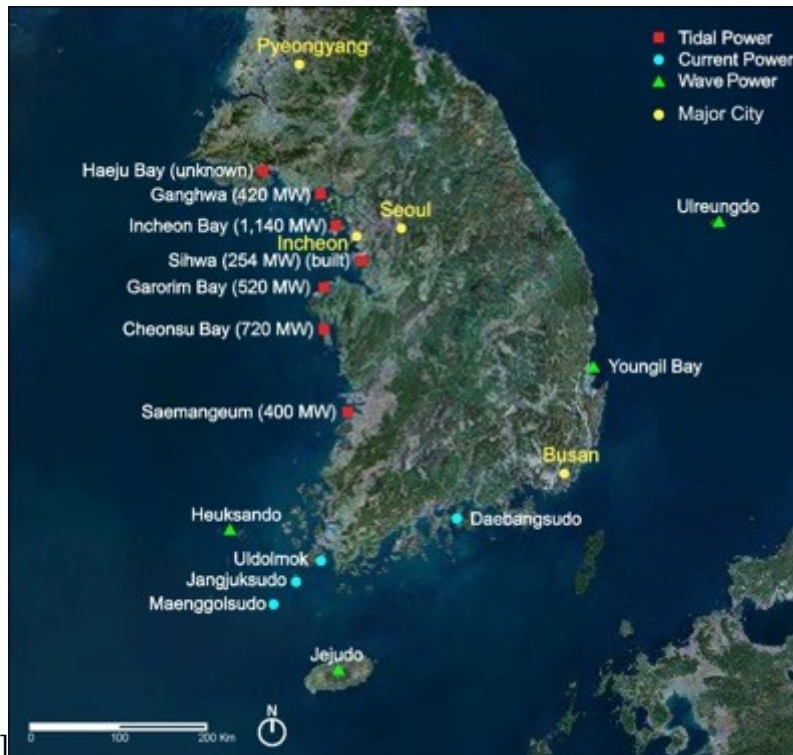
-“South Korea's Plans for Tidal Power: When a “Green” Solution Creates More Problems”

by Yekang Ko and Derek K. Schubert

Under the national slogan of Green Growth, South Korea spurred profound changes in its energy policy [1]when it adopted a nationwide Renewable Portfolio Standard (RPS) in 2010. This standard requires utility companies to generate a certain portion of energy from renewable resources: about 2 percent (1,474 MW) by 2012 and 8 percent (6,648 MW) by 2020. Faced with this urgent pressure, utility companies have launched plans to switch to renewable energy through a variety of projects, mostly large-scale and involving partnerships with government entities. Their plans for mega-scale tidal power generation are exemplary.

The large tides in the Yellow Sea off South Korea's western coast present a source of energy ideal for being harnessed on a large scale. According to “Green Energy Industry Development Strategies” prepared by the Ministry of Knowledge and Economy in September 2008, various agencies within South Korea were planning to build a total of six tidal power plants along its western coast (plus a seventh one in North Korean territory). (**Figure 1**) Most of these plants would operate as “tidal barrages”: shallow coastal expanses of the sea would be isolated with gated sea walls; after the rising tide flows in, the gates would be closed, and the tide outside the wall would ebb and create a differential in water levels, and then water would be released through turbines at controlled outlets to generate electricity. [2]

[caption id="attachment_15548" align="aligncenter" width="396" caption="Figure 1 South Korea's plans for ocean energy generation, showing capacities of tidal power plants. (Haeju Bay Tidal Power Plant would be located in North Korean territory; its capacity is not available.) © Ko, Schubert, and



Hester"]

[/caption]

The only tidal power plant built so far is Sihwa Tidal Power Plant (TPP) near Incheon, the smallest of the six proposed but nevertheless the highest-capacity tidal power plant in the world now. Located about 20 km south of Incheon, this project opened in August 2011. Its capacity of 254 MW surpassed the previous record-holder, the 240-MW Rance Tidal Power Station, in northwest France, which opened in 1966. The Sihwa station is registered as a Clean Development Mechanism project under the United Nations Framework Convention on Climate Change (UNFCCC) and is expected to reduce 315,440 metric tons of CO₂ equivalents per year. [3] The Sihwa station features a sea wall that stores water at high tide, but it generates power only from incoming tides, while outgoing tides flow without driving the turbines. [4] As a body of water artificially isolated from the sea by a continuous sea wall, “Sihwa Lake” had suffered from poor water quality since 1994, but opening the wall to allow water to enter and leave the “lake” has provided greater circulation.[5]

In spite of this anticipated reduction of greenhouse gas emissions, South Korea’s plans for large-scale tidal power generation are stirring up controversy about whether tidal power is truly “green”. In this report, we discuss four aspects of the tidal power projects proposed in Incheon to evaluate how well they contribute to achieving South Korea’s “green” goals: 1) the environmental/ecological impact of tidal power barrages (particularly on tidal wetlands), 2) the impact of tidal power projects on local communities, 3) the global trend of tidal power projects, and 4) the cost-benefit analysis of tidal power generation.

The Environmental/Ecological Impact of Tidal Power Barrages

As a source of power not emitting greenhouse gasses (GHGs) or other air pollution, tidal power generation (broadly under the category of “ocean energy”) could be an essential part of South Korea’s efforts to enlarge its renewable energy supply, but the specific proposed projects would threaten tidal-flat wetlands that support unique ecosystems and host tens of thousands of migratory birds, especially around Gyeonggi Bay. Three of the six tidal power plants would be located in this bay, which is adjacent to the border between North and South Korea near Ganghwa [6] and Incheon Metropolitan City (Incheon), the third-largest city in South Korea and home to 2.7 million people. (Figure 2)

[caption id="attachment_15549" align="aligncenter" width="455" caption="Figure 2 The areas of existing (Sihwa) and two proposed tidal power plants in Gyeonggi Bay, showing conflicts with a Natural Heritage Site and a Wetland Preservation Area. The earlier larger proposal for Ganghwa Tidal Power Plant is shown with dashed lines. © Ko, Schubert, and Hester"]



[/caption]

Northwest of the existing Sihwa plant, two other tidal power plants of unprecedented size are proposed: Incheon Bay TPP and Ganghwa TPP. Incheon Bay TPP would be built by a partnership between the national Ministry of Land, Transport and Maritime Affairs (MLTM) and Korea Hydro and Nuclear Power. At 1,320 MW this plant would have a capacity more than five times that of the current record-holding Sihwa plant. Farther north, the Ganghwa TPP would be built by a partnership between Incheon City and Korea Midland Power Corporation [7]. Ganghwa TPP would be one of the key factors in the “Incheon City Low-Carbon Green Growth Plan,” [8] released in December 2009. With a capacity of 420 MW, this project may seem small compared to Incheon Bay TPP but it would still be 65% larger than the Sihwa plant. An earlier proposal for Ganghwa TPP had a capacity of 840 MW, but that figure has been cut in half because of local opposition. In spite of this unprecedented scale of tidal-power development, the environmental impact assessments of these projects have not considered the cumulative impact of three mega-projects to be located within 60 km of each other.

Besides the issue of scale, the proposed location of these two tidal power plants also raises problems, as they would threaten ecologically important wetlands that are protected under Korean law. As Figure 2 shows, the current plan for Incheon Bay TPP would encroach onto 24.7 km² of the Jangbongdo Wetland Preservation Area, which was designated in 2003 (at 68.4 km², the largest of Korea’s Wetland Preservation Areas). In 2008, MLTM began to prepare a request to register Jangbongdo as a protected wetland under the Ramsar Convention because of its habitat value for marine life and rare waterbirds, including the Chinese Egret (*Egretta eulophotes*, Natural Heritage no. 361) and Eastern Oystercatcher (*Haematopus ostralegus osculans*, Natural Heritage no. 326), and its unique geomorphology, with high tidal ebb and flow and a vast delta. [9] Ganghwa TPP is also proposed to be built right next to “Ganghwa Tidal Flat and the Black-Faced Spoonbill Habitat,” which is South Korea’s largest Natural Heritage Site (370 km² in area) (no. 419), designated as such in 2000. Ganghwa Tidal Flat, along with the Han River estuary and other tidal flats near Incheon, hosts tens of thousands of migratory birds that travel along the East Asian-Australian Flyway, including the Black-faced Spoonbill (*Platalea minor*), a species that is listed as an endangered wildlife species of the Ministry of Environment, is classified as “endangered” by the IUCN, and is

itself Natural Heritage no. 205.

Even as non-governmental organizations (NGOs) express rage over the government's destruction of valuable wetlands, MLTM claims the right to rescind natural heritage sites or cancel wetland preservation when the public interest is at stake. [10] In 2010, the national government stripped protection from Baweenupgoobi wetland, a critical habitat for natural heritage and endangered plants and animals, to allow dredging for the controversial Four Rivers Project. [11] MLTM is considering reducing the official size of the Jangbongdo Wetland Preservation Area, and is considering requesting Ramsar registration for only the part of Jangbongdo that does not conflict with the tidal power plant. [12] Due to a pattern of favoring development over preservation, the unique landscape character of Korea's tidal flats is becoming more rare, as people fill these shallow wetlands to "reclaim" land. According to a report prepared for a 2008 Ramsar meeting by the Korea NGO Network, more than half of the tidal flats in South Korea had been drained or filled from 1910 to 2007; 2,907 km² had been destroyed and 2,550 km² were remaining.

The Impact of Tidal Powers on Local Communities

Like many other energy sources, tidal power generation has trade-offs at the local, national, and global levels. However, tidal power generation requires more sacrifices of local communities (**Table 1**), especially when planned at a scale as large as the three projects around Incheon. In spite of the projected benefits of reducing carbon emissions for mitigating global climate change, various environmental NGOs—local, national, and international—and local fishermen's groups strongly oppose the tidal power plants (**Figure 3 & 4**). Those groups anticipate deep and lasting impacts to the tidal flat and fisheries, which today provide livelihoods for 2,800 fishermen and have sustained a unique local culture for generations. Environmental NGOs and experts have brought up other potential problems, such as instability of electricity supply, damage to landscapes due to transmission facilities, and flooding (in Ganghwa Island and even more severely in North Korea). [13]

	PROS	CONS
Local	<ul style="list-style-type: none"> • Secure, non-polluting energy supply • Creation of short-term, construction-related jobs 	<ul style="list-style-type: none"> • Destruction of ecosystem • Decline of local fisheries and related long-term jobs • Lost opportunity for long-term jobs in eco-tourism and related fields • Increased risk of flooding • Impact on natural landscape
National	<ul style="list-style-type: none"> • Achievement of national goals to reduce greenhouse gasses (GHGs) • Fiscal saving from reducing imports of fossil fuel • Immediate stimulation of employment 	<ul style="list-style-type: none"> • Large initial cost for construction • Decline or extinction of legally protected species • Decline of fisheries and eco-tourism along the west coast and associated possible long-term net loss in employment • Disruption of tidal processes in Yellow Sea
Global	<ul style="list-style-type: none"> • Achievement of global goals to reduce GHGs • Delay in the depletion of fossil fuels 	<ul style="list-style-type: none"> • Decline of biodiversity • Destruction of globally unique ecosystems and natural landscapes

Table 1

Tradeoffs of tidal power projects, at various scales. © Ko and Schubert.

[caption id="attachment_15550" align="aligncenter" width="375" caption="Figure 3 Marching demonstration by fishermen opposing tidal power plants (March 25, 2010), Incheon, South Korea. © Korean Federation for Environmental Movement"]



[/caption]

[caption id="attachment_15551" align="aligncenter" width="379" caption="Figure 4 Satirical cartoon by a local artist, criticizing Ganghwa Tidal Power Plant. © Heung Ryeol Park. In a museum, a teacher says to her students, “These are the organisms that used to live in Ganghwa Tidal Flat.” The displays include river puffers, swimming crabs, large-eyed herring, akiame paste shrimp, and a



fisherman."]

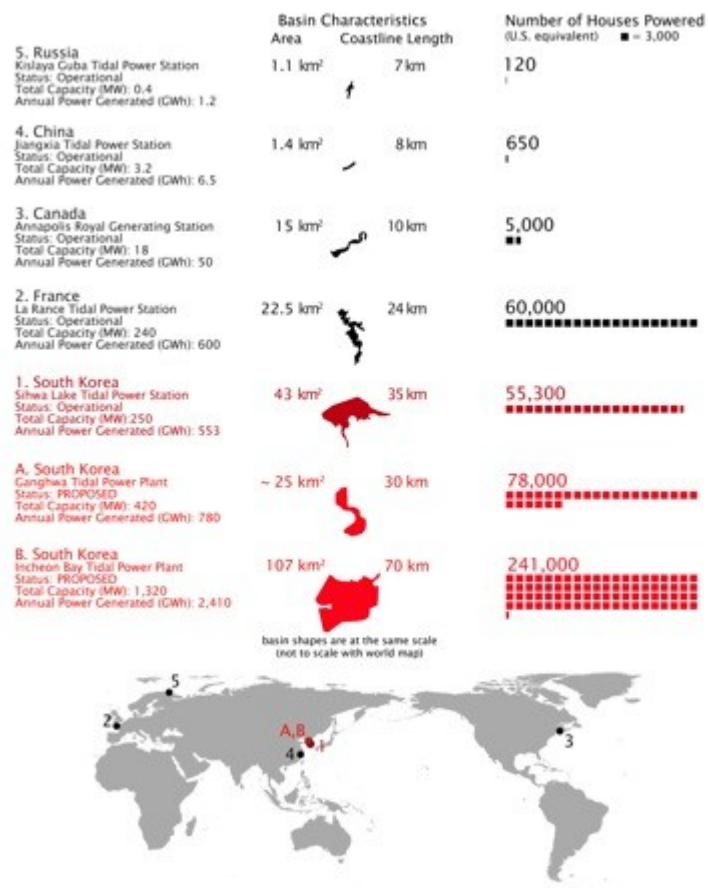
[/caption]

Global Comparison of Tidal Power Plants

Other nations considering tidal power in their own waters have generally found the obstacles insurmountable. Before the opening of South Korea's Sihwa station in 2011 only a few large-scale tidal power plants in France, Russia, and Canada had been built, and small-scale plants had been built in China. (Figure 5) In the United Kingdom the Severn Barrage, an ambitious proposal that could have provided 5% of that nation's electricity, received enormous criticism from environmental NGOs such as the National Trust, Royal Society for the Protection of Birds (RSPB), World Wildlife Fund (WWF), and the Angler's Trust. Furthermore, the British government's revised cost estimate was US\$54 billion, more than twice its initial estimate of US\$24 billion. Due to this projected high cost and risk, the British government finally decided to withdraw its support for the Severn Barrage in November 2010 .

[caption id="attachment_15552" align="aligncenter" width="360" caption="Figure 5 A comparison

of the five largest tidal power plants in the world, along with two projects proposed in South Korea.



© Janes"]

[/caption]

Most potential sites for tidal power plants around the world, including in South Korea, are unique marine ecosystems, with habitat for migratory marine animals and shorebirds. [18] Even when tidal power plants seem economically feasible, they create ecological disturbances for which it may be difficult to assign an economic cost, such as reduced salinity, weaker currents, and reduced water exchange. [19] (Table 2)

Process	Change	Summary, with Reference	Location
Tidal Mixing	↓	• Altered Dissolved Oxygen dynamics [20]	1 (Sihwa), 2 (Rance)
Tidal Range	↓	• Dramatic Decrease: Severn [21] [22] • Minimal Decrease: Puget Sound [23]	1 (Sihwa)
Low Tide	↑	• Submergence of all inter-tidal habitat below mean tide level[24] • Loss of inter tidal areas [25]	1 (Sihwa), 2 (Rance)
Salinity	↓	• Reduce the salinity range due to less mixing with the ocean[26]	1 (Sihwa), 5 (Kislaya Guba)
Turbidity	↓	• Turbidity changes [27]	1 (Sihwa), 2 (Rance)
Productivity	↑	• Decreased turbidity yields higher phytoplankton growth and benefits the food web dependent on phytoplankton. Potential for algal blooms and eutrophication. [28] [29]	1 (Sihwa), 2 (Rance), 3 (Annapolis)
Habitat	↓ ↑	• Mudflats unavailable to foraging birds. [30] [31]	1 (Sihwa), 2 (Rance)

Deposition/ Erosion	↓ ↑	<ul style="list-style-type: none"> • Altered, with regions of erosion, deposition, and changes in grain size. [32] 	1 (Sihwa)
Water Chemistry	varies	<ul style="list-style-type: none"> • Because tidal mixing is decreased, runoff into estuary must be improved to maintain current condition. [33] • Produce clearer, calmer waters but the extreme tidal nature of the estuary would be altered. [34] 	1 (Sihwa), 2 (Rance), 3 (Annapolis)
Migration	↓	<ul style="list-style-type: none"> • Fish and mammals somewhat blocked depending on turbine design. [35] • Migration of birds change negatively. [36] 	1 (Sihwa), 3 (Annapolis)
Biodiversity	varies	<ul style="list-style-type: none"> • Local extinctions and population collapses predicted for designated fish. [37] [38] 	1 (Sihwa)

Table 2

The Observed and Anticipated Ecological Impacts of Tidal Power Generation around the World © Rivas, Sousa, Janes, Farrington, and Rubin

Cost-benefit Analysis of Tidal Power Generation

The last debate in tidal power generation is the economic valuation of tidal power projects, as the lost natural and social benefits of tidal flats should be counted as a cost of any proposed project. The benefits of tidal flats—environmental processes such as water purification, and long-term sustainable jobs for people—were not properly counted in the cost-benefit analyses, which seemed to support the proposed projects in South Korea. The initial cost-benefit analysis of Ganghwa TPP did not include any costs of environmental impacts to the tidal flat. [39] The original analysis for Incheon Bay TPP cited a cost of tidal flat loss from the 1997 research of Costanza et al. (US \$9,990/ha/year, assuming US \$1 = KRW 1,200), [40] but tidal flats in Korea seem to have a greater value than the global average estimated by Costanza. According to a 2006 study by the Korean Ocean Research and Development Institute, the average value of Korean tidal flats estimated from 13 other Korean studies was US \$32,660/ha/year [41], roughly three times the Costanza estimate. A 2007 study by the Korea Environment Institute argued that the tidal flats around Incheon provided \$27,972/ha/year of benefits from water purification alone [42]—7.6 times greater than the 2006 Korean Ocean Research and Development Institute’s study. The 2007 Korea Environment Institute study also estimated the carbon reduction by tidal flats at about 10 tons/ha/yr, with a value of about KRW 34,000,000/ha/yr (US \$28,300/ha/yr), a value 2.8 to 9.5 times greater than the range (KRW 3,600,000 to 12,000,000) estimated by Ministry of Maritime Affairs and Fisheries in 2005. [43]

However, new studies are causing the South Korean government to reconsider these large-scale tidal power projects. In June 2011, Incheon Development Institute reported that the cost-benefit analysis for Incheon Bay TPP was flawed. Rather than returning a benefit-cost ratio of 2.10 (\$2.10 in benefits for every dollar spent) as the proponents’ analysis [44] showed, the new study reported a ratio of 0.814 to 0.833 (81 to 83 cents in benefits for every dollar spent) [45], which makes it appear uneconomical to build the plant. In addition, Korea’s Ministry of Environment pointed out considerable flaws in the preliminary Environmental Impact Assessment for Incheon Bay TPP. MLTM has had to defer their plans for the Ganghwa and Incheon Bay projects until more studies are done.

Conclusion

South Korea’s tidal power projects, as discussed in this report, support Yun and Cho’s argument: South Korea’s current “green” policy puts a high priority on economic growth and national industrial competitiveness, but overlooks local communities and energy democracy. This controversy over tidal

power also reveals that today's debates are no longer as clear as "economic development versus natural preservation" and all sides can truthfully claim some sort of "green" credentials. Faced with conflicting "greens", we could distinguish some approaches as "segmented green" and others as "systematic green": that is, addressing environmental issues piecemeal and therefore inadequately, or addressing the issues holistically. [46] When a problem is simple or isolated, there are often many equally valid ways to solve it. If the real problem is complex, however—as today's energy decisions are—then addressing only one aspect might create problems with other aspects. Nuclear power and tidal power would reduce carbon emissions, but they generate other, even greater problems, such as nuclear waste, the threat of a catastrophic release of radiation, or damage to coastal ecosystems and endangered species.

As technology advances it would seem prudent for South Korea to rethink the large-scale tidal barrage. The United Kingdom's rejection of the Severn Barrage shows that today's technologies do not necessarily minimize environmental impacts and produce an economically viable project, even with a benefit as great as obtaining five percent of the nation's energy from a single renewable source. New technologies for ocean energy—tidal power, wave power, and current power—are being researched around the world, and as technologies develop, perhaps a different technology or scale for tidal power could meet South Korea's demands in the future.

If the genuine intent of "green growth" is to minimize environmental impacts while promoting economic growth, a more appropriate solution than building a few large projects (especially in fragile and critical ecosystems) could be a distributed system of micro-scale generation, combined with subsidizing energy conservation or other forms of demand-side management. For example, given similar conflicts in desert ecosystems, the United States Bureau of Land Management and six southwestern state governments recently implemented new regulations on large-scale facilities for solar energy ("solar farms"), to minimize habitat loss and to mitigate harmful environmental impacts. [47] In order to resolve conflicts among apparently green policies, South Korea and other countries should consider implementing regulations to protect wildlife habitat from large-scale energy development, even when the energy itself is renewable or non-polluting.

It will take immediate attention and decisive action to mitigate global climate change, but urgency should be no excuse for hasty decisions that overlook more serious trade-offs. If South Korea continues its rush to build these tidal power plants, it will not be living up to its own stated "green" goals. When assessing future proposed projects, related to tidal power or not, South Korea should consider a wider range of alternatives, use more comprehensive methods of evaluation (e.g. ecological accounting and life-cycle assessment), allow time for thorough review by the local community and by relevant experts, and fairly address any suggestions or criticisms. In South Korea and in every nation, sustainable energy policies will emerge only if scientists, planners, policymakers, and everyday citizens alike recognize that not all "greens" are equal.

Acknowledgements

The authors acknowledge SAVE International for their continuing support; Kelly Janes, Cynthia Rivas, Ricardo Sousa, Jeffrey Farrington, and Zan Rubin of the graduate course LA205 (Environmental Planning Studio) at the University of California, Berkeley, for their contribution to the global trend of tidal power; and Professor Jong Ho Hong and Professor Sun-Jin Yun (of the Graduate Institute of Environmental Studies at Seoul National University) for their comments.

III. References

- [1] For a detailed examination of South Korea's current energy and economic policies, please read "Case Study of Green Economy Policies: Korea" by Sun-Jin Yun and Myungrae Cho (Nautilus, September 13, 2011).
- [2] Wikipedia, Tidal barrage, http://en.wikipedia.org/wiki/Tidal_barrage (accessed 14 January 2011).
- [3] United Nations Framework Convention on Climate Change (UNFCCC), Project 0349: Sihwa Tidal Power Plant CDM Project, <http://cdm.unfccc.int/Projects/DB/DNV-CUK1143710269.08> (accessed 27 July 2010).
- [4] Park, Noyoung. "Sihwa Tidal Power Plant: a success of environment and energy policy in Korea."
http://www.eer.wustl.edu/McDonnellMayWorkshop/Presentation_files/Saturday/Saturday/Park.pdf
(accessed 4 October 2011)
- [5] C. H. Koh, "Korean Megatidal Environments and Tidal Power Projects: Korean Tidal Flats—Biology, Ecology and Land Uses by Reclamations and Other Feasibilities," *La Houille Blanche*, no. 3 (1997): 66–78.
- [6] Ganghwa is an island (Ganghwa-do) and a county within Incheon Metropolitan City.
- [7] An artist's rendering of this project is available at <http://www.hec.co.kr/pr/news/news/view.asp?code=5040&page=8>. Your browser must be able to display Korean characters for the image to load properly.
- [8] Incheon Metropolitan City, "Incheon City Low Carbon Green Growth Plan for the World Best Green Incheon," press release (through Incheon TV News Network) (Republic of Korea, 10 December 2009).
- [9] Ministry of Land, Transport and Maritime Affairs, "South Korea Is Increasing Ramsar Registered Wetlands Twice More," press release (Seoul, Republic of Korea, 3 November 2008)
- [10] Wetland Preservation Act of 1999, Law 5866, 8 February 1999, Republic of Korea. Under the current Wetland Conservation Act, "With an executive order, it is possible for the Minister of MLTM, local mayors, and governors to rescind and/or shrink the wetland preservation area in case of public interests and military purposes."
- [11] D. Normile, "Restoration or Devastation?", *Science* 327, no. 5973 (March 26, 2010): 1568–1570.
- [12] Ministry of Land, Transport and Maritime Affairs, Environmentally-Friendly Development Strategies for Incheon Bay Tidal Power Generation, internal report (Seoul, Republic of Korea, March 2009).
- [13] Ibid.
- [14] Ibid.
- [15] Ministry of Land, Transport and Maritime Affairs, "South Korea Is Increasing Ramsar-Registered Wetlands Twice More," press release (Seoul, Republic of Korea, 3 November 2008).
- [16] J. Vidal, "Severn Tidal Power Shortlist 'Biased', Campaigners Say," *guardian.co.uk*, 8 May 2009,
<http://www.guardian.co.uk/environment/2009/may/08/severn-estuary-tidal-scheme?intcmp=239>

(accessed 14 July 2010).

- [17] B. Dorminey and The Daily Climate, "Testing the Waters with Tidal Energy," *Scientific American*, 6 December 2010, <http://www.scientificamerican.com/article.cfm?id=testing-the-waters-with-tidal-energy> (accessed 29 January 2011).
- [18] M. J. Dadswell and R. A. Rulifson, "Macrotidal Estuaries: A Region of Collision Between Migratory Marine Animals and Tidal Power Development," *Biological Journal of the Linnean Society* 51, no. 1 (1994): 93-113.
- [19] R. H. Charlier, "Sustainable Co-generation From the Tides: A Review," *Renewable and Sustainable Energy Reviews* 7, no. 3 (2003): 187-214.
- [20] Nakamura, Y., and T. Fujino, "Dynamics of dissolved oxygen concentration in the lower reaches of a rivermouth barrage of the Nagara River." *Ecology and Civil Engineering* 5, no. 1 (2002): 73-84.
- [21] Goss-Custard, J. D., R. M. Warwick, R. Kirby, S. McGrorty, R. T. Clarke, B. Pearson, W. E. Rispin, S. E. A. L. V. D. Durell, and R. J. Rose, "Towards Predicting Wading Bird Densities from Predicted Prey Densities in a Post-Barrage Severn Estuary." *Journal of Applied Ecology* 28, no. 3 (1991): 1004-1026.
- [22] Department of Energy and Climate Change, *Severn Tidal Power: Feasibility study conclusions and Summary Report* (2010).
- [23] Polagye, B., M. Kawase, and P. Malte, "In-stream tidal energy potential of Puget Sound, Washington." *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, 223, no. 5 (2009): 571-587.
- [24] Charlier, R. H., and C. W. Finkl. *Ocean energy: tide and tidal power*. Springer Verlag, Berlin (2009).
- [25] Department of Energy and Climate Change, *op. cit.*
- [26] Charlier and Finkl, *op. cit.*
- [27] *Ibid.*
- [28] Choi, K. H., S. M. Lee, S. M. Lim, M. Walton, and G. S. Park, "Benthic habitat quality change as measured by macroinfauna community in a tidal flat on the west coast of Korea." *Journal of oceanography* 66, no. 3 (2010): 307-317.
- [29] Louters, T., J. H. v. d. Berg, and J. P. M. Mulder, "Geomorphological Changes of the Oosterschelde Tidal System during and after the Implementation of the Delta Project." *Journal of Coastal Research* 14, no.3 (1998): 1134-1151.
- [30] Desroy, N., and C. Retiere, "Using benthos as a tool for coastal management: The impact of the tidal power station on benthic communities of the Rance basin." *Aquatic Ecosystem Health & Management* 7, no. 1 (2004), 59-72.
- [31] Goss-Custard et al., *op. cit.*
- [32] Louters et al., *op. cit.*

- [33] Charlier and Finkl, op. cit.
- [34] Department of Energy and Climate Change, op. cit.
- [35] Tidmarsh, W., "Assessing the environmental impact of the Annapolis tidal power project = Evaluation de l'impact sur l'environnement du projet marémoteur d'Annapolis." *Water Science and Technology* 16, no. 1-2 (1984): 307-317.
- [36] Department of Energy and Climate Change, op. cit.
- [37] Ibid.
- [38] Charlier and Finkl, op. cit.
- [39] Incheon Metropolitan City et al., Master Plan for Ganghwa Tidal Power Plant Joint Development Project, internal report (Republic of Korea, May 2007).
- [40] R. Costanza et al., "The Value of the World's Ecosystem Services and Natural Capital," *Nature* 387 (September 1997): 253-260.
- [41] The estimated annual value of a hectare of Korean tidal flats (US \$32,660) includes marine products (\$9,993), ecosystem preservation (\$8,548), habitat (\$7,533), water purification (\$3,702), recreation (\$1,443), and disaster prevention (\$1,442). This estimation is from the Ministry of Maritime Affairs and Marine Products, "Coastal Wetlands Conservation Plan," presented at the Symposium for Tidal Flat Conservation and Sustainable Use, Gochang, Republic of Korea, 28 September 2006.
- [42] J. H. Mang et al., Improving Environmental Assessment in Tidal Flat Reclamation (Seoul, Republic of Korea: Korea Environment Institute, 2007),
<http://library.me.go.kr/DLiWeb25/comp/search/viewer.aspx?type=F&cid=176063&id=20391&url=>
 (accessed 20 July 2010).
- [43] Ibid.
- [44] J-H. Lee and Y-H. Noh, "Economic Valuation of Tidal Power Plant Project in Incheon Bay: CVM and IO Approaches," *Korean Energy Economic Review*: 9:2 (September 2010), 43-82.
- [45] C. Kim, "Incheon Bay Tidal Power Economic Feasibility 'Overstated'", *Incheon Shinmun*, 28 June 2011, <http://www.i-today.co.kr/news/articleView.html?idxno=79825> (accessed 14 October 2011).
- [46] Y. Ko et al., "A Conflict of Greens: Green Development and Habitat Preservation—the Case of Incheon, South Korea," *Environment: Science & Policy for Sustainable Development*: 53: 3, 3-17.
- [47] Federal Register, Notice of Availability of the Draft Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States and Notice of Public Meetings,
<http://www.federalregister.gov/articles/2010/12/17/2010-31725/notice-of-availability-of-the-draft-programmatic-environmental-impact-statement-for-solar-energy#p-3> (accessed 13 January 2011).

IV. Nautilus invites your responses

The Northeast Asia Peace and Security Network invites your responses to this report. Please send responses to: bscott@69.195.70.34. Responses will be considered for redistribution to the network only if they include the author's name, affiliation, and explicit consent.

View this online at: <https://nautilus.org/napsnet/napsnet-special-reports/south-koreas-plans-for-tidal-power-when-a-green-solution-creates-more-problems/>

Nautilus Institute

608 San Miguel Ave., Berkeley, CA 94707-1535 | Phone: (510) 423-0372 | Email:

nautilus@nautilus.org