19 Renewable Energy

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Renewable energy is energy derived directly or indirectly from sunlight, wind, rain, tidal flows and ranges, waves, and thermal energy stored in the oceans, which are naturally replenished over fairly brief periods of time. Geothermal energy is also regarded as renewable because of the extremely large amounts of heat available from the earth's core. Major sources of renewable energy include hydro power, wind power, solar power, geothermal power and bioenergy.

Energy derived from fossil fuels such as coal, oil and gas is not classified as renewable because it typically takes millions of years before carbon from living matter is transformed into these fossilised forms.

Moving rapidly to greater reliance on renewable energy in place of fossil fuels has become critically important because of the urgent need to control global warming by reducing carbon dioxide emissions to the atmosphere.

Earlier times

In the more distant past humans relied strongly on energy sources such as wood, burnable crops and animal fat for cooking, heating and lighting. Provided these sources are maintained, for example new trees are planted or grow naturally to replace those used for fuel, the energy is effectively being supplied on a renewable basis.

Some other forms of renewable energy also have a long history of use. Geothermal heat energy has been used for cooking and heating since prehistoric times[1]. Wind power drove sailing ships on the river Nile as early as 5000 BC and probably earlier than that in other areas. By 200 BC windmills were being used to pump water in China and to grind grain in Persia[2]. Water wheels were being used to grind grain and irrigate fields more than 2000 years ago[3]. Tidal plants, which also used water wheels, were being used to grind flour in the 6th century, but the use of this technology likely goes back to earlier times[4].

Fossil fuels have also been used to a limited extent in some areas since ancient times, but the major reliance was on renewable energy. This all began to change in earnest with the industrial revolution which commenced around 1760. Coal started to be utilised in rapidly increasing quantities for industrial, transport and domestic purposes, followed by large scale recovery and use of oil from around the 1850's, which also resulted in the retrieval of natural gas, initially as a by-product which was often just flared away, but later recovered separately.

Energy use per capita in developed areas of the world is now far higher than it was in pre-industrial days, with most of this additional energy currently being supplied by fossil fuels.

Global overview

The estimated breakdown of total global primary energy consumption (2014 figures) is:

Fossil fuels	78.3%
Renewables	
Traditional biomass	8.9%
Modern renewables	10.3%
Nuclear power	2.5%
	100%

Traditional biomass relates to fuels used mainly for heating and cooking in remote and rural areas of developing countries. *Modern renewables* includes all other sources of renewable energy[5]. In New Zealand approximately 40% of primary energy comes from renewables[6]. The term "primary energy" refers to a renewable or non-renewable energy form found in nature that has not been subjected to any conversion or transformation process, for example, converted into electricity.

While the percent of total global energy coming from renewables is still much lower than from fossil fuels, rapid developments are occurring in some areas. For example, in 2015 global renewable power generation capacity achieved its largest ever increase – an estimated 147 GW. This exceeded the new capacity from all fossil fuels combined, with renewable power now able to supply almost a quarter of the world's electricity requirements[5].

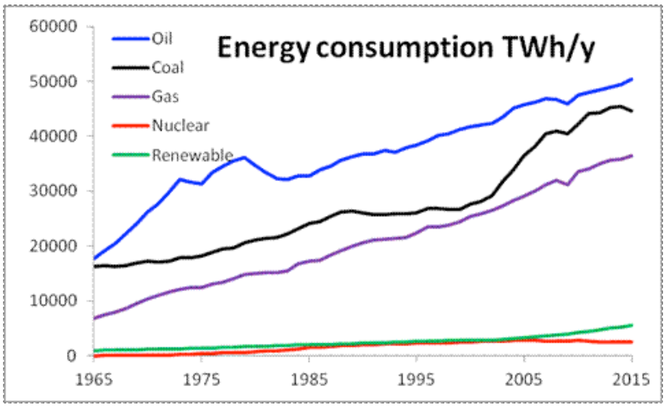

Figure 1: World energy consumption by source 1965-2015. *Attribution: Wikipedia, Creative Commons*

Major sources of renewable energy

Hydro

After the first hydroelectric power scheme came on line in Northumberland, England in 1878[7] this method of generating electricity developed rapidly, with many of the most suitable sites now in use. In 2015, global capacity increased around 3% to 1,064 GW[5]. New Zealand's hydro resources have been strongly developed over the past hundred years, with around 57% of our electricity now generated from this source[8].

Most hydro power comes from constructing large dams and running the water through turbines to extract the energy, but there are also plants that require small dams or no dams, such as the Chief Joseph Dam run-of-river plant on the Columbia River in the US[9] , the Aratiatia station on the Waikato in New Zealand, which has the smallest storage capacity of all the dams on this river and the Manapouri power station in New Zealand where the water runs through a tunnel under a mountain range and is discharged to the sea[10].

Although hydro dams produce very clean and often low-cost energy, there are significant carbon dioxide emissions resulting from cement manufacture and energy inputs used in their construction. They also cause a loss of land through flooding and have effects on water quality and aquatic life. Dams slowly lose their water storage capacity as sediment from upstream settles on the bottom of the reservoir and some dams are already having their generating capacity reduced as climate change affects rainfall patterns in their catchments.

Figure 2: Roxborough hydro dam, Clutha River, showing the eight penstocks, generation capacity 320 MW. *Attribution: Kelisi (CJMoss), Creative Commons*

Tidal power

This is another form of hydro power. Most commonly, water is retained behind a dam or weir when the tide rises and then released back into the sea via a turbine when the tide falls. In some locations, where the tide is causing water to flow through a channel, turbines can just be secured in place and no dam is needed. The power output falls to zero at some parts of the tidal cycle. Recovery of tidal power can have an adverse effect on sea life.

The first large-scale plant, the Rance Tidal Power Station in France, began operating in 1966. Water is stored and released from behind a barrage[11]. By 2011 there were 7 tidal power stations in operation and a number more proposed[12]. These stations were built in areas with a high tidal range, which can be as much as 8m between high and low tide, and even more in some locations. In New Zealand the tidal range is generally only 1-2m.

However, New Zealand does have potential to recover tidal energy in some locations from tidal currents. In 2008 approval was given for the installation of a 1 MW single-turbine experimental. power recovery system in Cook Strait[13]. This body of water offers enormous potential for electricity generation because the high tide on the Pacific Ocean side occurs five hours before it does on the Tasman Sea side, so that the strait behaves like a very large river with currents of up to 2.5 metres per second. The company involved, Neptune Power, says that it would be possible to generate 12 GW of power from this source, which is 50% more than New Zealand's total current demand. It is understood that so far this project has not yet been started.

In 2011 approval was given to construct a major power recovery system that would draw energy from tidal currents in the Kaipara Harbour in Northern New Zealand, with up to 200 turbines on the sea bed giving it the potential to generate around 200 MW of electricity. If it had proceeded it would have been the largest system recovering tidal-generated energy in the world at the time, but the project was abandoned in 2013 by the backers, Crest Energy, reportedly primarily because of concerns about New Zealand's future electricity market[14].

Wave power

Extracting energy from waves is effectively recovering a form of hydro energy mostly resulting from wind, but sometimes also partly from tidal effects. Several methods of recovering wave energy have been developed. One of the challenges in doing this is designing a system that will stand up to occasional severe wave conditions.

The first plant feeding into a national grid was the Sotenäs Wave Power Plant in Sweden, which came on line in late 2015 with a starting capacity of 1 MW[15]. There are now a small number of wave farms (around 7 in 2017) in existence, but this form of technology is still in the early days of its development. One estimate is that around 40% of the world's power demand could be supplied from wave power, if fully exploited[16,17].

Figure 3: Buoy being attached at the Sotenäs wave energy plant. A cable running to a generator on the sea floor allows energy to be captured from waves. *Attribution: Seabased.*

Ocean thermal energy

Ocean thermal energy conversion (OTEC) is a method of capturing energy using the temperature difference between shallow and deep ocean water[18]. The sea surface temperature can exceed 25 °C in tropical latitudes, while 1 km below the surface it can be between 5 °C and 10 °C. This temperature difference can be used to power a heat engine from which energy can be extracted. A temperature difference of 20 °C between the hot and cold water is normally considered necessary to make this form of energy capture viable.

Systems can be either open-cycle, where the engines use the vapour of the sea water itself as the working fluid, or can be closed-cycle using working fluids such as ammonia that have low boiling points.

While this form of energy capture is considered to have major potential, it is still in the early stages of development. According to recent information, there are currently only two fully operational plants in the world. One located on Kume Island in the Okinawa Prefecture of Japan, which started generating power in 2013, consists of two 50 kW units[19]. The other, built by Makai Ocean Engineering on the Kona Coast of the island of Hawaii, which went into service in 2015, can generate up to 105 kW, enough to power about 120 homes[20].

Wind

The move to generating electricity from wind power started in 1887[21]. Use of this energy source is now growing very rapidly. In 2015 a record 63 GW was added globally for a total of around 433 GW, giving an extraordinary annual growth rate of around 17%[22]. The use of wind power is also growing in New Zealand, and this energy source now produces over 5% of our electricity[8].

Most wind turbines now have a similar design – a horizontal axis supporting three upwind rotating blades. Often they are now deployed in groups, known as wind farms and have the advantage of allowing activities such as agriculture to continue around them. There is a strong incentive to place them at locations such as on ridges and in coastal areas which get good wind speeds, or off-shore. They have become very cost-competitive in areas with good winds, and turbines are now available that can generate up to 8 MW.

Wind turbines are not able to generate electricity when the wind velocity is too low, or too high to be handled by the turbine design. Despite their reasonable quietness, there is a history in New Zealand of some people taking a 'nimby' (not in my back yard) approach and fighting hard to stop wind turbines being erected near or in sight of their communities.

Figure 4: A small part of the Gansu Wind Farm in China, the world's largest in 2016
Attribution: Popolon, Creative Commons

Solar photovoltaics

Solar photovoltaic systems convert light energy to electrical energy using the photovoltaic effect[23]. They typically consist of solar panels, each of which contains a number of solar cells which generate electricity with no moving parts and no pollution. The use of solar PV is rising very rapidly on a global scale as advances in technology increase efficiency and reliability while increased scale of manufacturing reduces cost. Global PV generation capacity rose 25% in 2014 to 227 GW[5].

Greater adoption of solar PV in New Zealand is currently being held back by the low prices offered by power companies for power fed back into the grid, typically 7-8 c / kWh, while retail rates charged are around 28 c / kWh (2017 figures). If there is an associated battery storage system then power generated during the day can be stored and used in the evening, but going down this route has a significant cost.

Figure 5: The Solar Settlement, a development of 59 homes in Freiburg, Germany, that produce more electricity than they use. *Attribution: Andrewglaser at English Wikipedia*

Concentrating solar power systems

Concentrating solar power systems (CSP), use mirrors or lenses to concentrate heat derived from solar radiation onto a small area where it can be captured to create steam that drives electrical power generators, or the heat can be used for other purposes. There are a number of different system designs[24]. Total global capacity increased by around 10% in 2015 to nearly 4.8 GW as new plants came on line[5]. Costs are expected to decrease, but there are not a large number of these plants in operation from which to gain a clear perspective.

CSP also has the potential to store energy, for example in molten salt, which means that plants can be designed to generate electricity a few hours before the sun rises and a few hours after it sets. Even without this storage ability CSP plants give much smaller variation in output from short term cloud cover than solar PV[25]. This technology is not well suited to New Zealand because our solar radiation levels are much lower than in some areas closer to the equator.

Solar hot water, building heating and cooking

Solar water heating (SWH) refers to the capture of solar energy to heat water, typically using a collector mounted on the roof of a building. In close-coupled systems natural convection causes the hot water from the collector to flow into the top of a storage tank mounted above it, while the cooler water from the bottom of the storage tank flows back to the collector for re-heating. In pump-circulated systems the water is pumped between the collector and the storage tank, which can be located below the collector.

SWH systems can be designed to provide hot water during most of the year, but in the winter and under certain weather conditions the heating may not be sufficient so it is normal to have an electric or gas booster[26]. While New Zealand is in an excellent position to make use of this form of renewable energy, the uptake to date has not been large compared to some countries.

Using what is termed passive solar design, houses and other buildings can be constructed so as to allow them to be largely reliant on solar heat for warmth during the winter, while at the same time shading out the sun to control over-heating in the summer. Some houses that have been designed this way in New Zealand can be inhabited year-round with essentially no additional heating or cooling required.

Solar energy is also used for cooking using stoves with heat concentrating mirrors, mostly in sunny developing countries.

Geothermal

Geothermal energy is thermal energy stored in the earth from its original formation and also generated in the earth from radioactive decay. In some regions this energy is accessible close to the earth's surface and can result in hot springs and other surface thermal activity. It was used for district heating and public baths in Pompeii in Roman times, and a district heating plan established in 1330 in Chaudes-Aigues in Central France is still operating today[27]. Geothermal district heating systems are also operational in other locations.

The world's first commercial geothermal power plant started producing electricity from the Larderello dry steam field in Italy in 1911[28]. The next commercial plant was built at Wairakei in New Zealand in 1958[29]. Around 24 countries now generate electricity from geothermal energy and the global capacity is about 13.2 GW[5]. This energy source has the great advantage that it can supply a steady flow of energy. New Zealand is currently extracting energy from six geothermal fields which between them are providing around 750 MW or about 16% of the country's electricity[29,8].

Initially geothermal plants used only steam passing through a condensing steam turbine to generate electricity. Some now use the hot brine which results to boil a secondary working fluid, which can then power additional turbines. This is normally referred to as a binary system. It is particularly useful for extracting energy from lower temperature geothermal resources and is currently used in New Zealand at Wairakei and in two small plants at Kawerau[30].

Although geothermal energy is normally regarded as a renewable energy form, in practice the energy that can be extracted from a reservoir tends to fall with time. The reservoir longevity can be improved by re-injecting extracted water and through other steps[31]. Geothermal operations can contaminate waterways because the extracted hot water often contains high levels of sulfur, salt, arsenic and other minerals. This can be largely overcome by pumping the extracted water back into the geothermal reservoir which also has heat conservation benefits. Geothermal plants can also emit significant amounts of carbon dioxide, but atmospheric emissions from geothermal plants are, on average, only about 10% of those from fossil fuel-fired plants, per kWh of electricity generated[32].

Figure 6: The Wairakei geothermal power station. The two main blocks are at the left rear and the binary plant is in front.

Bioenergy

Bioenergy can be split into *biofuels* which are liquid or gaseous fuels derived from organic matter and *solid biomass* which is usually wood products or other organic material burned as a solid to provide heat and power. Both types of bioenergy create carbon dioxide when burned, but if produced in a sustainable manner the carbon dioxide is recycled back into the next crop of plants or trees.

Biofuels are often used for transport, with the two commonest ones being biodiesel and bioethanol. In New Zealand, biodiesel is being produced from tallow derived from meat processing, used cooking oil and rape seed and is used as a blend of up to 20% with ordinary diesel[33]. The first commercial scale biodiesel plant was opened in Wiri by Z Energy in 2015[34]. Bioethanol is produced as a by-product of the dairy industry and is also imported from Brazil where it is made from sugarcane. Blended petrol normally contains up to 10% of bioethanol[33].

It is also possible to make a biogas by anaerobic bacterial digestion of organic feedstocks that can be upgraded to a synthetic natural gas, bio-SNG, with a similar composition of methane. It is normally produced by anaerobic (oxygen free) digestion or thermal gasification of organic matter. The first large scale plant for producing bio-SNG became operational in Gothenburg, Sweden, in

2014. It has capacity to produce gas with an energy output of 20 MW from forestry residues as its feedstock and feeds into the Swedish natural gas grid[35].

In New Zealand, some landfill and sewage treatment plants generate biogas and use it to meet some of their heating and power requirements[36, 37], but there are no large-scale plants feeding bio-SNG into the New Zealand gas grid.

Solid biomass is typically wood, wood chips or charcoal derived from trees, but can also be other combustible crops such as miscanthus, a type of grass that is being increasingly used throughout the world as a bioenergy crop. In New Zealand, some use is made of this energy source. For example, the Kinleith pulp and paper mill at Tokoroa has a cogeneration plant fuelled by wood waste that generates around 40 MW of electricity, most of which is used on-site, plus heat for other on-site purposes[38]. However, currently a very large quantity of biomass from New Zealand forestry operations goes unused.

One negative aspect of generating biofuels from crops is that it requires agricultural land which is then no longer available for food production. This does not apply to fuels generated from forestry waste crop residues or animal waste because the land involved is already being used for timber production or farm-related activities.

Figure 7: A bus fuelled by biodiesel

Energy storage, transfer and demand management

Because some renewable energy comes from “variable” sources that do not produce a steady supply, such as wind, solar and waves, energy storage systems may be needed. Hydro stations provide an excellent way of achieving this. For example, water can be retained behind a dam during the day when solar panels are generating, and then released at night to provide power when the solar panels are inactive. Batteries can be used to store energy, for example in electric vehicles and to provide electricity at night to buildings that have solar panels and are not connected to the national electricity grid. Large batteries are also now starting to be used on power grids, though this is an expensive option.

The non-steady supply of electricity from renewable energy can also be addressed through energy transfer systems. For example, one current proposal is to install a high-tension super grid that links wind farms (and possibly also solar farms) in the Gobi Desert to Korea, Japan, China and possibly also to other countries. Another proposal is to link European grids with solar power stations in North Africa[39]. New Zealand’s two main islands are already electrically linked, but perhaps in the future there could also be a connection to Australia allowing the export of electricity produced from renewable energy.

Smart grids are another way of balancing available supply with demand. The supply network uses digital communications technology to react to changes in usage. Charges per kWh can be changed as demand changes in relation to available supply, and consumers can be kept informed about this. They can then change their demand in response. Also, in some cases the supply network can turn off some consumer devices when demand is high, for example electric hot water heaters. Moving in the smart grid direction is already under way in New Zealand[40].

New Zealand’s position

New Zealand is in a very favourable position to increase its use of renewable energy in place of fossil fuels, with excellent hydro, wind, geothermal and biomass resources, as well as the possibilities of recovering energy from tidal flows and waves. Despite this, we are not developing these options nearly as rapidly as some other countries.

One factor that is holding both New Zealand and many other countries back is low charges for carbon dioxide (CO_2) emissions. Figures for the damage done by these emissions (sometimes referred to as the social cost of carbon) vary, but two recent studies have placed this cost at around NZ $300 a tonne of CO_2 [41, 42]. Meanwhile, under our Emissions Trading Scheme (ETS) in late 2017 charges are still well below even the $25 a tonne figure which was signalled as the cap when this scheme was first legislated in 2008.

Based on recent data for our annual CO_2-e emissions from coal, gas and liquid fuels (almost all from fossil sources) of around 30.7 Gt[8] the total annual damage figure is over 8 billion dollars. This is effectively a massive subsidy for fossil fuel users. To encourage greater uptake of renewable alternative energy sources it needs to be rapidly diminished.

Power

Currently around 80% of our electricity comes from renewable sources which typically receive no government subsidies[43]. This is a very high percentage compared to most countries, but we are also in an excellent position to improve on it. For example, if we followed the German approach[44] and gave electricity generated from renewable sources priority access to the grid over electricity generated from fossil fuels then we would rapidly move to close to 100% renewable generation, with our fossil fuel-fired stations retired to backup status. Around 50 countries have now followed the German example and given electricity generated from renewables priority access to their grid systems[45]. In some cases, there are also feed-in tariffs (FITs) which provide a cost-based price for electricity, making it economically possible for energy from different sources to feed into the grid, and hence for different technologies to be developed.

In New Zealand we have been moving in the opposite direction. People with solar panels are typically being paid low rates for any power they feed into the grid. A feed-in tariff system would likely see a rapid increase in solar power generation and use, and would probably also encourage wind power and other options.

Heat

Although coal is a dirty fossil fuel in terms of its CO_2 emission in relation to heat energy supplied, it is still in major use in New Zealand, for example by the dairy industry, some hospitals and schools, and for home heating. Meanwhile our forestry industry produces large quantities of wood waste that go unused. Estimates are that there is a sufficient supply of this material to allow many of these coal users to convert to wood chips or charcoal, though in many instances this would require some equipment changes.

Transport

Around 20% of our greenhouse gas emissions currently come from transport[46]. The government has recently introduced some incentives to promote use of electric vehicles[47] but in this respect, we still lag well behind regions such as California, which offers rebates of up to $US5000 off the purchase of zero emissions or light-duty plug-in hybrids[48]. We could also reduce emissions by introducing standards for imported vehicles, for example requiring a certain percentage to be hybrid and electric vehicles.

Better public transport systems in our cities, powered mainly by renewable fuels, also has the potential to make a significant reduction in our emissions, while at the same time allowing many people to get to work faster and at less cost. For example, on a per capita basis, trains in Sydney are used around nine times more regularly than in Auckland, because the Sydney system serves a far greater portion of its suburbs and gives excellent access to the central city. Electric buses are now also a possibility for New Zealand.

Moving to greater reliance on electrically-powered inter-city trains, and re-establishing regular passenger and goods train connections between major New Zealand cities would result in a significant reduction in emissions.

In Conclusion

On an international basis, although still small compared to the energy coming from fossil fuels, the amount of energy consumed that is derived from renewable resources is growing extremely rapidly. New Zealand already makes strong use of renewably sourced energy, but we could do a lot better if we took the necessary steps. Besides reducing our CO_2 emissions, moving to greater use of renewable energy would create new business opportunities and jobs, while at the same time start to reduce the sum of around $7 billion we spend annually on importing fossil fuels.

Notes:
Foreign values converted to NZ dollars at trading rates for mid 2016.

Abbreviations:
CO_2 - carbon dioxide
CO_2-e – for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP).
ETS - emissions trading scheme

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