The Other Renewables: Beyond Solar and Wind

May - 2019

The Abdullah Bin Hamad Al-Attiyah International Foundation for
Energy & Sustainable Development

ABDULLAH BIN HAMAD AL-ATTIYAH INTERNATIONAL FOUNDATION
FOR ENERGY AND SUSTAINABLE DEVELOPMENT

Issue 33: May 2019

Al-Attiyah Foundation
Research Series

Expert energy opinion and insight

The Other Renewables: Beyond Solar and Wind

Most attention on the rapid rise and importance of renewable energy has focussed on wind and solar power. But numerous other forms of renewable energy are available, some commercially exploited today, some in development and some more speculative. What role could they play in future? Are they just a useful adjunct to wind and solar, or do they make an indispensable and differentiated contribution? What technical, commercial, policy and environmental barriers do they have to overcome to realise their potential?

Krafla geothermal power plant, Iceland (Source: Ásgeir Eggertson, Wikimedia Commons)

Executive Summary

- Most recent media and policy attention on renewables has focussed on solar and wind power, but this neglects other important forms of renewable energy.
- Hydroelectric and biomass today make a larger contribution than wind and solar, although they are more environmentally problematic and have limited room for further expansion.
- Geothermal is mainly limited to favourable locations, while ocean energy is technologically and commercially very immature, though potentially large.
- “Other renewables” contribute more than just kilowatt-hours – including water management, low-carbon transport fuels, heat, and carbon capture.
- The large “other renewables” are likely to grow only slowly, so not providing much new competition for gas, wind and solar. However, they are complementary to solar and wind power.
- Even though global growth is expected to be constrained, specific markets may have high shares of other renewables, making them important for analysis.

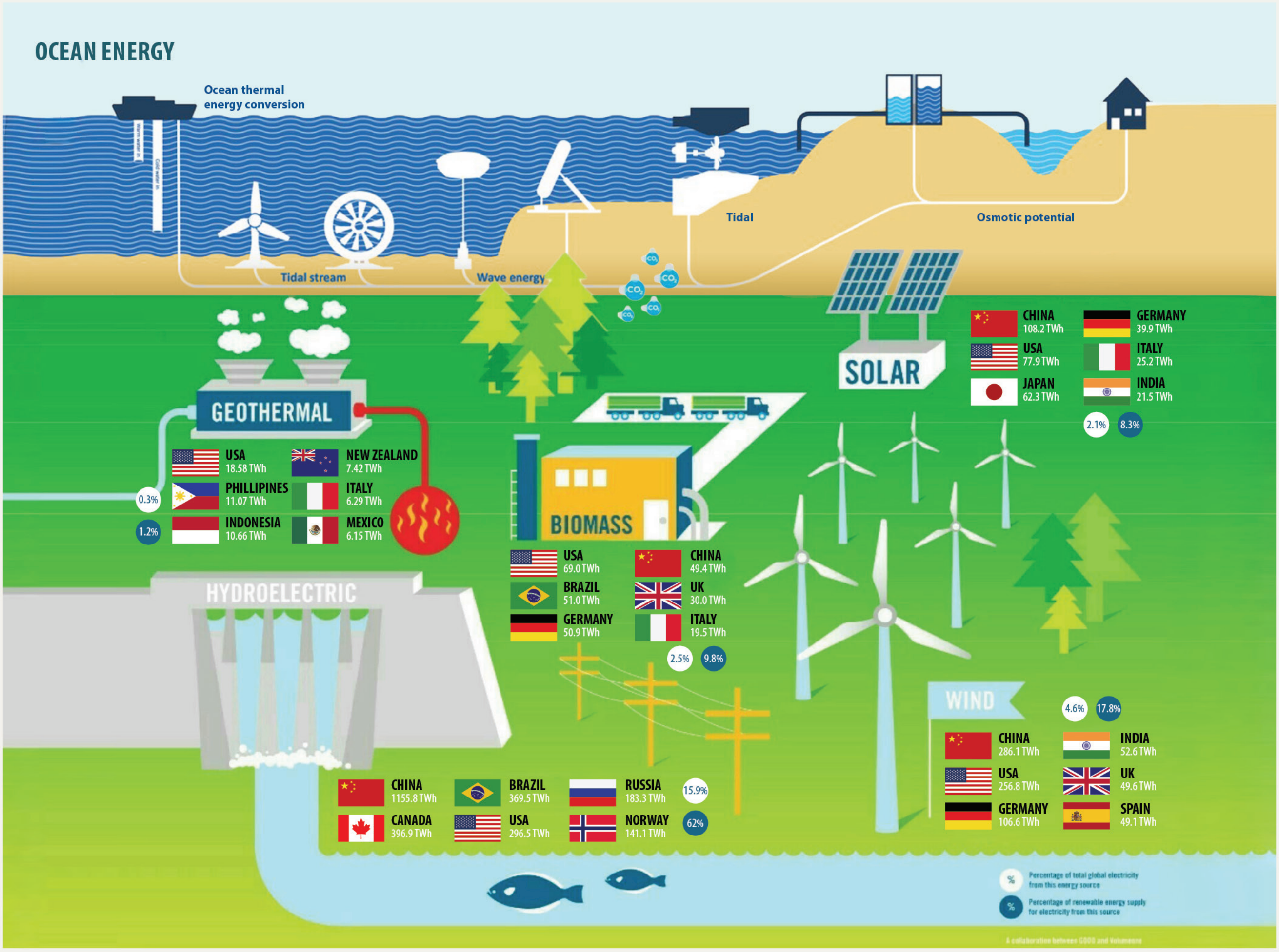
Implications for leading oil and gas exporters

- Hydropower, biomass and geothermal provide large shares of power and heat in certain markets, but can be considered as part of the ‘background’ energy mix. They are constrained from growing rapidly on a global scale.
- Biogas and geothermal could steadily gain a share of the heating market, thereby reducing gas demand, but this will probably be secondary to electrical and solar heating.
- Biofuels will expand gradually, but in the absence of technical breakthroughs, their use is likely to be concentrated in sectors not easily electrified, notably aviation.
- Ocean energy has large potential but is technologically and commercially immature, and unlikely to make a significant contribution before 2040.
- Collectively, the ‘other renewables’ are a complement to wind and solar, not an alternative.

“Other renewables” are larger than wind & solar

“Other renewables” cover a wide range of technologies, exploiting different kinds of energy available in the natural environment.

FIGURE 01: **DIAGRAM OF DIFFERENT RENEWABLE TYPES**[1]



Hydropower, the longest-established renewable form of electricity generation, uses the energy of falling water to turn a turbine, either at a dam or, on a smaller scale, as "run of river". Pumped storage uses cheap electricity in off-peak periods to pump the water back above the dam to store energy for on-peak times.

Geothermal uses naturally-occurring hot underground water (as in volcanic areas such as Iceland and Indonesia), or pumps water into artificial fractures underground ("hot dry rock"). The resulting hot water at surface can be used to drive a turbine to generate power, or for heating directly. This definition does not include ground-source heat pumps, which use electricity to remove heat from the shallow subsurface.

Biomass involves burning wood or other plant matter, whether waste or specifically cultivated. This can be done in power plants, very similar to coal power, or used for heating.

Biofuels are liquid fuels, including ethanol, biodiesel and potentially synthetic crude oil, made from plants, animal fats or in future algae. The plant material may be waste or may be from deliberate cultivation of, for instance, corn and sugarcane for ethanol. They are used as a low-carbon option to fuel ground transport, ships and aeroplanes with only minor modification to existing engines and fuel delivery systems.

Biogas is a mix of methane and other gases, generated from digesting organic material or processing wood and other feedstocks. It can be used as a substitute or complement to fossil natural gas. Biogas contains carbon dioxide, hydrogen sulphide, siloxanes and other contaminants; it can be purified to form biomethane, a close substitute for fossil natural gas.

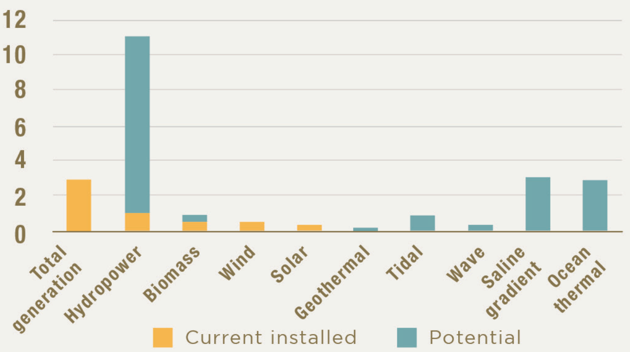
Ocean energy is the least mature of this group. It includes **tidal** (using the rise and fall of the seas to drive a turbine), **wave** (generating electricity with a machine that harnesses the motion of waves), **ocean current energy** (using currents to drive machines much like wind turbines, but underwater[2]), **salinity gradient** (exploiting the difference between fresh and salt water to create an electric current), and **ocean energy thermal conversion** (OTEC, exploiting the difference between warm surface waters and cool deeper ocean waters).

The continuing reduction in wind and solar costs, and advancements in batteries have widened their potential commercial application. The other renewables are often used to generate electricity, like wind and solar. However, they have other niche roles and advantages:

- **Geothermal**, **biomass** and **hydroelectric** provide predictable 'dispatchable' power in the same way as a fossil-fuelled or nuclear power plant;
- **Hydroelectric** can be used to store power cheaply over long periods, as a way of managing seasonal demand fluctuations or periods of low renewable output.
- **Ocean energy** can provide variable renewable power with a different daily and seasonal pattern from wind and solar, hence compensating for intermittency;
- Some (**biomass/biogas, geothermal**) can produce heat directly (as can solar thermal), for space and water heating in buildings, and industrial process heat;
- **Biofuels** can be used to power vehicles, particularly those where batteries' role is limited (aviation, shipping, long-distance trucking);
- Other renewable resources may be available in areas that have poor wind and/or solar conditions.

Global other renewable energy potential is large compared to total global electricity generation, which operated at an average of about 2.9 TW in 2017, out of total world energy use of about 18 TW (FIGURE 2). Wind and solar potentials are extremely large (wind is about 42 TW and solar at 7500 TW[3], practically infinite) so have not been plotted. Not all these capacities are exactly comparable, because of different capacity factors, different assumptions made on technical and economic feasibility, and so on. But they suggest that hydropower could theoretically meet almost four times 2017 world electricity demand, saline gradient and ocean thermal energy about 100% each, biomass and tidal about 35% each, and wave and geothermal smaller amounts.

FIGURE 02: **GLOBAL GENERATION POTENTIAL FROM OTHER RENEWABLES, TW[4]**

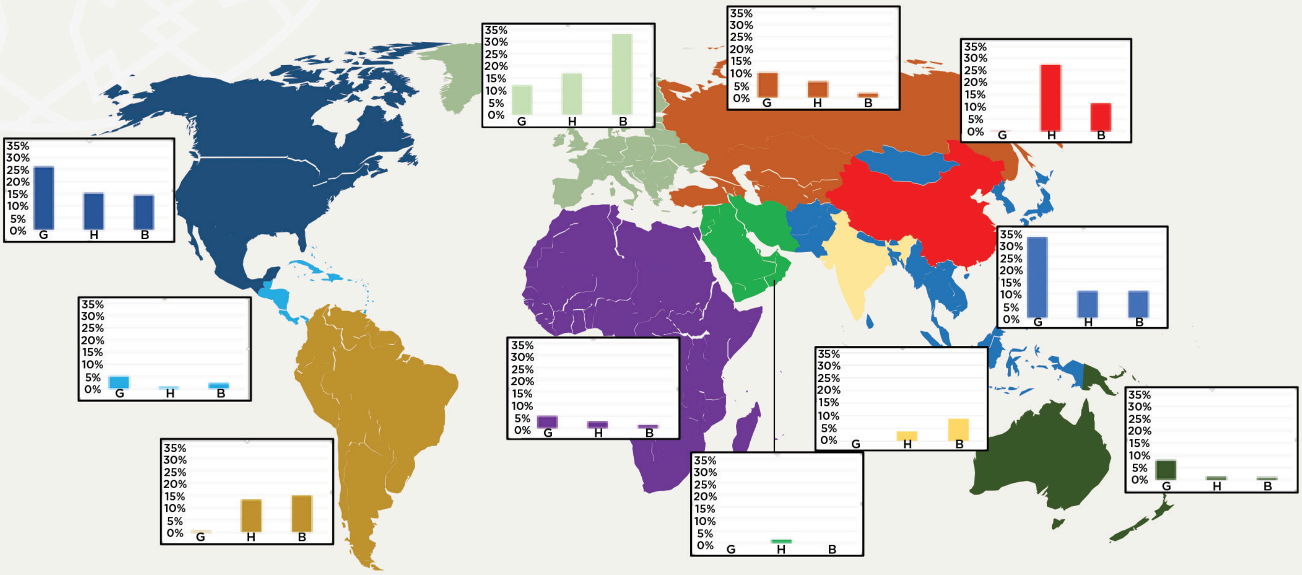


The share of other renewables in each region is determined by policy, economics and the resource endowment (FIGURE 3). Geothermal is shared between Asia (Indonesia, Philippines), New Zealand, Europe (Iceland, Italy), Turkey, the Rift Valley in East Africa, the USA and volcanic countries in Central America. Hydropower is more evenly distributed, but China, with 27% of the global total, is the clear leader. Europe and North America are significant users of hydropower but have little undeveloped potential. Europe is ahead in bioenergy, with 33% of world use despite its limited land area, which requires imports from elsewhere. Despite great resources of volcanic regions, rivers and agricultural land, Africa is a very minor part of global use of these three renewables, due to lack of development.

Costs vary widely and are location-dependent

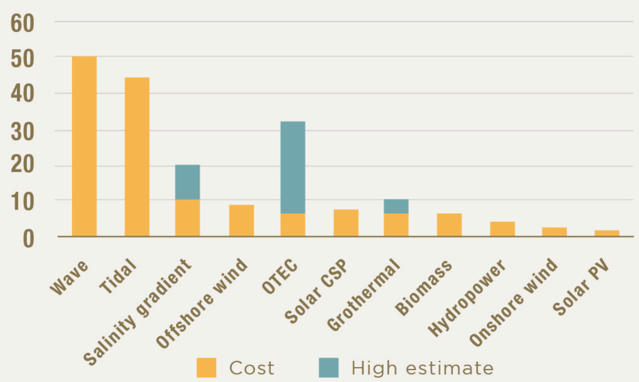
As typical of all renewables, the cost of electricity (or heat) produced by the non-wind/solar renewables is highly dependent on location. FIGURE 4 shows the typical best achieved levelised costs globally for each technology, and also for the different types of solar and wind.

FIGURE 03: **SHARE OF WORLD INSTALLED CAPACITY OF GEOTHERMAL (G), HYDROELECTRIC (H) AND BIOENERGY (B), BY REGION**[5]



These costs can be compared with a coal, gas or nuclear plant with generating costs typically in the range of 5-10 US$c/kWh.

FIGURE 04: **LEVELISED COST OF ELECTRICITY OF RENEWABLE TECHNOLOGIES, US$c/kWh**[6]



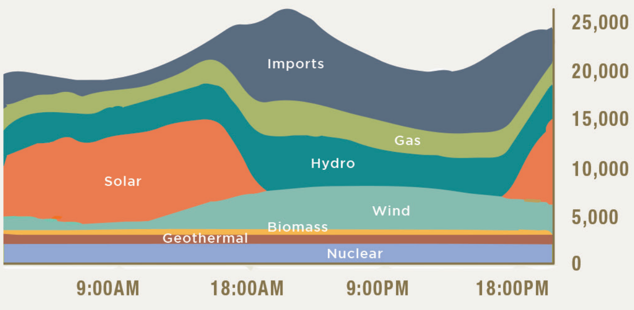
Wave and tidal are immature and have very high costs, which could fall significantly (as offshore wind has) with improved technology and experience. OTEC and salinity gradient show potentially attractive costs, but have only been deployed in very small pilot projects to date.

Geothermal is a fairly mature technology. Most future expansion will have to rely on “hot dry rock”, more costly than naturally-occurring hot waters.

Hydropower and biomass are very mature and have limited room to reduce costs further. In fact, hydropower costs are tending to rise as the best sites have been developed, and new ones are more remote, less suitable or environmentally sensitive. However, hydroelectric dams have additional value, including flood control, irrigation and recreation.

Costs for the more established other renewables are very competitive with fossil and nuclear generation. They are not as low as onshore wind and solar PV, but these technologies are dispatchable and their output is thus of higher value, not needing backup by batteries or fossil power plants. FIGURE 5 shows how for California, geothermal and biomass (and nuclear) run steadily through the day, and hydro, gas and imports are used to balance solar (in daytime) and wind (higher at night) with demand.

FIGURE 05: **DAILY POWER GENERATION MIX IN CALIFORNIA, 13TH MAY 2019 (MW)**[7]



Other renewables are not only about electricity

Other renewables can provide three other important services: **carbon capture and sequestration (CCS)**; **transport fuels**; and **heat**.

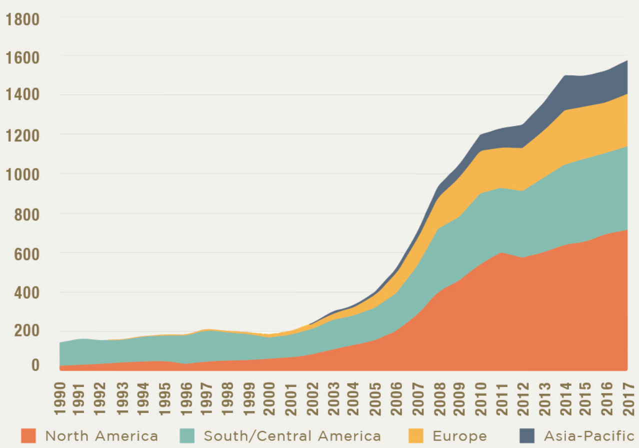
Bioenergy with carbon capture and storage (BECCS) is one promising approach for “negative emissions”. Biomass takes in carbon as it grows; when it is burnt or fermented, the CO_2 can be captured and stored underground. This is the same as carbon capture applied to fossil fuels, but rather than simply preventing new emissions, it actually reduces atmospheric CO_2 – negative emissions. To meet the Paris Agreement’s climate targets, even with major development of low-carbon energy, about 12 gigatonnes of CO_2 would have to be removed from the atmosphere by BECCS annually after 2050[8] (there are other options alongside BECCS, such as removing CO_2 directly from the air).

The Decatur ethanol plant in Illinois, the Arkalon ethanol facility in Kansas[9], and the Drax biomass power plant in North Yorkshire, UK[10], are trialling BECCS.

Biofuels for transport have been seen as a way of reducing dependence on oil, boosting agricultural prices (and favoured voting constituencies), and cutting CO_2 emissions.

Biofuels production was low and rather flat from 1990-2000 (FIGURE 6), mostly represented by Brazil's historic bio-ethanol programme. After that, rising oil prices and growing concern over climate change sparked policies to support the sector, with the US's corn ethanol expanding greatly, biodiesel becoming important in Europe, and palm oil (for biodiesel) in Asia. Rapid overall growth slowed, though, following the 2008-9 financial crisis. Despite its extensive tropical agricultural land, Africa's output of biofuels is still minimal and has substantial room to grow.

FIGURE 06: **HISTORIC PRODUCTION OF BIOFUELS BY REGION, kbbl/day**[11]



Biofuels for ground transport will probably be overtaken by batteries as the low-carbon option. Biofuels for planes may be essential, at least in the medium term, for reducing their carbon footprint. One view (FIGURE 7) sees road biofuels rising only modestly to 2030 and falling thereafter as batteries and hydrogen take over; use in aviation and shipping, however, contributes to accelerating output by about 2035.

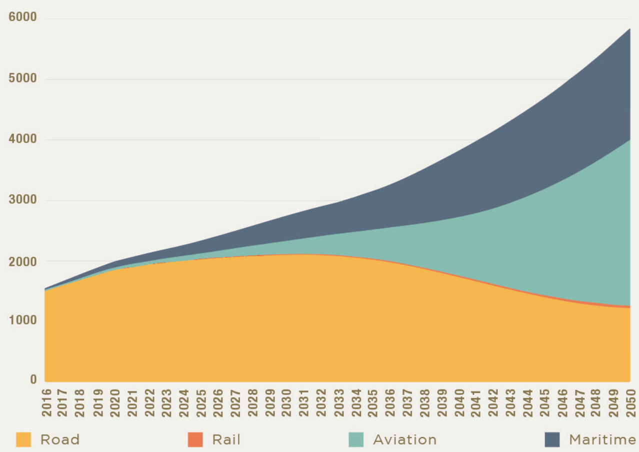
But even by 2050, total consumption of about 5 million barrels per day (Mbbl/day) is only 5% of current consumption of oil, or about 10% of current transport oil consumption. As a competitor to oil and electric vehicles, then, biofuels are not negligible, but not very significant either.

Future expansion of biofuel use may include genetically-engineered organisms, including algae. Algae can grow quickly in hot, saline, sunny conditions, such as arid coastlines in areas such as the Middle East and Australia. This would minimise competition for scarce fresh water and agricultural land.

Algal biofuels created a lot of excitement about a decade ago, but struggled to achieve reasonable costs and scale, encountering problems with invasive species, the energy for processing the algae, and large consumption of water and fertilisers[12]. New approaches aim to produce synthetic plastics and other materials alongside fuel, which would compete with the petrochemical industry. Recent research is promising, but the technology remains a long way from commerciality.

Providing **heat** (space and water heating in buildings in cold climates, and industrial heat), is a significant challenge for the next stage of decarbonisation. In the UK, for instance, 50% of total energy demand is for heat. Of this, 66% comes from burning gas and oil, and 11% is from electricity generated from fossil fuels. Heat demand is three times electricity demand in winter, but far less in summer[13].

FIGURE 07: **FORECAST CONSUMPTION OF BIOFUELS PER TRANSPORT SECTOR, 2016-50, kbbl/day**[14]



This creates a problem for an electric-only heat system, which would need enormous winter capacity that would be unused most of the year. Northern Europe, North America, Russia, Iran, Korea and northern China have the same issue or even more so.

Various options include district heating systems (common in the former Soviet Union), solar heating (where the climate permits), electrically-driven heat pumps, or replacing natural gas with hydrogen. Biomass burning (wood) is popular in parts of Europe, but causes air pollution. The non-solar/wind renewables provide two options: biogas, and geothermal.

Biogas in the form of biomethane has the advantage of compatibility with existing gas pipelines and boilers. It can be captured from landfill sites (reducing harmful methane emissions) or produced by processing agricultural, forestry and food waste.

Geothermal could gain a larger role by expanding the use of "hot dry rock"[15]; bringing in oil industry techniques for drilling wells, mapping reservoirs and hydraulic fracturing, and pumping warm water from abandoned coal mines. It could provide building heating, low-temperature heat for some industries (such as food processing), desalination, and air-conditioning in hot climates (using absorption chillers).

Some geothermal reservoirs contain CO_2, giving them about 3% the carbon footprint of an equivalent coal-fired power plant. However, in 2017, Reykjavik Energy began reinjecting CO_2 underground in Iceland, where it reacts with the basaltic rocks to become trapped indefinitely[16]. The ultramafic rocks in the Semail Ophiolite in Oman also react readily with CO_2 and are good candidates for enhanced carbon capture[17].

Biomass and hydroelectric are large today, but face challenges in expanding

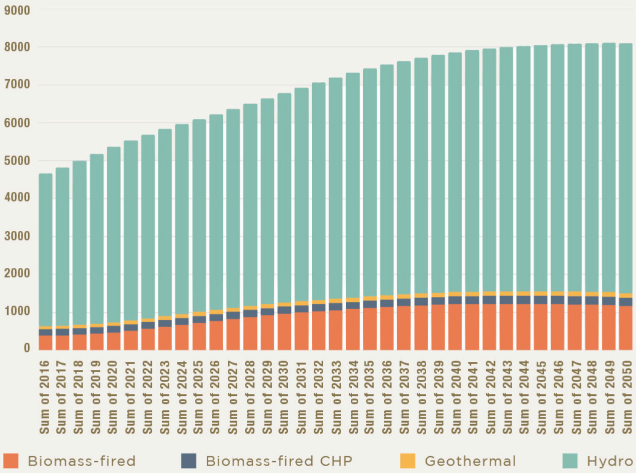
Forecasts suggest limited growth in other renewables. DNV's projection, for example (FIGURE 8), has compound annual growth rates during 2016-50 of 1% for geothermal, 1.5% for hydroelectric and 2.7% for biomass, compared to 9.2% for wind and 14% for solar photovoltaic. It does not include any role for ocean energy.

In DNV's view, solar overtook biomass as the third most important renewable energy in 2018, and it will dethrone hydro from top spot in 2031, with wind pushing hydro into third place in 2032.

Current global **hydroelectric** dams exist primarily in North America, Europe, Brazil, China, the Indian subcontinent and south-east Asia (FIGURE 9). But under-construction and planned new dams concentrate in Brazil, the Balkans, Turkey, parts of east and west Africa, the Himalayas and the Greater Mekong in south-east Asia. Siberia and the Congo basin have large hydro potential but plants would be far from sizeable electricity markets.

In industrialised countries, such as those in Europe, the best hydroelectric sites have already been developed.

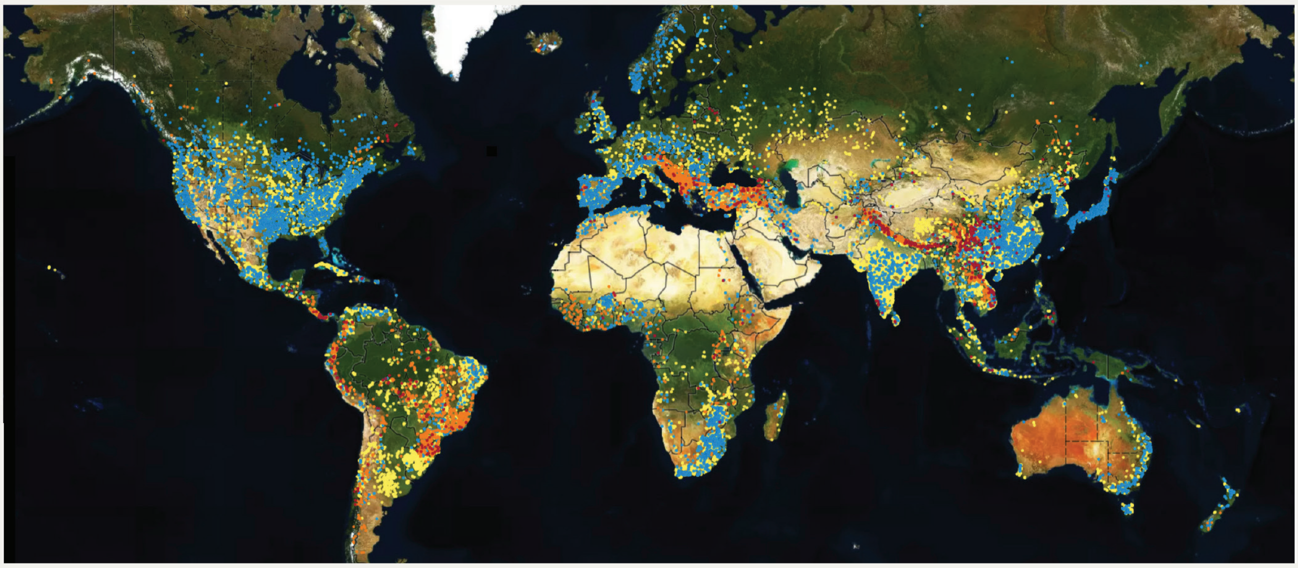
FIGURE 08: **FORECAST OTHER RENEWABLE GENERATION TO 2050, TWh[18]**



Elsewhere, new dams flood large areas, displacing people, and destroying ecosystems and ancient heritage, as with Turkey's historic town of Hasankeyf[19]. In the Himalayas and on the Tigris-Euphrates system and Nile, dams create concerns over upstream countries abstracting water rights from those downstream. This may become more acute as climate change leads to local droughts and melting of glaciers that feed these rivers. Rotting vegetation along the banks of dammed lakes produces methane. Dam methane represents about 1.3% of human greenhouse gas emissions[20].

Biomass, **biogas** and **biofuels** are also problematic. There is a practical upper limit on the amount of biological materials the global ecosystem can provide, without causing massive losses of habitat, biodiversity and related problems such as desertification, loss of soil carbon, and eutrophication (excessive fertiliser runoff into lakes and oceans, leading to algal blooms and oxygen-depleted 'dead zones'). Ecosystems are already under severe pressure from climate change and

FIGURE 09: **EXISTING, UNDER-CONSTRUCTION AND PLANNED DAMS[21] (YELLOW & BLUE – EXISTING; RED – UNDER CONSTRUCTION; ORANGE – PLANNED)**



the expansion of human activities, particularly livestock farming.

Cultivation of wood for biomass-burning power plants leads to large monoculture plantations, that consume water and soil nutrients while providing little biodiversity. Transporting wood from, for instance, North America to the UK also leads to CO_2 emissions.

Methane is a powerful greenhouse gas in its own right, so biogas has to avoid leakage. Biogas is also limited in volume. For example, estimates suggest European potential for 20-50 billion cubic metres (BCM) per year of biomethane in 2040, and optimistically up to 98 BCM in 2050[22], while the continent consumed 532 BCM of natural gas in 2017[23].

The EU has taken moves to tighten up on the sustainability of biofuels. Its 2009 Renewable Energy Directive required a minimum 10% share of biofuels in transport diesel and petrol, but an act of 13th March 2019, currently before the European parliament, would ban the use of palm oil for biodiesel. Malaysia and Indonesia account for 85% of global palm oil production, but its expansion has led to concerns about deforestation, destruction of wetlands and loss of biodiversity.

However, biofuels grown in very favourable conditions, such as Brazilian sugarcane ethanol, can be economically competitive and environmentally acceptable. The waste cane material is used to fire the processing plants, reducing their carbon footprint.

Ocean energy has potential, but is technologically and commercially immature

The various forms of ocean energy have struggled to advance because of the high costs of operating offshore, and difficulties with reliability, maintenance and corrosion in a rough and saline environment.

Tidal power in a few good sites provides significant amounts of power – 240 MW at Rance in France, 254 MW at Sihwa Lake in South Korea - Sihwa Lake in South Korea - and proposed systems, such as Swansea Bay in Wales (320 MW), Incheon in South Korea (1320 MW)[24], and Severn Barrage in the UK (potentially 8600 MW). However, the Severn Barrage plan was scrapped in 2010 due to high cost and environmental concerns[25].

Otherwise, ocean energy is limited to small pilot projects of a few megawatts or less each, mostly in waves and tidal streams. Installed capacity worldwide in 2017 was just 17 MW of tidal current and 8 MW of wave power. The most notable tidal stream project is probably that being built in northern Scotland with 6 MW initially, and potential up to 398 MW[26], using a 2 MW turbine design developed with GE[27].

Ocean energy may be useful for remote coastal communities and islands, currently dependent on expensive diesel generators. Here, it may compete with wind and solar with battery backup. For instance, Kiribati in the South Pacific is constructing a 1 MW OTEC plant, and Reunion (15 kW) and Hawaii (105 kW) have small operating pilots[28].
However, given its immaturity and limited funding, it does not seem likely that ocean energy will make a significant global

Conclusions

In growth rates and absolute quantity, biomass/biofuels and hydropower are set to lose their leading role to wind and solar. However, they remain very significant contributors to global energy. Along with geothermal, they also provide unique advantages, particularly dispatchability; the energy storage and water management role of dams; carbon capture; and heat. Their costs are reasonably low (in the case of good locations, very low) compared to alternatives.

Ocean energy is in sharp contrast: it is negligible today, still expensive, yet has large, but uncertain and technically-challenging potential.

The large incumbent non-solar/wind renewables will not grow very rapidly, and their ultimate potential is limited. There could be a breakthrough in algal biofuels or ocean energy, but even then it would take decades to scale up, as wind and solar have before it. Therefore their global competition to fossil fuels, nuclear and solar/wind will be marginal.

However, the other renewables can be very sizeable in specific regions and markets. They are also vital complements to variable renewables. When assessing demand for electricity, gas or oil in a particular case, it is important to capture the unique economic, environmental, regulatory and political drivers behind these technologies.

Three Gorges Dam, China. (Source: Allen Watkin)

References

1. Company websites, Ocean Energy Europe https://www.oceanenergy-europe.eu/ocean-energy/, solar, wind, hydro sourced from BP, 2017 figures; geothermal and bioenergy from IRENA, 2016 figures

2. http://large.stanford.edu/courses/2014/ph240/zarubin2/

3. https://www.sandia.gov/~jytsao/Solar%20FAQs.pdf

4. BP Statistical Review of World Energy 2018; World Energy Council https://www.worldenergy.org/data/resources/resource/marine/; International Renewable Energy Agency https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/IRENA_REmap_2030_Biomass_paper_2014.pdf, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Power_2017.pdf; Blue Economy Forum http://blueeconomyforum.ris.org.in/offshore-ocean-energy; Intergovernmental Panel on Climate Change http://www.ipcc-wg3.de/report/IPCC_SRREN_Ch06.pdf; Ocean Energy Systems annual report 2017 https://report2017.ocean-energy-systems.org/

5. Drawn from data in International Renewable Energy Agency, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf

6. https://www.irena.org/documentdownloads/publications/salinity_energy_v4_web.pdf, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf, https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Resources-Full-report-2016.10.03.pdf

7. California ISO

8. UN Framework Convention on Climate Change https://unfccc.int/sites/default/files/resource/28_EASAC%20Report%20on%20Negative%20Emission%20Technologies.pdf

9. https://hub.globalccsinstitute.com/publications/global-technology-roadmap-ccs-industry-biomass-based-industrial-co2-sources-biofuels-6

10. https://www.drax.com/press_release/world-first-co2-beccs-ccus/

11. Drawn from data in DNV, https://eto.dnvgl.com/2018/#132548

12. https://www.power-technology.com/features/algal-biofuels-challenges-opportunities/

13. https://energypost.eu/36bn-gwh-the-limitless-geothermal-from-old-uk-coal-mines/

14. DNV, https://eto.dnvgl.com/2018/#132548

15. https://power.nridigital.com/future_technology_may19/could_cornish_granite_unlock_deep_geothermal_energy_in_england

16. https://qz.com/1100221/the-worlds-first-negative-emissions-plant-has-opened-in-iceland-turning-carbon-dioxide-into-stone/

17. https://www.thenational.ae/world/scientists-seek-holy-grail-of-reversing-climate-change-in-oman-s-carbon-mountains-1.71655

18. DNV, https://eto.dnvgl.com/2018/#132548

19. https://www.nationalgeographic.com/magazine/2018/11/turkey-flooding-dams-displaced-antiquities-mesopotamia/

20. https://academic.oup.com/bioscience/article/66/11/949/2754271

21. http://globaldamwatch.org/map/

22. Oxford Institute for Energy Studies https://www.oxfordenergy.org/wpcms/wp-content/uploads/2019/02/Narratives-for-Natural-Gas-in-a-Decarbonisinf-European-Energy-Market-NG141.pdf

23. BP Statistical Review of World Energy 2018

24. https://power.nridigital.com/future_technology_may19/in_focus_a_change_in_the_wind_for_swansea_tidal

25. https://www.power-technology.com/features/feature99909/

26. https://simecatlantis.com/projects/meygen/

27. https://www.oedigital.com/news/466283-simec-inks-technology-partnership-with-ge?utm_source=AOGDigital-ENews-2019-05-17&utm_medium=email&utm_campaign=OEGDigital-ENews

28. https://report2018.ocean-energy-systems.org/

Thank you to our Members

WOQOD

Qatar Petroleum

QATARGAS

QATAR INSURANCE GROUP

QNB

QATAR ELECTRICITY&WATER CO. Q.S.C.

QAPCO QATAR PETROCHEMICAL COMPANY

North Oil Company

DOLPHIN ENERGY

QATAR AIRWAYS

sasol

QAFCO QATAR FERTILISER COMPANY

QChem QATAR CHEMICAL COMPANY LTD

ConocoPhillips

Marubeni

NAKILAT

GULF HELICOPTERS

Nebras Power

QATAR COOL

The Abdullah Bin Hamad Al-Attiyah
International Foundation for
Energy & Sustainable Development

Barzan Tower
4th Floor
West Bay
Doha
Qatar

Tel: +974 4042 8000
Fax: +974 4042 8099

Website: www.abhafoundation.org
E-mail: info@abhafoundation.org