Carbon Emissions Pinch Analysis (CEPA) For Emissions Reduction in the New Zealand Electricity Sector

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Carbon Emissions Pinch Analysis (CEPA) is a recent extension of traditional thermal and mass pinch analysis to the area of emissions targeting and planning on a macro-scale (i.e. economy wide). This paper presents a carbon pinch analysis of the New Zealand electricity industry and illustrates some of the issues with realising meaningful emissions reductions. The current large proportion of renewable generation sources (~67% in 2007) complicates wholesale emissions reductions. The biggest growth in renewable generation is expected to come from geothermal energy followed by wind and hydro. A four fold increase in geothermal generation capacity is needed in addition to large amounts of new wind generation to reduce emissions to around 1990 levels and also meet projected demand. The expected expansion of geothermal generation in New Zealand raises issues of GHG emissions from the geothermal fields. The emissions factors between fields can vary by almost two orders of magnitude making predictions of total emissions highly site specific.

Introduction

As a major objective of the 2007 National Energy Strategy the New Zealand Government set a 90% renewable energy target to be met by the electricity sector by 2025. To help achieve this new base load, the Government legislated against any new thermal generation from fossil fuels for a 10 year interval from 2008 by making an amendment to the Electricity Act 1992. New Zealand already has a high proportion of renewable generation (67% in 2007) mainly due to the large amount of hydro generation (55%). However, there is a lack of hydro storage capacity, which leads to security of supply concerns in dry years. In 2008 there was a severe nation wide drought with very low hydro lake levels. The renewables target therefore became a topical issue, especially during the 2008 national election. Despite a change of government and repeal of the moratorium on new fossil fuel electricity generation, the 90% renewables target is seen as a key strategy to reduce greenhouse gas (GHG) emissions. Although a high renewables target is an aspiration, detailed analysis of the actual effect on the generation mix, emissions levels, economic costs to the country, and security of supply impacts have not yet been thoroughly presented or debated in the public arena. Considering that almost all of the "easy" hydro generation capacity has already been fully utilised, a thorough analysis as to possible generation scenarios is needed, and it seems likely that geothermal generation will provide most of the extra "renewable" generation needed to reach the target and to meet increased electricity demand. However despite the view that geothermal generation is renewable, it can have a significant "carbon footprint" depending on the geology and associated geothermal systems of the area, which needs to be taken account of in any analysis. This paper will use a novel method known as Carbon Emissions Pinch Analysis to examine the implications of the renewables target on the generation mix and emissions levels in 2025. Specific focus is given to the potential growth of geothermal generation and the sector emissions.

Carbon Emissions Pinch Analysis

Carbon Emissions Pinch Analysis (CEPA) was first developed by Tan & Foo and co-workers (Tan & Foo, 2007; Lee et al., 2008; Foo et al., 2008). It is based on the application of traditional pinch analysis techniques commonly utilised as a process integration tool by chemical and process engineers. Emissions targeting was originally confined to total site analysis, which focused on optimisation and emissions reduction of industrial sites (Linnhoff & Dhole, 1993). CEPA extends the pinch analysis technique from industrial sites to broader macro-scale applications and can be readily applied to the electricity generation sector, although it can also be applied to primary energy usage. CEPA can also be used to optimise the generation mix based on demand/emissions targeting including economic constraints, such as the cost of generation, carbon prices, and the like. Such analysis is beyond the scope of this paper, however it is anticipated that economic analysis will be conducted by the authors in the near future. A detailed outline of the methodology is beyond the scope of this paper and the reader is referred to Tan & Foo (2007) and Foo et al., (2008).

New Zealand Electricity Sector

The electricity sector in New Zealand has experienced consistent growth in demand since 1990 and a corresponding increase in net emissions. There was also significant restructuring of the electricity industry, which has had a profound affect on investment behaviour of both generators and distributors (Barton, 2004). Fig. 1 shows the increase in generated electricity from 1990 to 2007, the projected demand for the next few decades, and the historic Grid Emissions Factor (GEF). The Grid Emissions Factor is simply the average total emissions factor or specific emissions for the entire system. The increase in demand from 1990 to 2007 averaged 1.77% per year (dashed line) and there has been an increasing trend to higher GEF over the same period, which demonstrates that increased demand has been satisfied predominantly by increased fossil-fuel based generation. The GEF is sensitive to the generation mix and also the level of the hydro storage lakes, which is illustrated by the sharp jump in the GEF in 1992 due to a "dry year' and low hydro-lake levels. The large dashed line is an adjusted forecast based on New Zealand Electricity Commission (NZEC) data (NZEC, 2008) and projects that demand will increase on average 1.32% per year over the next two decades. The dotted lines are the high and low Electricity Commission forecasts and correspond to a 1.67% and 0.93% increase per year respectively.

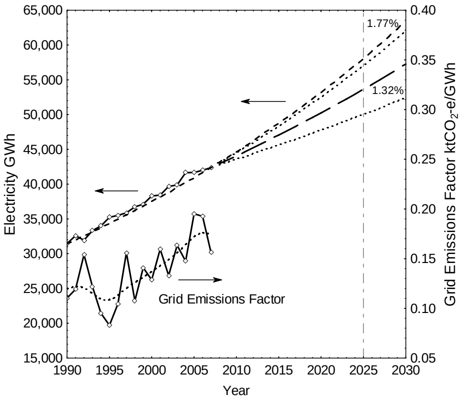

Figure 1. Historical and forecast demand and Grid Emissions Factors for New Zealand 1990 – 2007.

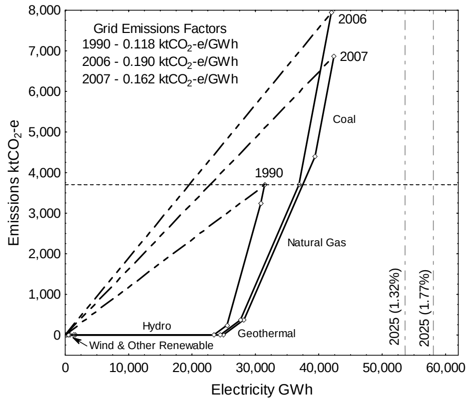

Figure 2. Generation mixes for 1990, 2006, 2007.

The demand and supply composite curves for the years 1990, 2006, and 2007 are illustrated in Fig. 2 along with two demand increase forecasts: the historic average since 1990 (1.77%) and the NZEC forecast (1.32%). The difference between the two forecasts in 2025 is around 4,500 GWh. The additional installed generation capacity needed between the two forecasts is around 640 MW, which represents a significant investment (over NZ$1.5 billion) and more than adequately justifies considerable additional investment in efficiency measures and demand-side management. The demand composite curve has combined the demand from the various sectors so that only an aggregated demand curve is shown. Emissions factors are calculated based on data from the Ministry of Economic Development (MED) Energy Data Set (MED, 2008). The generation mix from 1990 to 2006 and 2007 has changed significantly with the bulk of the increased generation coming from geothermal (which has doubled since 1990), and the remainder from a large increase in generation from natural gas and coal. Only a minor increase in generation from hydro or wind has occurred since 1990. It should also be pointed out that the emissions factors for coal and natural gas have improved since 1990 as a result of efficiency increases due to the increased use of combine cycle gas turbines.

Emissions & Renewable Generation Targets

A possible generation mix that both achieves the 90% renewables target in 2025 while also simultaneously meeting increased demand is shown in the Fig. 3. The additional renewables include wind and hydro as well as geothermal. The amount of fossil-fuel based thermal generation is fixed at 10% of the total demand and it is assumed in the analysis that this thermal generation would come from natural gas at the 2007 emissions factor. It has been assumed that the demand growth rate will be 1.5% per year from 2007 until 2025. This estimate of 1.5% is roughly half way between the historic growth rate (1.77%) and the NZEC forecast (1.32%). At this growth rate the demand in 2025 is equal to 55,396 GWh, illustrated by the vertical dashed line in Fig. 3.

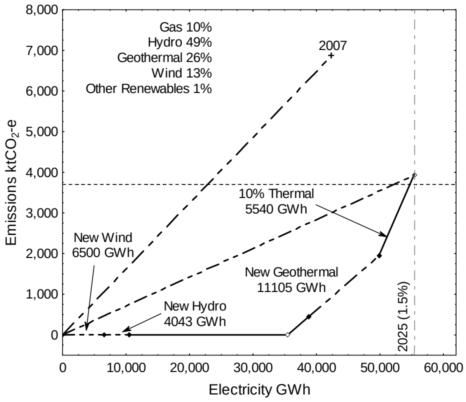

Figure 3. 90% Renewables target 2025 generation mix.

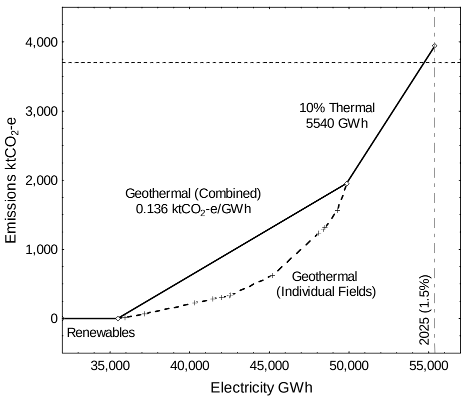

Figure 4. Geothermal section breakdown by individual fields.

Achieving the 90% renewable target based on the generation mix presented in Fig. 3 requires significant amounts of existing natural gas and coal generation capacity will be reduced or eliminated. Coal fired generation would need to be completely eliminated and gas generation would need to be reduced by around 50% from 11,200 to 5,540 GWh. If the amount of available gas generation is converted to installed capacity at a 90% load factor only two 350 MW gas turbines would be permitted. The potential implications on security of supply (especially in dry years), the increase in the cost of electricity across all sectors, and transmission issues following from a 90% renewables scenario all need to be more thoroughly debated in the public and political arena. To complicate matters there is also a projected domestic natural gas supply shortfall projected to occur in around 2013 without more discoveries.

Geothermal Generation

New Zealand has already utilised a large amount of renewable energy mainly in the form of hydro. It is improbable that the additional renewables will come from wind and hydro alone and therefore increased geothermal electricity generation also needs to be considered. Furthermore, there is also an upper limit to the amount of wind generation that the transmission system can adequately handle, and the accepted estimate of the feasible limit is around 20% (Energy Link, 2005). It should be pointed out that as the amount of wind generation increases so does the amount of spinning reserve required to ensure stable supply. Currently there is a slight surplus of spinning reserve, however as more wind is added, additional spinning reserve will need to be available.

It is important to note that although geothermal generation is often referred to as renewable generation it does have greenhouse gas emissions and the amount can vary considerably depending on the geology and fluid circulation within the geothermal field. Similarly if a lifecycle approach is taken, all of the renewable generation sources have emissions factors due to construction, materials, maintenance, and the like. Lifecycle emission factors reported in the literature vary considerably depending of the technology and location, however, despite the variation, the life cycle estimates for wind and hydro are typically at least one to two orders of magnitude lower than geothermal and fossil-fuel based thermal generation and therefore the life cycle emissions have been ignored in this analysis (Spadaro et al., 2000).

The increase in electricity generation from geothermal sources to reach the target represents a four fold increase over 2007 levels. Predicting the emissions from the additional geothermal generation is a challenge as the emissions factors for each geothermal field can vary by almost two orders of magnitude. Furthermore, there are seasonal variations depending on the local geological and meteorological conditions. The development potential of each field is also dependant on the geothermal fluid temperatures and pressures, as well as re-injection requirements. Fig. 4 highlights the geothermal section of the supply composite curve from Fig. 3 and plots the breakdown of that section of the curve with the individual fields using the data from Table 1. Fig. 5 illustrates a map of the major geothermal fields in NZ which are nearly all located in the Central North Island in the Taupo Volcanic Zone. There is already nationally significant installed generation capacity in this area, however there remains scope for a substantial increase in the amount of possible generation. Table 1 lists the potential installed capacity, electricity production, and the emissions factor for the geothermal fields shown in Fig. 5. The highest emissions factor is 0.69 ktCO_2-e/GWh from the Ngawha field located in the far north of the North Island, which is almost 80% higher than the emissions factor for natural gas. This is an extreme case, however it highlights the need for detailed information on the emissions factors for each site. The lowest emissions factor is 0.043 ktCO_2-e/GWh for the Mokai field. The two fields with the greatest potential are Kawerau and Wairakei, each having different emissions factors.

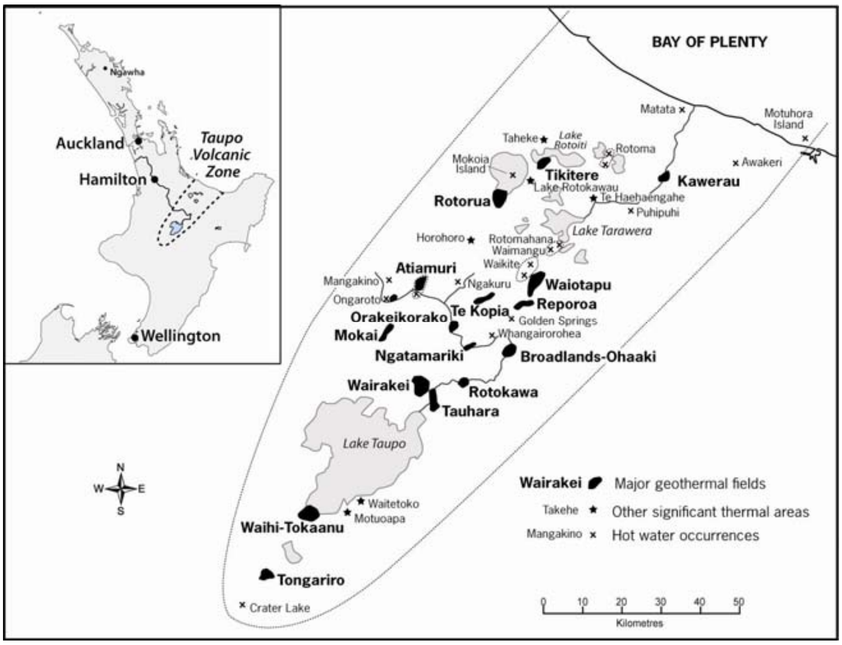

Figure 5. Major geothermal fields in New Zealand.

Table 1 Potential generation and emissions factors for geothermal fields in NZ.

Geothermal Field	2025 Potential Installed Capacity* MW	2025 Electricity Production* GWh	Emissions Factor* $ktCO_2$-e/GWh
Kawerau	372	2,928	0.21†
Wairakei	331	3,164	0.05
Rotokawa	331	2,611	0.11†
Mokai	152	1,204	0.043†
Ngatamariki	140	1,104	0.05‡
Ohaaki	104	820	0.30
Ngawha	73	571	0.69
Tauhara	70	550	0.05‡
Mangakino	65	512	0.05‡
Pohipi	55	482	0.03
Rotoma	35	280	0.21‡
Tikitere-Taheke	10	80	0.21‡
Horohoro	9	70	0.05‡
Total	**1,747**	**14,376**	

* MED estimate unless otherwise indicated (MED, 2004)

† Supplied by utility company ‡ Estimated Emissions Factor based on location

Conclusions

CEPA is a useful technique for macro-level emissions planning and targeting. There have been substantial increases in the emissions from the NZ electricity sector from 1990 to 2007 although the levels are still relatively low by comparison with most other countries due to the high level of renewables. A 90% renewable generation target by 2025 is achievable if coal fired generation is completely eliminated, gas-fired generation is cut in half, the amount of geothermal generation is quadrupled, and significant amounts of additional wind and hydro generation capacity are installed. The merits of these developments need to be more fully explored. Emissions from geothermal generation can vary by almost two orders of magnitude between fields and therefore care needs to be taken when predicting emissions from geothermal generation.

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