GSDR 2015 Brief

Blue Energy: Salinity Gradient Power in Practice

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Related Sustainable Development Goals

Goal 06	Ensure availability and sustainable management of water and sanitation for all (6.1-6.3 - 6.5 - 6.6 – 6.a)
Goal 07	Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 11	Make cities and human settlements inclusive, safe, resilient and sustainable (11.1 – 11.6)
Goal 12	Ensure sustainable consumption and production patterns (12.1 - 12.2 – 12.a)
Goal 13	Take urgent action to combat climate change and its impacts (13.2 – 13.3 – 13.a – 13.b)

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Introduction

The global total primary energy supply and demand has doubled between 1971 and 2012, mainly relying on fossil fuels.[1] This affects the world's environment in aspects such as climate change and other long term effects mainly caused by the increase in quantity of greenhouse gases (GHGs) emissions.[2] Moreover, the present constant use of combustion fuels such as oil and natural gas will result in an expected depletion in 2050 onwards.[3] Therefore, the need of renewable energy sources has increased during the last years in order to meet the world energy demand and progressively divert fossil energy sources. One of these new renewable energy sources is the so-called 'Blue Energy' or 'Salinity Gradient Power' (SGP). In broad terms it is energy obtained by the controlled mixing of a stream of saltwater (e.g. seas) and a stream of less saline water, treated wastewater or fresh river water.

The most well-known and most investigated techniques to generate energy from SGP are Pressure Retarded Osmosis (PRO) and Reversed Electrodialysis (RED), herein respectively transport of water or ions through semi-permeable membranes takes place (for a technical summary see Appendix II).[4,5] Both PRO and RED have a large potential for producing energy for the coming years and they could be used for different applications as well (see Facts & Figures).[6]

At this moment there are two other SGP techniques, namely Capacitive Mixing (CAPMIX) and Capacitive Reversed Electrodialysis (CRED) that both are supposed to have a larger potential after more research is done. The first will probably take another several years to be implemented in a plant and the second is already available for implementation.[7,8,9,10,11]

Academic research mainly done in laboratories, shows that SGP has an enormous theoretical potential of ~1.9 TW. This indicates 80% of the total global demand of energy. However, as can be seen in Appendix III, the technical potential is ~60% of the theoretical potential: ~980 GW.[12,13] Additionally, the truly exploitable potential is dependent on economical and local capacity constraints. Therefore, further analysis has to be carried out in order to find out these local capacity constraints.[14]

FACTS & FIGURES

- Energy production, distribution and consumption will be more expensive in the upcoming 30-40 years.[i]
- It is indicated that theoretically 80% of the total global demand could be produced by SGP (1724 GW).[ii,iii]
- Reduce of 10 Pg CO2-equivalent, or in other ways a 40% of the global energy related greenhouse gas emissions (GHGs).[iv]
- The investment costs are higher than for wind, but the possibility of power generation is 24/7.

Scientific Debate

Present global development

The research, development and pilot plants of SGP in the Netherlands are completely based on RED.[15,16] However, in other developed and transition countries such as Spain, Singapore, Japan, the Middle East, Australia, Norway, China and South Korea the focus is more on PRO.[17,18,19,20]

After analyzing these present developments, there is an indication that implementation is dependent on 1) the local constraints 2) the applications (energy production, desalination and purification) it is meant for, and 3) the general improvements within the technology. The factors to evaluate the possibility of its implementation in the developed or in the developing countries are the technical, environmental, political and financial/fiscal criteria.[21]

Implementation

In this section, two companies (REDstack and Statkraft) are discussed, because as far as could be found, these are good examples of pilots that produced, or have produced energy by SGP. Firstly, regarding the technical criteria, the development and improvement of the components required in an SGP plant are essential for the sustainable expansion of SGP in the upcoming years. A way to obtain these is through the support of a public or private company. For instance Fujifilm is already investing and providing REDstack with membranes, to ensure the required electricity amount in the future (of USD 0.10/kWh).[22] Hence, REDstack is very positive about the outcome of their current pilot.[23] On the contrary, this technical support did not happen in the Statkraft pilot in Norway in 2009. They were not able to find a company that was willing to invest in the production of cheaper and more efficient membranes to achieve their research goals.[24,25,26]

Secondly, regarding the environmental criteria, the GHGs emissions from an SGP plant are lower than 10 g CO_2-e/kWh (Table 1). However, if there is a natural estuary (i.e. there is an open connection with the sea/delta areas) the distinction between fresh and salt water is too small. In this case the construction of a dam, dike, water barrier or a long pipe system with a separate inlet and outlet of fresh and salt water is needed. This infrastructure might have an effect on the landscape, the unique ecological system, hydraulic systems and water management rules. It is important to note that, compared with for instance wind energy, implementing an SGP plant will produce the same amount of energy, while having smaller impact on landscape, noise and it requires less land usage.[27] Regarding the unique ecological system the influence on the microorganisms in the water should be taken into account as a possible and very important environmental impact.[28,29] In order to implement the SGP technology, the local differences in legislation and regulations of hydraulic systems and water management have to be addressed as well.

Thirdly, regarding the political and fiscal/financial criteria based on the North-European countries, it can be assumed that the present governmental and local policies in developed countries are more willing to implement SGP than developing countries.[30] In practice, currently the implementation of an SGP plant is in both type of countries not financial achievable.[3132333435] Therefore the support from a local/ national/international government is necessary. Actually, it is estimated that around €900 million is needed for the implementation of a complete RED plant in a developed country.[36] For instance in the case of REDstack, the research is indirectly co-financed by the Ministry of Economic Affairs through The Northern Netherlands Provinces Alliance and the province of Fryslân.[37] On the other hand, Statkraft did not get enough governmental subsidies, being another reason why they did not achieve their objectives.

Commitment and Non-commitment

FOOD FOR THOUGHT

- SGP cannot be implemented in countries without any coastal areas.
- Take into account: not affecting navigation and drinking water
- Easier implementable in engineered deltas (presence of dikes, sluices etc.)v
- There is a threshold from technical developments towards implementation.

The aforementioned positive and negative aspects of SGP will have an impact on the (non)commitment for its implementation. To explain it, a comparison with other types of energy sources is done.[38]

The values in Table 1 show several benefits of SGP compared to other energy sources. For instance, it is possible to generate power 24/7 without emitting any GHGs. Furthermore, because the renewable energy source (i.e. water) is always flowing there is a more accurate source of energy which makes the prediction of the amount of Watts more easily than for instance in wind and solar energy. However, it has to be taken into account that this kind of energy cannot be generated in countries without a coastal area. Furthermore, it has a better prediction possibility and is therewith also more accurate. Besides, the efficiency of energy conversion is on average similar to the other ones. It is important to note that the Energy Return On Invested (EROI) and the price of SGP are theoretical values made upon academic research.[39,40,41,42] They are not achievable yet because this technology is still in the pilot phase and they will vary depended of the coming technical advancements and the context wherein they will be implemented.[43, 44]

Table 1: Comparison SGP with other energy sources (vi, vii, viii, ix, x, xi)

	GHGs emissions	price of generated electricity	EROI	availability of renewable sources	efficiency of energy conversion
Unit	g CO2-e/kWh	USD/kW h	(-)	(-)	%
Photovoltaic	90	$0.24	1.6 - 6.8	Dependent	4-22%
Wind	25	$0.07	18	Dependent	24-54%
Hydro	41	$0.05	>100	Always available	>90%
Geothermal	170	$0.07	n/a	Dependent	10-20%
Coal	1004	$0.042	80	Non-renewable	32-45%
Gas	543	$0.048	10	Non-renewable	45-53%
SGP (RED)	<10	$0.10	7	Always available. But not in non-coastal countries	50-70
SGP (PRO)	<10	$ 0,065-0,13 with subsidies $0,05-0,06	6 - 7	Always available. But not in non-coastal countries	40

It is important to note that for the private and public bodies that are willing to implement SGP technology, other applications are possible as well. Amongst others, energy storage in batteries, desalinization, making energy from gas emissions and purification of the water can have an added value for different local contexts.[4546] Moreover, some of these aforementioned applications can be combined to save energy during the process (Appendix IV).[47]

Summarizing, regarding implementation issues; in the upcoming years the technical developments will be crucial for producing the required amount of energy by SGP. Also changes in the hydraulic systems and water management rules that have its impact on the local environment must be studied before building the plant. Finally the importance of financial support of a political body or private company is crucial for the execution of an SGP plant in a specific country.

Developed countries are assumed to have better environmental, political and financial possibilities for implementing SGP than developing countries. This ensures that it is easier to accomplish SGP pilots and plants in developed countries than it will be in developing countries. It is expected that it will take between 5-8 years before the first operational plants are placed in developed countries.[48] It is also expected that the first operational plants in developing countries will only be commercial in more than 10 years.[49, 50]

Concluding, regarding the SDGs; SGP plants can create a modern type of production of reliable and sustainable energy sources. Furthermore, it could be used for desalinization and purification purposes. This creates a more sustainable way of management of water and sanitation in nearby cities and settlements. Nonetheless it will only be affordable with public and private support.

Goals & Targets

SGP could be a reliable, sustainable, renewable and modern type of energy source for the future (SDG 7;13). For implementing SGP an improvement of the fresh and salt water resource management is placed (SDG 6.5;12.2). This will have an added value in mitigating climate change (e.g. a decrease in GHGs emissions) and it does not have an effect on the air quality (SDG 11.6). Furthermore, it can also restore unique ecological systems (e.g. creating a fish migration stream from salt to fresh water and vice versa; SDG 6.6).

Next to the production of energy, other applications (purification and desalinization of water) can create an adequate, safe and affordable way of creating drinking water. And another application is storing large amounts of energy in batteries, both as services for housing and slums (SDG 6.1;6.3;11).

Moreover, developed countries will take the lead in creating and adopting these SGP pilots and plants. Herein, these countries can help strengthening the scientific and technological capacity of developing countries afterwards (SDG 12.1; 12.a).

Recommendations

Based on the aspects discussed in this science digest, it is feasible to conclude that the local implementation of SGP depends of the context of the place where it is intended to be implemented. However, for the worldwide inclusion of this technology in the political agendas the recommendations are based on two main streams:

- Financially: financial incentives are required to increase the further development and research of SGP techniques. The importance of these incentives is regarding the membrane market, purification techniques of river water and the creation of new pilots and demos, these kinds of incentives are essentially important for the start of the producing of energy.
- Political: implementation of new policy measurements (such as fostering of present international platforms (for instance INES) and certifications) would allow local, national/international governments and companies to discuss local implementation issues and therewith improve SGP systems more easily. Also the political willingness in developing countries will be larger in this sense.

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Appendix 1: Research methodology

To start with the choice whether we wanted to do this topic or the other ones; David thought at first place that this type of energy would have an enormous potential to mitigate climate change. During a past assignment regarding renewable energy Arvid already ran into this term 'blue energy'. However, at that moment he was not quite sure what it was about, but when Mirle was talking about the first overall idea his attention was attracted. Moreover, Arvid remembered that a fraternity mate of his had worked on this topic for his MSc thesis and that this fraternity mate of his was really fond of the topic. Moreover, for both counted that this type of subject was by far the most interesting, compared to the other three ones.

It is actually quite remarkable that we both chose this topic because we both have no real personal background in these kind of environmental technicalities. However, on the contrary this was seen as a real and nice challenge for the both of us. The Science Digest is based on a literature research, 6 interviews and a pilot plant visit at the Afsluitdijk (REDstack).

The literature research was started by inserting the keywords 'blue energy' in search engines as Google Scholar and Scopus and only for articles from 2007 onwards was searched. We read several articles regarding this topic and we found out that a lot of research was actually done by Dutch researchers. Moreover, we ran into a couple of the same names several times (amongst others J.W. Post, M. Saakes, D. Vermaas, S. Grasman & C.J.N. Buisman). After doing some small research regarding the researchers, most of them even seemed to be (or were) somehow related to Wetsus and the WUR. Therefore we decided to request these persons, amongst others, for an interview. That these researchers were mostly Dutch had actually two sides: on the one hand this made the communication more easy, but on the other hand it made sure that we did not find other applications/pilots/demos around the world regarding 'blue energy'.

After having done the first interview (C.J.N. Buisman, 12-11-2014), which was really helpful, we also asked Mr. Buisman whether he knew other researchers that were useful to contact as well. He indicated that Mr. Neumann would be a good one to talk to. Besides, especially J.W. Post would really be a good one to talk to as well because he is the one that had written a complete PhD thesis regarding blue energy. Luckily at that moment we had already seen his name in a couple of articles and had already planned an interview with Mr. Post on the 17th of November.

Especially during this interview with J.W. Post (17-11-2014) we noticed 1) that there were more applications possible than only producing energy with the system of blue energy, such as desalination, purification etc. and 2) the reason why we mostly found Dutch researchers. The research term 'blue energy' is actually only being used in the Netherlands for this kind of specific renewable energy. Other countries are more focused on other water related energy sources when talking about 'blue energy', such as Hydro-, Tidal- and Wave Energy. For the type of energy source we were looking for, the other countries mostly use the terms 'Osmotic Power' or 'Salinity Gradient Power'.
These two new terms really helped us to also find other literature (and therewith names) from researchers and companies around the world.

After having finished the draft, the incorporated feedback (from our colleagues and the validation from the experts) was very constructive and there was not much overlap or contradiction between them.

Appendix 2: Explanation regarding technicalities of two salinity gradient power generation

Reverse Electrodialysis (RED)

A RED system works in the following way: "a number of cation and anion exchange membranes are stacked in an alternating pattern between a cathode and an anode (Post, 2009)" (For the figure see down on the right side). "The electric potential difference between the outer compartments of the membrane stack is the sum of the potential difference over each membrane." "The chemical potential difference causes the transport of ions through the membranes from the concentrated solution to the diluted solution. For a Sodium chloride solution, sodium ions permeate through the cation exchange membrane in the direction of the cathode and chloride the other way around." (Post, J.W., (2009) Blue Energy: electricity from salinity gradients by reverse electrodialysis. Retrieved from: http://www.waddenacademie.nl/fileadmin/inhoud/pdf/06-wadweten/Proefschriften/thesis_jan_Post.pdf)

Pressure Retarded Osmosis (PRO)

"This membrane allows the solvent (i.e. water (H2O) to permeate and retains the solute (i.e. dissolved salts)." (Post, 2009) This transport of water from the low-pressure diluted solution to the high-pressure concentrated solution results in a pressurization of the volume of transported water. This transported water can be used to generate electrical power in a turbine. (Post, 2009)

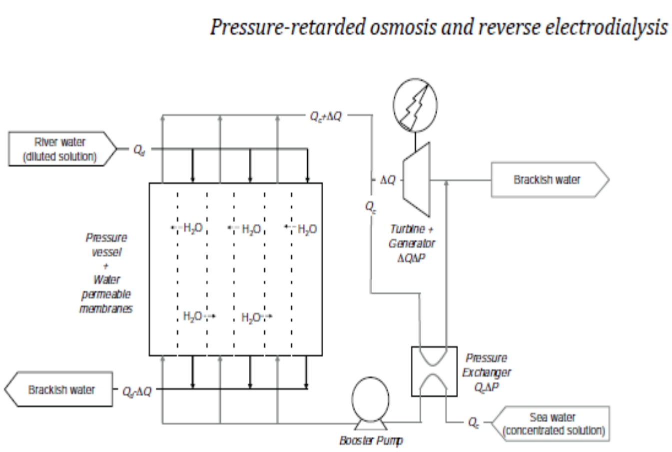

Figure 1: Conceptual representation of an energy conversion scheme using pressure-retarded osmosis; Q is the volumetric solution flow (m^3/s), ΔQ the transported amount of water in time through the membranes (m^3/s), ΔP the applied hydrostatic pressure difference between both solutions (Pa), whereas the power generated by means of a turbine and generator is $\Delta Q \cdot \Delta P$ (W).

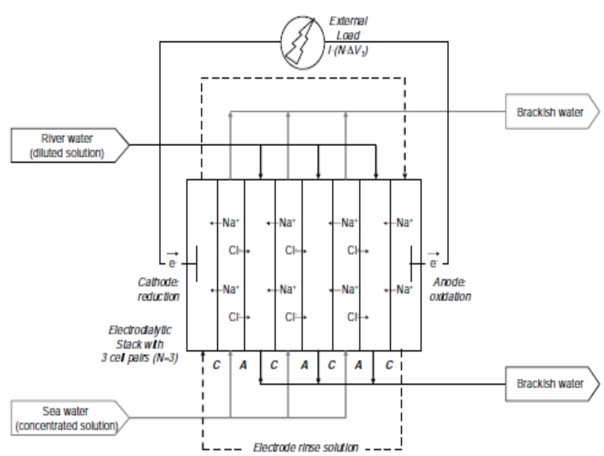

Figure 2: Conceptual representation of an energy conversion scheme using reverse electrodialysis; A is an anion-exchange membrane, C a cation-exchange membrane, I the electrical current or transported charge (A), N the number of cell pairs (in this case N=3), $N{\cdot}\Delta V_1$ the potential difference over the applied external load (V), whereas the power generated is $I{\cdot}(N{\cdot}\Delta V)$ (W).

Appendix 3: Definitions and assumptions to calculate the energy potential

(Post, J.W., (2009) Blue Energy: electricity from salinity gradients by reverse electrodialysis. Retrieved from: http://www.waddenacademie.nl/fileadmin/inhoud/pdf/06-wadweten/Proefschriften/thesis_jan_Post.pdf)

Potential	Definition	Assumptions
Theoretical potential	Energy that is potentially available if all energy being dissipated at the river mouths was harnessed without any energy losses	- Annual averaged river water discharge - Average sea salinity and temperature at river mouth (as if pure sodium chloride solutions) - 1 m^3 of river water mixing with 1 m^3 of sea water
Technical potential	Share of the theoretical energy that can be recovered with current technology, regardless other restrictions.	- Minimum monthly energy density (determined by monthly averages) - Energy recovery by current technologies[2] of 70% [3] - 50 kJ per m^3 water (13 Wh per m^3) is substracted for transport and pre-treatment, i.e., for energy consumption of pumping [6]
Economic potential	Part of technical potential that can be developed at costs competitive with other energy sources.	- Chemical composition of feed water [4] - Fouling characteristics, dependent on water quality related to technology [5-6] - Site-specific study to identify required civil infrastructural works
Exploitable potential	Fraction of economical potential that can be used if the environmental, political and other unique constraints are accounted for.	- Site-specific study to identify the environmental impact, political agendas, and other specific constraints

[2-6] *Validated or investigated in this thesis: numbers refer to chapters*

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