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Carbon Emissions Pinch Analysis (CEPA) for emissions reduction in the New Zealand electricity sector

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ABSTRACT

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 an extension to the current methodology that accounts for increased demand and a carbon pinch analysis of the New Zealand electricity industry while illustrating some of the issues with realising meaningful emissions reductions. The current large proportion of renewable generation (67% in 2007) complicates extensive reduction of carbon emissions from electricity generation. The largest growth in renewable generation is expected to come from geothermal generation 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.

1. Introduction

As a major objective of the 2007 National Energy Strategy [1] the New Zealand Government set a 90% renewable energy target for the electricity sector to meet by 2025. To help achieve this new base load, the Government legislated against any new fossil-fuel based thermal generation 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 [2]. In 1992 and 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 accounted for 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.

2. Carbon Emissions Pinch Analysis

Carbon Emissions Pinch Analysis (CEPA) was first developed by Tan, Foo and co-workers [3–5] and was based on the application of traditional pinch analysis techniques commonly utilised as a process integration tool by chemical and process engineers. Pinch analysis was developed in the 1970s and has been successfully applied to a number of areas including heat and mass integration to minimise energy and water usage. A detailed explanation of the pinch analysis methodology for heat integration can be found in Kemp [6] and Smith [7] and for mass integration in El-Halwagi [8] and Mann and Liu [9]. Emissions targeting was originally confined to total site analysis, which focused on optimisation and emissions reduction of industrial sites [10]. CEPA extends the pinch analysis technique from industrial sites to broader macro-scale applications and can be readily applied to the electricity generation

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sector, although it can also be applied to primary energy usage. The only published case studies have been focused on the Irish electricity sector [11–13]. Sectoral and regional studies can also be conducted for emissions planning and reduction. CEPA can also be used to optimise the generation mix based on demand/emissions targeting (as above) 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 further analysis, including economic analysis will be conducted in the future. The method has also been extended to include Carbon Capture and Storage (CCS) and the additional required generation that needs to be provided due to the substantial energy penalties incurred by the use of CCS [14]. A review of the methodological developments to date has recently been presented [15].

A brief explanation of the technique is presented here; however for a detailed explanation of the methodology for constructing composite curves, see Tan and Foo [3] and Foo et al. [5]. The basis of the technique is constructing what are called composite curves of both the demand and supply. These composite curves are then manipulated and modified depending on the desired objectives. Example demand and supply composite curves are illustrated on the left in Fig. 1 for the data given in Table 1. The supply composite curve is constructed (shown as the solid black line in Fig. 1) by plotting cumulatively the quantity of electricity generated for the several fuel sources against total emissions from those sources. The fuel source with the lowest Emissions Factor (EF) (the amount of emissions produced per unit of electricity, e.g. $ktCO_2$-e/GW h) is plotted first, followed by the next highest and so on. The slope of the line is equal to the emissions factor. All emissions factors are expressed as carbon dioxide equivalent and include all relevant greenhouse gases.

The demand composite curve (dashed black line) is also constructed using the same method as the supply composite curve however as a first approximation it can be assumed that the emissions from the various demand sectors is proportionate to the electricity usage and therefore will produce a straight line from the origin to the end of the supply composite curve. The demand curve could consider demand by sector, as in this case, or also by region. The ends of the total supply and demand composite curves should coincide. The slope of the demand line then is known as the Grid Emissions Factor (GEF), which is simply the average total emissions factor or specific emissions for the entire system. In this example the GEF is equal to 1 $ktCO_2$-e/GW h.

Table 1
Example electricity and emissions scenario.

	Quantity (GW h)	Emissions ($ktCO_2$-e)	Emissions factor ($ktCO_2$-e/GW h)
Demand			
Industrial	350	350	1
Residential and commercial	650	650	1
Total demand	1000	650	
Supply			
Renewables	300	0	0
Fuel A	400	200	0.5
Fuel B	300	800	2.67
Total supply	1000	1000	

Once the composite curves are constructed for the base case, a new demand curve is drawn that ends at the target demand and emissions levels. The graph on the right in Fig. 1 illustrates a new demand curve with no increase in demand but a 600 $ktCO_2$-e decrease in the emissions levels. The supply composite curve is shifted to the right until the supply and demand curves intersect and the point at which they cross is known as the "Pinch Point". The amount that the supply has been shifted then becomes the amount of renewables (zero emissions) that need to be added in order for the target to be met. The overhang of the supply curve to the right of the pinch point represents the amount and type of generation that needs to be substituted with renewables. The amount of renewables needed to meet the target would need to be increased if fuel types below the pinch point were substituted instead of those above. Likewise if non-zero emission generation sources are substituted instead the generation profile would also be different for the target to be met. In this example the amount of generation from Fuel A could be increased in addition to adding renewables in order to reach the targets, however it is clear that this amount is constrained by the pinch point.

3. Incorporating increased demand

The methodology outlined above can be extended to include an increase in demand in addition to a decrease in emissions. An increase in the electricity demand can be accounted for by shifting the demand composite curve so that the end of the line falls on

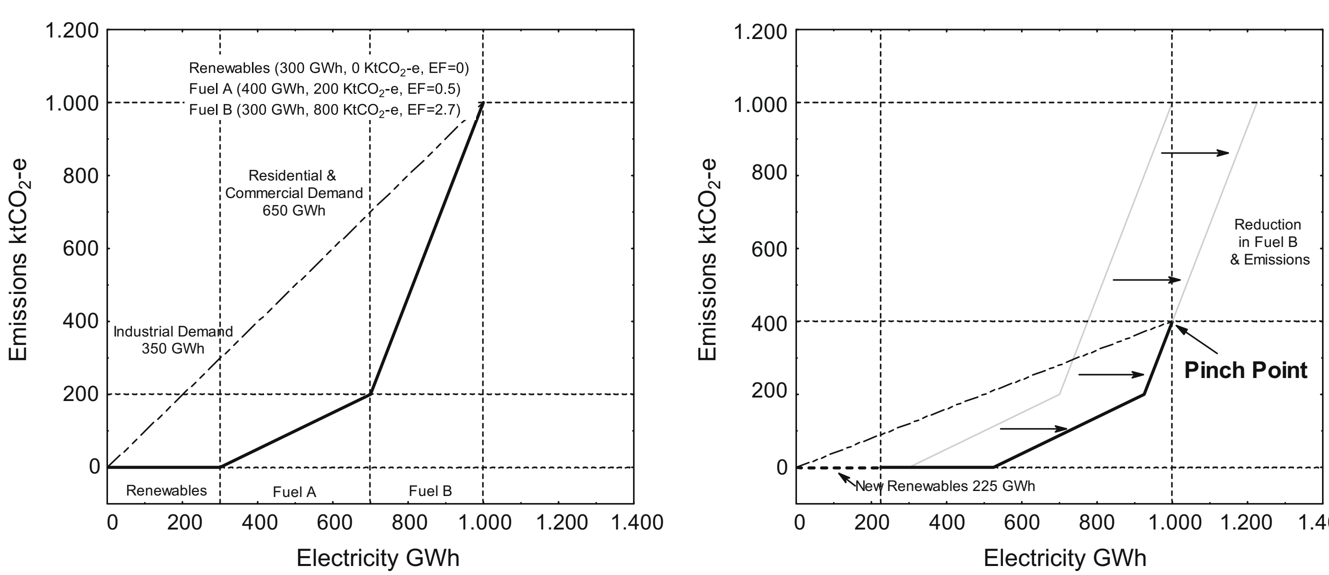

Fig. 1. Example demand and supply composite curves.