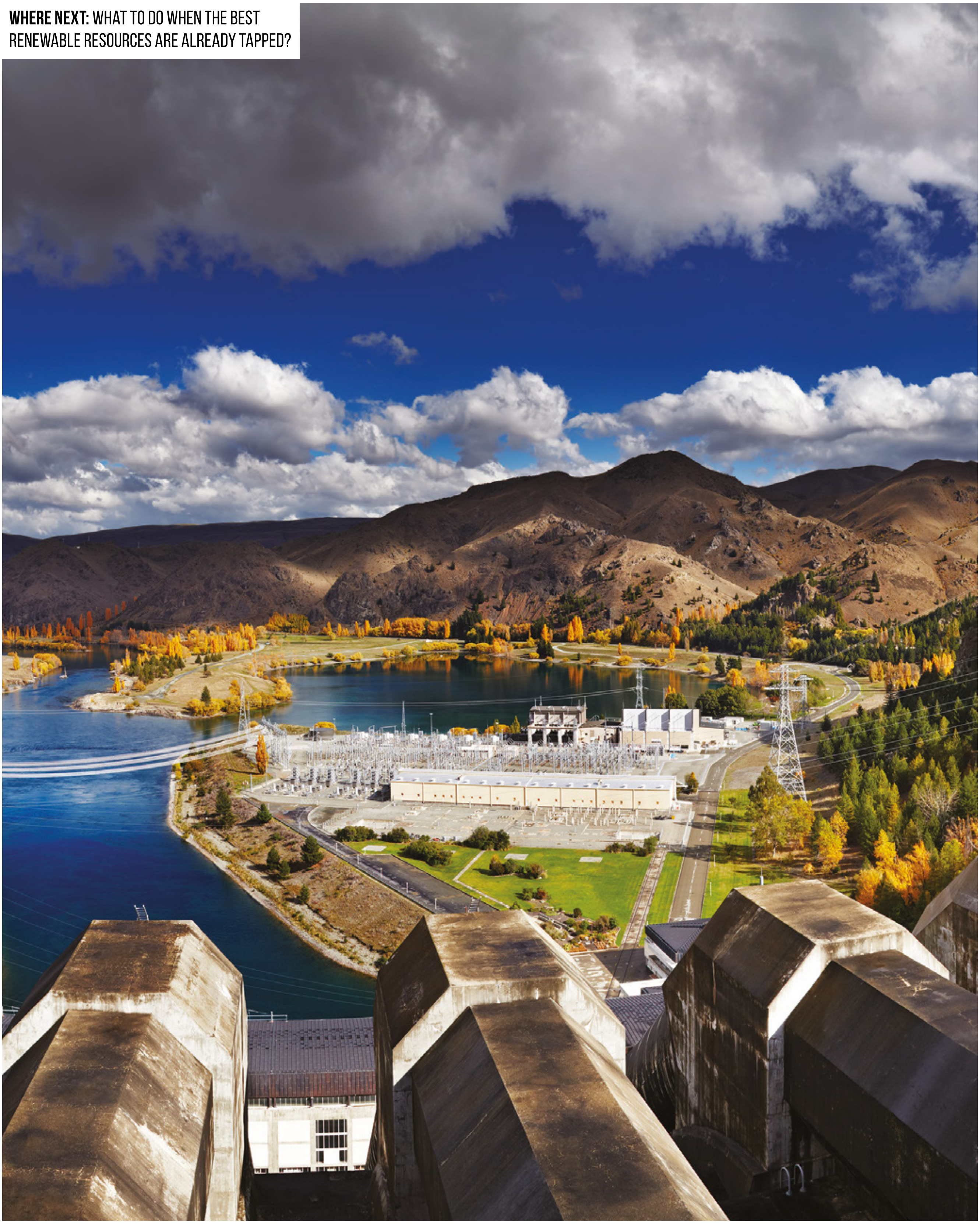
WHERE NEXT: WHAT TO DO WHEN THE BEST RENEWABLE RESOURCES ARE ALREADY TAPPED?



Choice Cuts

With the race for renewables gathering pace, New Zealand has lessons to share for those planning to go greener

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RENEWABLE electricity targets feature prominently in many countries' emissions reductions strategies, but are all renewables the panacea that they are often made out to be? As countries plan and evaluate renewable generation to transition to lower carbon economies, various types of energy systems analysis, such as energy return on energy invested, should be used to provide additional insights and explore the many tradeoffs involved. With growing electricity demand and the widespread electrification of passenger vehicles, these types of analyses should be important tools to assist policymakers and energy companies as they plan and evaluate renewable electricity generation systems of the future.

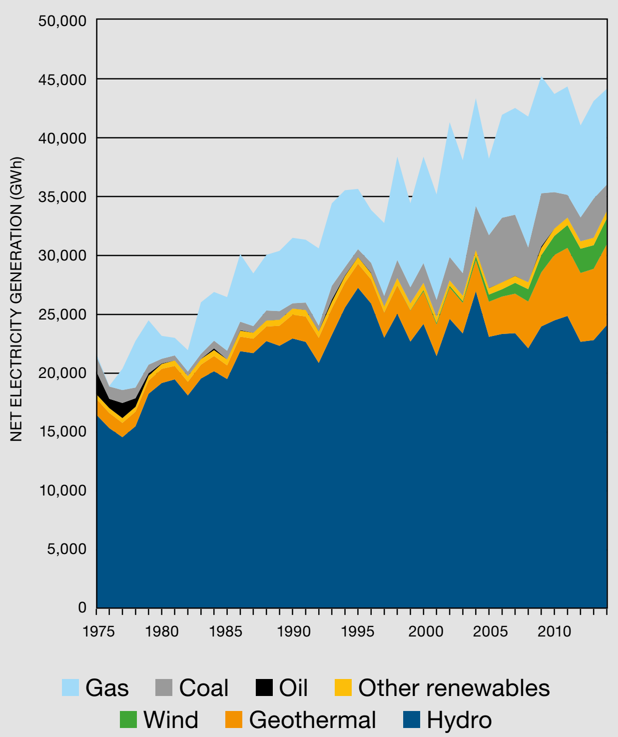
NEW ZEALAND'S ELECTRICITY SECTOR ILLUSTRATES HOW HIGH LEVELS OF RENEWABLE ELECTRICITY CAN BE ACHIEVED, ALTHOUGH THE RIGHT MIX IS NEEDED TO ENSURE RELIABLE SUPPLY AND LONG-TERM SUSTAINABILITY

Now that the Paris Agreement on climate change has been reached, many countries are developing sector-specific plans and policies to achieve their emissions reduction commitments. For many countries, renewable electricity will play an important role and many have already set targets and started along this path. However, there are many other factors to consider with renewable electricity, such as other environmental impacts, economics, grid management, reliability, and scale. As the proportion of renewable electricity in a national electricity system increases, these other considerations become increasingly important and complex. New Zealand's electricity sector is an interesting example that illustrates how high levels of renewable electricity can be achieved, although the right mix is needed to ensure reliable supply and long-term sustainability.

NEW ZEALAND ELECTRICITY SECTOR

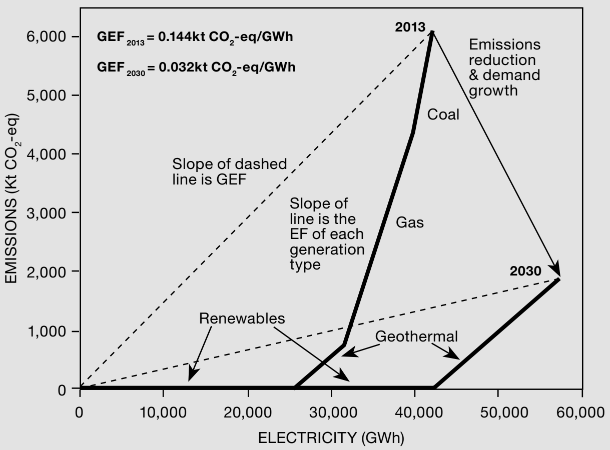
For many decades New Zealand has relied heavily on large hydro schemes to generate 50–80% of total electricity demand (*see Figure 1*). However, one of the weaknesses of this approach is the limited storage capacity that exists in its major hydro schemes. With about eight weeks of storage in the hydro lakes, electricity supply is vulnerable during years of low rainfall. During these dry years (eg 1992, 2001, 2008) additional thermal generation, mainly from natural gas, has been used to make up the shortfall.

FIGURE 1: NEW ZEALAND ELECTRICITY GENERATION 1975–2014



Back in the mid 1970s renewable electricity was 90% of New Zealand's generation but this slowly dropped, reaching a low of 65% in 2008 before rising to 80% in 2014. For the past ten years, successive governments have had the goal of reaching 90% renewable electricity by 2025; however with most of the good hydro resource used, the growth has needed to come from

FIGURE 2: A GENERATION MIX FOR A GIVEN YEAR CAN BE SHOWN USING SUPPLY COMPOSITE CURVES. THE SUPPLY CURVE IS CONSTRUCTED BY PLOTTING CUMULATIVELY THE QUANTITY OF ELECTRICITY GENERATED AGAINST TOTAL EMISSIONS FROM EACH GENERATION SOURCE. THE SLOPE OF EACH SEGMENT IS THE EMISSIONS FACTOR FOR THAT GENERATION TYPE. THE SLOPE OF THE LINE FROM THE ORIGIN TO THE END OF THE CURVE (DASHED LINE) IS THE GRID EMISSIONS FACTOR, GEF



other forms of renewable electricity, with most from geothermal and wind.

New Zealand has a long history of using geothermal steam with the first wet steam plant in the world being constructed in 1958 at Wairakei just north of Taupo. Growth in geothermal was non existent or slow until about 2000 when it had a resurgence. Between 2005 and 2013 geothermal generation more than doubled and it currently contributes around 15% of total generation. Geothermal is now considered the lowest-cost base load generation, and further plants are planned.

Dry and flash steam-type geothermal plants with condensing steam turbines are common, especially for large plants with high temperature/high enthalpy resources. Binary or organic Rankine cycle plants are also common for smaller type plants or low temperature/low enthalpy. Recently, a hybrid or combined-cycle approach has been used where the binary plant is integrated as the condenser for the steam turbine.

WITH MOST OF THE ATTRACTIVE AND ACCEPTABLE HYDRO RESOURCES HAVING ALREADY BEEN EXPLOITED, THE BULK OF FUTURE GROWTH IS EXPECTED TO COME FROM GEOTHERMAL AND WIND

Interestingly, one of the seldom-discussed facts about geothermal (and this tends to come as a surprise to many) is that greenhouse gas emissions are associated with extracting and using geothermal fluids. These emissions are due to non-condensable gases, also called fugitive emissions, which are also brought up with the geothermal fluid. The gases are mainly carbon dioxide and in New Zealand are included as part of the Emissions Trading Scheme (ETS). Also, the quantity can vary substantially depending on the geology of the field, and emissions factors (EFs) can range from around 0.03–0.70 kg CO_2-eq/kWh. By comparison, a typical high efficiency combined cycle natural gas turbine (CCGT) has an emissions factor of about 0.35 kg CO_2-eq/kWh (open cycle 0.58 kg CO_2-eq/kWh). In New Zealand the combined average geothermal emissions factor is around 0.12 kg CO_2-eq/kWh.

With most of the attractive and acceptable hydro resources having already been exploited, the bulk of future growth is expected to come from geothermal and wind (*see Figure 2*). Nuclear energy is not an option based exclusively on political and national identity issues. Many New Zealanders take great pride in the nation's nuclear-free stance which began in the mid 1980s. Photovoltaics are likely to play only a small part because New Zealand has a well-developed transmission and distribution system, which allows lower-cost wind farms to integrate well, making widespread use of photovoltaics uneconomical. In the short to medium term there is unlikely to be any direct government intervention to promote its uptake, rather leaving it to the market to control rate and scale. However, in some parts of the country photovoltaics will be economically viable as part of distributed generation schemes.

EMISSION REDUCTION TARGETS

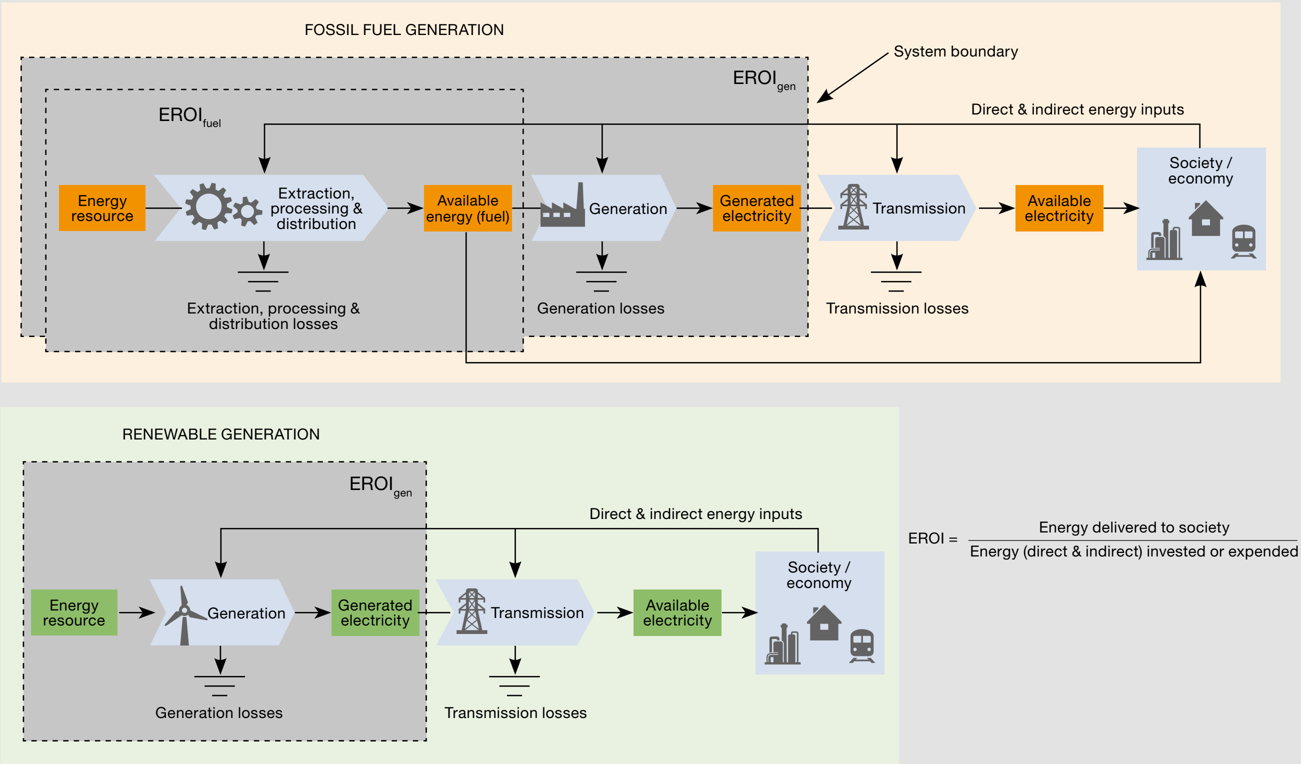
Under the Paris Agreement New Zealand committed to an emissions reduction target of 30% of 2005 levels by 2030. The ETS is

TABLE 1: GRID EMISSIONS FACTORS FOR SELECTED COUNTRIES

	GEF KG CO_2-EQ/KWH (2008)	% RENEWABLES (2011)	% NUCLEAR (2011)
New Zealand	0.144[a]	80[a]	0.0
Australia	0.802[a]	15.0[a]	0.0
Canada	0.181	64.5	14.0
Sweden	0.040	56.2	38.4
Germany	0.441	22.1	17.8
China	0.745	17.8	1.9
Russia	0.326	16.7	16.2
US	0.535	12.7	19.3
France	0.083	12.5	79.0
Japan	0.436	11.1	14.7
UK	0.487	10.6	19.1
Malaysia	0.656	6.5	0.0
South Africa	0.835	1.0	5.3

[a] *2013 data*

FIGURE 3: SCHEMATIC OF EROI CALCULATION WITH SYSTEM BOUNDARIES FOR $EROI_{FUEL}$ AND $EROI_{GEN}$ INDICATED. EXAMPLE RE $EROI_{GEN}$ IS ALSO SHOWN. PROCESSES SUCH AS EXTRACTION, GENERATION ETC ARE SHOWN WITHIN A BLUE ARROW WHILE A STOCK OF ENERGY IS SHOWN IN AN ORANGE OR GREEN BOX.



the main policy instrument designed to achieve that reduction, although its effectiveness is currently under review and further changes are likely. The electricity sector has limited emissions reduction potential due to the high levels of existing renewable energy and the relatively low (but not inconsequential) emissions factor from geothermal.

THE SCOPE FOR EMISSIONS REDUCTION FROM THE ELECTRICITY SECTOR IS DEPENDENT ON TWO MAIN FACTORS; THE INITIAL GRID EMISSIONS FACTOR (GEF), AND THE POTENTIAL FOR RENEWABLE ELECTRICITY

The scope for emissions reduction from the electricity sector is dependent on two main factors; the initial grid emissions factor (GEF), and the potential for renewable electricity. The grid emissions factor is simply how much carbon is emitted per unit of electricity generated for the entire grid taken as a whole and is typically expressed as the mass of carbon dioxide equivalent emitted per unit of electricity generated (eg kg CO_2-eq/kWh).

Internationally there is a huge range of grid emissions factors depending on the amount of renewables and nuclear generation used (*see Table 1*).

Australia, for example, has a large potential for renewable electricity, especially in the form of solar and wind. However, in 2014 Australia generated only 15% from renewables, 60% from coal (down from 79% a decade earlier) with the remainder from natural gas. Even with generous federal and state government incentives for residential photovoltaics in the form of rebates and generous feed-in tariffs, and strong growth in other renewables, the overall grid emissions factor is still high at 0.802 kg CO_2-eq/kWh. For Australia it would be possible to easily meet its Paris Agreement commitments entirely by changes in the generation mix. Over half the commitment could be met if 60% of the coal generation were replaced with high efficiency CCGTs without adding any further renewables.

New Zealand, on the other hand, has limited scope for large-scale emissions reductions from the electricity sector because of the already-high levels of renewables. Only about 20% of the country's Paris Agreement commitment would be met if it reached 100% renewable electricity by 2030 (which is unlikely). The government is forecasting that around 12–15% of the target would be met from the electricity sector and the renewable electricity share of total generation to peak at around 90%. Around half of New Zealand's total emissions come from the agriculture sector (with livestock emissions making up the bulk for this sector). There is limited scope for major reductions in this sector and it is the cornerstone of the economy. Significant reductions will be required from other sectors such as transportation, industrial process heat, and forestry.

Countries with low grid emissions factors will have less scope for emissions reductions from national renewable electricity targets and may also need to examine electricity use *per capita* (eg efficiency gains) to reduce emissions from the electricity sector.

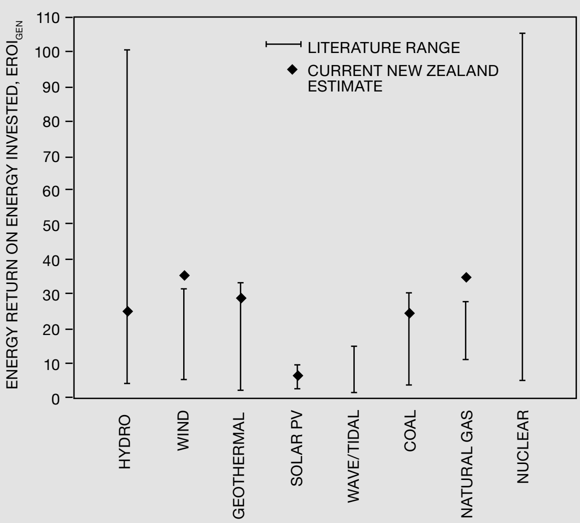
ENERGY RETURN ON ENERGY INVESTED

Energy return on energy invested (EROI) is an energy systems analysis technique that can simply be defined as the ratio of the amount of 'useful' energy extracted, produced or generated to the amount of energy 'invested' or 'expended' to extract, produce, and generate the useful energy[1] (*see Figure 3*). Many renewable electricity technologies, such as wind and solar, do not require extraction, processing and distribution in the way fossil fuels do. Direct inputs include fuel and electricity, while indirect inputs include embedded energy in construction materials. Separate EROI values can be defined for different energy types or carriers, such as for a fuel, $EROI_{fuel}$, or electricity, $EROI_{gen}$.

While it may sound like a relatively simple concept, the values quoted in the literature vary greatly due to different quality resources and methodological differences (*see Figure 4*). Renewable resources can vary greatly in their quality, such as average wind speed or solar irradiation, which can have a major influence on the EROI value. The use of different or ill-defined system boundaries and definitions of what constitutes energy 'invested' also contribute to the large differences found, especially for the same energy type or resource. Sometimes the disparity in values is simply due to the story the author is trying to tell! A good example is the range of EROI values reported for nuclear power – values range from less than 1 (ie more energy is invested than it produces) to over 100!

DOWN UNDER(ACHIEVING): AUSTRALIA HAS A LARGE POTENTIAL FOR WIND AND SOLAR BUT ONLY GENERATED 15% FROM RENEWABLES

FIGURE 4: $EROI_{GEN}$ VALUES AND RANGES FOR VARIOUS ELECTRICITY GENERATION TYPES AND RESOURCES



RENEWABLE ELECTRICITY WILL CONTINUE TO GROW IN IMPORTANCE AS COUNTRIES GREEN THEIR ENERGY SYSTEMS BUT THE WIDER IMPLICATIONS OF HIGHER LEVELS ALSO NEEDS TO BE EXAMINED

Despite the uncertainty around exact EROI values the merit of EROI studies is perhaps best illustrated by looking at corn ethanol. There are numerous studies that calculate EROI for corn ethanol and there is considerable debate as to whether it actually yields a net positive energy gain[2]. The range of published values from the major studies is relatively small, from 0.8–1.5, whereas EROI for sugar cane ethanol is estimated to be from 8–30. But if you step back and look at the big picture you quickly realise that for all of the studies the amount of net energy gained from corn ethanol is very marginal, which begs the question – is it worth the effort in the first place? Are there better 'energy investments' that could be made?

Another factor that is not often discussed in the context of renewable electricity is that the quality of renewable resources, and therefore EROI, tends to decrease as more renewable electricity is added because the high-quality resources (usually the most economic ones) are exploited first. EROI values tend to decrease over time as more generation is added due to the best sites being utilised first (ie highest average wind speed) but can also increase (at least in the short term) as the technology to harvest and exploit these resources improves, as in the case of photovoltaics. It must also be noted there is consensus that EROI values for fossil fuels are declining globally because they are generally becoming more difficult to extract and their EROIs have fallen and will continue to fall.

The implication is that the overall $EROI_{gen}$ for most countries' electricity sector will decrease over time as more renewable electricty is added. That is to say that more energy will need to be invested to generate each unit of electricity. For the New Zealand electricity sector, we estimated the overall $EROI_{gen}$ was 34 in 2011, down from 36 in 1990, and is expected to continue a gradual decline as more renewable electricity is added[3]. The only other $EROI_{gen}$ estimate for an entire electricity sector has been for the UK, which was estimated to be 5.4[4].

CARBON CAPTURE AND STORAGE

For many countries carbon capture and storage (CCS) is seen as a central part of the future low-carbon generation mix. But even though billions of dollars have been spent on research and development, little work has been published on the EROI implications of CCS.

We estimate that for post-combustion carbon capture from coal (based on amine separation and 90% carbon removal) energy invested would increase between 35–85%. The $EROI_{gen}$ for a coal-fired station with an $EROI_{fuel}$ of 30 and $EROI_{gen}$ of 9.34 (based on 33% thermal efficiency) would decrease to as low as 5.

The largest factor influencing EROI reduction is the energy penalty due to CCS, which can be either burning more fuel or reducing net electricity supplied to the grid. Much more work is needed to carefully weigh the wider energy implications and carbon reduction benefits of CCS before it is extensively adopted.

FINAL THOUGHTS

Renewable electricity will continue to grow in importance as countries green their energy systems but the wider implications of higher levels also needs to be examined so that the various tradeoffs are understood. Energy systems analysis tools, such as EROI are important to inform the debate about which renewable electricity methods should be used, how much and where, and the overall effect on both the economy and the environment. ■

REFERENCES

1. Hall, CAS, Cleveland, CJ, and Kaufmann, RK, *Energy and Resource Quality: The Ecology of the Economic Process*, 1986.
2. Murphy, DJ, Hall, CAS, Powers, B, "New Perspectives on the Energy Return on (Energy) Investment (EROI) of Corn Ethanol", *Environment, Development and Sustainability*, 2011, 13(1): p179-202.
3. Walmsley, MRW, Walmsley, TG, Atkins, MJ, Kamp, PJJ, and Neale, JR, "Minimising Carbon Emissions and Energy Expended for Electricity Generation in New Zealand through to 2050", *Applied Energy*, 2014, 135: p656-665.
4. Raugei, M, and Leccisi E, "A Comprehensive Assessment of the Energy Performance of the Full Range of Electricity Generation Technologies Deployed in the United Kingdom", *Energy Policy*, 90: p46-59.