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The Water-Energy Nexus in the Indian Ocean Region

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Key Points

- Water is essential to energy production processes in both the mining of raw materials and in power generation.
- Energy is required for the extraction, purification, distribution, utilisation and disposal of water.
- The risks posed by the water-energy nexus manifest differently across the Indian Ocean region and the best approach to reduce the nexus will be contingent upon each country's geographical and social intricacies.
- Reducing the strength of the water-energy nexus will improve the resilience of both water and energy in a future of climate and economic variability.

Summary

The term water-energy nexus describes the interdependence, and often competing demands, of two of the world's most valuable resources: water and energy. Following agriculture, the energy industry is the second-largest user of freshwater. Water is essential to harness, extract and produce energy. In turn, energy is required for water production, treatment, circulation and disposal. The greater the strength of the nexus between the two, the greater the risks posed by this interdependence. A disruption in the supply of one resource will lead to similar disruptions in the other. The nexus is an integrated view of resources that spans many sectors to allow for a greater understanding and appreciation of the complex relationship between water and energy. This enables the identification of potential trade-offs and synergies so that policy and technologies may be developed to help manage these resources sustainably. The water-energy nexus is not a new model, however, the constraints and vulnerabilities associated with it are becoming more prominent, due to the disrupting effects of climate change and the resource demands that accompany population growth and economic development. This water-energy nexus affects each country differently, as demonstrated by Saudi Arabia, Iran, India, South Africa and Indonesia.

Analysis

The world's population is estimated to increase from seven billion today to nine billion by 2040. Water consumption to generate electricity is expected to double over the next 40 years. Global energy consumption is projected to grow by up to 50 per cent by 2035. Population growth and economic development will see increasing demands for both water and energy, which will simultaneously exert pressure on one another. Reducing the link between water and energy will be necessary to ensure the future security of both resources.

Water for Energy Production

Water is essential for the mining of raw materials, such as coal, oil and gas, and in power generation such as hydropower and thermal power plants. These processes may withdraw or consume water. Withdrawn water is diverted from a surface or groundwater source and returned to its original source, whereas consumed water is withdrawn and not returned to its source.

In the energy sector, water is predominantly used for the cooling of thermal power plants. Once-through cooling, which is an open-loop system, requires the withdrawal of water from surface sources before being run through a condenser and returned to its source at a higher temperature. Wet-tower systems are a closed-loop system where water is withdrawn and used within an internal reuse cycle. Water is run through a condenser before being pumped to the top of a cooling tower and then gathered at the bottom of the tower to be reused. Once-through systems withdraw as much as 60 times more water than wet-tower systems but consume much less water. Wet-tower systems generally have a much higher capital cost compared to once-through systems. Dry cooling is the third alternative; it passes large amounts of air over a heat exchanger to cool. Only small quantities of water are withdrawn or consumed. Dry cooling systems require a considerable amount of electricity and capital investment.

Energy for Water Production

Energy is required for the extraction, purification, distribution, utilisation and disposal of water. The most energy-intensive of these is purification through processes such as desalination and wastewater recycling. Desalination is the removal of dissolved minerals from sea water, brackish water or treated wastewater. Desalination consumes 75 terawatt hours of electricity globally every year, with 99 per cent of this energy coming from fossil fuels. There are three main desalination technologies: multi-stage flash distillation, multi-effect distillation and reverse osmosis. Multi-stage flash and multi-effect distillation are forms of thermal desalination that require both electricity and heat. Thermal technology heats water until it evaporates and then the vapours are cooled before the resulting purified water is collected. Thermal techniques have been the dominant desalination process in the Middle East due to the high seawater temperature and salinity of the Persian Gulf. Reverse osmosis is a membrane-based process where seawater diffuses through a membrane under high pressure, removing minerals from the water. Reverse-osmosis uses considerably less energy than thermal desalination.

Recycling processes consume less energy than desalination. Energy is used in wastewater treatment plants for the transportation of water to, from and within the plant, and for processes such as influent pumping, aeration, ultraviolet disinfection and solids handling.

The Middle East

The Middle East is characterised by significant water scarcity and abundant fossil fuel-based energy resources. The region's population and living standards continue to grow. Due to these factors, it is likely that water and energy demands will continue to rise steeply over the next 15 years.

Saudi Arabia

Desalination has emerged as a device to increase water availability in the Middle East as countries realise the damaging effects of the overexploitation of groundwater. Saudi Arabia is the largest producer of desalinated water in the world. Desalination is extremely energy-intensive and Saudi Arabia uses 25 per cent of its oil and gas production to generate power for its desalination plants. Desalination emits large amounts of greenhouse gases and increases the already high carbon intensity of Middle Eastern countries. These added emissions are likely to exacerbate the impacts of climate change on the region. Over the next 15 years, it is imperative that Middle Eastern countries look at mitigation efforts in fossil fuel-powered desalination to reduce emissions. The region should work toward integrating renewables and waste heat into the desalination process. In the long-term, this will reduce the impact of desalination on climate change and, by extension, its effect on water security in the region.

The water-energy nexus in the Middle East is lopsided. Energy systems in many Middle Eastern countries, Saudi Arabia included, are largely decoupled from fresh water resources. Their energy sector is not strongly tied to freshwater availability, most likely because they are historically accustomed to scarce water resources. Dependency on seawater for thermal cooling is high while dependency on freshwater for cooling is low. The energy infrastructure of Middle Eastern countries is therefore relatively robust from a freshwater availability perspective.

On the other side of the nexus, however, water infrastructure is not robust from an energy availability perspective. There is a heavy reliance on energy to obtain freshwater. The recycling of wastewater is a possible avenue to decrease this energy dependency in producing freshwater. Energy consumption is much lower for recycling processes when compared to desalination.

Fossil fuel-powered desalination plants are not a sustainable option to solve the long-term water crisis of Middle Eastern countries, due to the financial volatility of energy resources and increasing greenhouse gas emissions. Solar and waste heat powered desalination is an emerging solution, enabling countries to continue desalination processes with a more sustainable source of fuel. Saudi Arabia has one of the highest solar irradiation levels in the world, between 1,800 and 2,200 $kWh/m^2/year$. Utilising waste heat by co-locating with power generation, as Qatar has done at its Ras Abu Fontas desalination and power plant, is also an option. Desalination plants that employ reverse-osmosis use considerably less energy than traditional forms of desalination. Due to advances in reverse-osmosis technology, it is now cost competitive for countries bordering the Persian Gulf that have traditionally used thermal techniques.

Iran

Iran's annual precipitation is just one-third of the world average, yet its water usage is twice the global average. Decades of mismanagement and 14 years of drought have led to the rapid depletion of its water resources. Iran's freshwater is predominantly sourced from dams and wells. Iran is ranked third in the world for dam building and has built 600 dams over the past three decades. The construction of dams to irrigate farms and supply power has been a central policy for the Iranian Government over the past 30 years. The policy has been abandoned by President Hassan Rouhani. Due to Iran's water crises, the capacity of over 50 hydroelectric generation plants is dwindling and they are no longer a reliable source of power generation or irrigation. Generous energy subsidies mean that groundwater extraction, an energy-intensive process, is cheap, resulting in the overexploitation of water. Iran has as many as 500,000 water wells and many more illegal and undocumented wells. Pumping groundwater requires much more energy than using gravity-based conveyance from surface water.

Iran has the opportunity to decrease the strength of the water-energy nexus and preserve its groundwater resources through wastewater recycling and desalination. Iran has plans to construct seawater desalination plants, with the power said to be provided in part by small nuclear power plants. Nuclear power plants require water for cooling, but they do not produce the greenhouse gas emissions that fossil fuel plants produce. The water required could be provided by recycled wastewater for inland areas or by seawater in coastal areas.

Currently, Iran generates most of its energy through thermal power plants, with over 40 fossil fuel-powered plants in operation. Iran has the third-largest proven oil reserves and the largest proven natural gas reserves in the world. With the exception of three years, Iran has experienced 23 years of reduced rainfall and rising temperatures. Fossil fuel-based energy production should be limited due to climate change, but also because the resource is not infinite, and will eventually be depleted. When this time comes, a strong water-energy nexus where energy is primarily produced through fossil fuels will pose immense challenges. Iran has great solar, wind and geothermal energy potential. Iran must also address its water crises by educating the public on water usage and reducing subsidies to prevent waste.

India

India is the fastest growing major economy in the world, with a dedicated energy policy that focuses on securing energy to meet the increasing demands of its economy and people. It is the world's third-largest producer and consumer of coal, with 70 per cent of all energy generated coming from coal-fired power plants. India's energy sector suffers from ageing infrastructure and one-third of its power plants are due for rehabilitation. These power plants are extremely water-intensive and inefficient. Within the Indian energy sector, coal-fired power plants account for 95 per cent of total water withdrawals. Most traditional thermal power plants in India use once-through or closed-loop systems.

India's demand for power is increasing rapidly, growing 37 per cent over the past five years. Its power plants, however, are performing far below global standards, in part due to water supply issues.

Chronic power shortages are a recurring issue for India. In March 2016, India's state-run National Thermal Power Corporation was forced to shut down five units of its Farakka thermal plant due to water shortages. In October 2015, the Parli power plant in India's Maharashtra state was shut down due to poor water supply. This disrupts economic activity and affects millions of Indian people, 33 per cent of whom do not have access to electricity.

Coal is set to remain the leading source of energy in India through to at least 2050. It is India's most abundant energy resource, is relatively cheap to mine and constitutes the majority of existing energy infrastructure. It is, therefore, essential that India works to improve the efficiency of its plants in terms of both energy output and water use. India's energy infrastructure is extremely inefficient and the demand-supply gap for energy is widening. There is an opportunity for India to tackle both these issues by adopting more energy and water-efficient measures in its power plants. The World Bank is currently assisting India with a coal-fired plant rehabilitation project. It aims to develop a clean, water-efficient energy sector that closes the demand-supply gap.

India will, however, still need to find ways to reduce water use in its power plants. Water saving initiatives are beginning to gain traction. For instance, in April 2016, the state of Maharashtra commenced a plan to use treated sewage water for cooling coal-based thermal power plants. Other approaches involve improving overall plant efficiency. Approaches to reduce dissipated energy, and therefore increase energy efficiency, include utilising power cycles with higher theoretical efficiencies, recovery of waste heat and the reuse of water. A higher overall plant efficiency will indirectly reduce water consumption as greater efficiency lowers energy, and therefore cooling, requirements. Retrofitting or replacing inefficient plants will boost efficiency. The World Bank estimates that the renovation and modernisation of India's power plants will improve their efficiency by 10-15 per cent.

India needs to weaken the strength of the nexus between water and energy, or else face the effects of water shortages on energy production with increasing severity over the coming years.

South Africa

The energy-water nexus poses significant challenges for South Africa, a water-scarce country with a high dependency on coal-fired power. Population growth and urbanisation are exerting upward pressure on water and energy. This is exacerbated by the effects of climate change, such as rainfall variability and the increased incidence of extreme weather events.

The energy programme of South Africa is likely to be threatened by increased water scarcity in coming years. South Africa's water-intensive coal industry generates approximately 90 per cent of its domestic electricity supply. South Africa has suffered from chronic power outages since 2008, forcing the government to introduce a strategy of planned power outages on a rotating schedule known as "load shedding". These outages are reportedly no longer necessary as demand-supply gaps have been overcome, but challenges remain in the South African electricity sector.

The state-owned utility, Eskom, recently announced a 44 per cent increase in capital expenditure over the next five years to build new power stations and complete the Kusile and Medupi coal-fired power stations, which will produce 4,800 megawatts (MW) each. When completed the two power stations are expected to consume 26 million m³ of water annually. This will exacerbate water security issues in South Africa where climate change is already greatly impacting meteorological cycles to produce less moisture.

South Africa should look to alternative sources of energy production to reduce the strength of the water-energy nexus, but due to its abundant reserves, it is unlikely to reduce much of its coal-fired energy production. Coal is estimated to still account for 65 per cent of electricity generated in 2030. South Africa is believed to have immense shale gas reserves, which could emerge as an alternative to coal-based energy production as gas power plants consume much less water. The process to extract shale gas, hydraulic fracturing, could pose contamination risks to groundwater and still uses significant amounts of water. South Africa already suffers from declining water quality, with 40 per cent of freshwater systems in critical condition. South Africa does, however, have immense solar, wind and wave power potential, all of which use very little water. Given South Africa's energy supply gap, diversification of energy in the area of renewables would be important to reduce the strength of the water-energy nexus, as well as reduce greenhouse gas emissions in a region vulnerable to the effects of climate change.

South Africa has a strong water-energy nexus. South Africa's water and energy infrastructure is vulnerable to disruptions and a shortage in either resource is likely to severely impact the other. South Africa must work to reduce the dependency between water and energy to prevent a future of uncertain resources for its growing population.

Indonesia

On the other side of the Indian Ocean, Indonesia's energy programme features an equally strong water-energy nexus. Unlike South Africa, however, Indonesia is not a water-scarce country. It has access to two trillion m³ of internal renewable water sources per year, 21 per cent of the total freshwater available in the Asia-Pacific. Despite this natural abundance of water 37 million Indonesians still lack access to safe water due to poor water infrastructure and distribution networks.

Indonesia's energy sector relies heavily on fossil fuels, with 95 per cent of its primary energy supply coming from oil, coal and gas. Thermal power plants with high water requirements for cooling provide the majority of Indonesia's energy. Indonesia suffers from power shortages and a low electrification ratio. In May 2015, the government launched a 35,000 MW project to roll out power to the 70-80 million Indonesians who still lack access to electricity. The project outlined quotas of 25 per cent renewable energy, 25 per cent gas and 50 per cent coal. Given the project's dependence on gas and coal, it seems likely that the water-energy nexus will become stronger as Indonesia attempts to secure its energy goals. The amount of water required for cooling these thermal power plants will continue to rise unless similar approaches to those recommended for India are implemented. Independent of energy infrastructure, Indonesia must work on its water infrastructure and distribution network to reduce the likelihood of water shortages that could impact energy production, as well as provide water to the Indonesian people.

As an archipelagic country comprised of over 17,000 islands, Indonesia is extremely vulnerable to the effects of climate change. It is likely to experience rising sea levels, rainfall variability, increasing ocean temperatures and more severe weather events such as cyclones. To secure the future of its natural water resources and prevent the strength of the nexus increasing it must work to mitigate the effects of climate change. Indonesia must also address other environmental issues, such as the pollution of renewable surface water and the overuse of groundwater that has increased salinity in reserves and the rate of subsidence.

Indonesia has vast geothermal potential, which, with investment, could help develop a sustainable and renewable energy sector. Geothermal power plants can be cooled by water, air, or a combination of both, depending on water availability. The Indonesian Government aims to achieve 6,000 MW of installed geothermal power capacity by 2020. Acknowledging Indonesia's great hydropower potential, the Joko Widodo Administration has pledged to construct 65 dams during his five-year term. These dams would help alleviate the water-energy nexus by increasing water storage for the dry season and provide hydropower. Given the problems associated with large dam infrastructure, however, these projects will need to be developed carefully.

Despite these advances in renewables, Indonesia's ambitious goal to achieve high-income status by 2030 means it is likely to prioritise economic growth and energy production over water security and climate change over the next 15 years.

General Recommendations

The emphasis should be on developing both energy and water infrastructure that is resilient to the risks posed by the nexus. Reducing the overall water dependence of the energy sector will help decrease the strength of the water-energy nexus. This will require co-operation between both the public and private sectors. Energy project developers must consider the "water footprint" of their technology choices, which, if properly accounted for, will reduce the strength of the nexus, the likelihood of water shortage-induced disruptions to energy production and the potential for stranded assets. Governments should work towards developing sound water governance, including well-defined water rights, to facilitate confident decision-making by developers. Each country should work towards creating robust and resilient energy and water infrastructure, capable of responding to the demands and shocks that are likely to come from climate change, economic development and an increasing global population.

Conclusion

There is no universal approach to reducing the water-energy nexus. As illustrated by the different experiences of the Middle East, India, South Africa and Indonesia, the best technology to reduce the nexus will be contingent upon each region's geographical and social intricacies. This variability between regions means reducing the strength of the nexus requires a regional and local-level approach. It necessitates a view of economic development that recognises the increasing pressure on water and energy resources. Such a view would provide an opportunity to reduce the link between water and energy, which will increase economic resilience in a future of both climate and economic variability.

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