The Potential Impact of Industrial Energy Savings on The New Zealand Economy

Milad Maralani*and Basil Sharp

Department of Economics, The University of Auckland, New Zealand

Golbon Zakeri

Department of Engineering science, The University of Auckland, New Zealand

July 2015

Abstract

Industrial processes are highly energy intensive and currently account for one-third of global energy use (IEA 2012). Industrial technologies and their energy efficiency, especially in energy-intensive industries, play an important role in achieving improvements in energy efficiency that contribute to future energy security and environmental policy. However, a change in energy efficiency is not limited to the industry level; it has an effect on both energy and economic systems. In New Zealand approximately 39% of electricity is consumed by large industries. In 2012, The University of Auckland engineering team proposed to develop novel heat exchanger technology to allow electricity demand shaving and load shifting in light metal industries. This technology provides significant cost savings for such companies and preservs generation capacity at peak times for other users. The aim of this study is to represent the impact of adopting this technology in a particular, electricity intensive sector (e.g. steel or light metals manufacturing), on the electricity market and economic system as a whole. New Zealand's economy is represented as a static CGE model and the electricity sector is represented by a bottom-up model. An iterative algorithm settles the quantities and price between these two models; the general equilibrium sub-model uses the MCP format, and the electricity sector is based on optimization. Initial results show that a decrease in electricity demand by our targetted sector has an impact on some other sectors of the economy(e.g. manufacturing). Exports increase as a result of lower equilibrium prices for domestic intermediate goods. However, the domestic price of final products increased slightly as a result of more goods being exported.

*Corresponding Author, Electronic address: m.maralani@auckland.ac.nz

1 Introduction

1.1 Background and motivation

Industrial processes are highly energy intensive and currently account for one-third of global energy use (IEA 2012). Energy-saving technologies are currently used in the industrial sector to achieve energy efficiency targets and energy demand control. Politicians and economists, as well as engineers and managers, are keen to employ this efficiency improvement at an industrial level. There are several different types of policies and programmes that have been used all around the world to increase energy efficiency in the industrial sector. Regulations, fiscal policies, agreements and targets, reporting or benchmarking, audits, information dissemination, and demonstration and research and development are different ways to achieve this target(Price and Worrell, 2000).
Governments and environmental groups support energy efficiency improvement for future energy security and environmental issues. Industrial technologies and their energy efficiency, especially in energy-intensive industries, play an important role in achieving this target. Energy demand is affected by increasing efficiency in a specific industry. Energy demand control is not a new topic, and it has been around with scientists and policymakers since the oil crisis in the 1970s. Many policies for demand control previously focused on substituting alternative energy sources and on reducing energy consumption (De Beer, 2000). However, a change in energy efficiency is not limited to the industry level; it can have an effect on both energy and economic systems. On the energy supply side, it has an impact on the energy system cost structure and supply curve. An energy system supplies energy for the economy by minimising the cost of exploiting discrete and dissimilar technologies in response to an exogenous demand which comes from other sectors of that economy. A change in energy consumption leads to a new combination of energy technologies with different cost structures, so energy supply will change.
On the demand side of energy, an energy efficient technology will decrease the energy demanded as an input in the industry. This demand reduction has an impact on other sectors of the economy, which use energy as a production factor. Increased energy in other sectors and lower energy prices are the result of improved industrial energy efficiency. In addition, production in other sectors production could increase as a result of lower energy costs. This will increase the competitive power of other sectors in domestic and international markets, as well as in the energy efficient industry.
As a result, improved energy efficiency in one sector has a broad and indirect impact on many other parts of the economy.This suggest a need to consider both the supply and demand side of energy as an integrated system.
The aim of this paper is to estimate the potential impact of an energy-saving technology in an energy-intensive industry on the energy (electricity) and economic system of New Zealand.

2 Literature review

Many studies attempt to show the impact of industrial energy policy and technological change on the economy. Hepbasli and Ozalp (2003)investigated the development of industrial energy efficiency in Turkey up to 2001, and concluded regulation in the industrial sector accelerated energy efficiency in Turkey. Mecrow and Jack (2008) demonstrated the trend in electrical machinery in the United Kingdom. Their results showed that replacing fixed speed machines with variable speed machines in the industrial sector would lead to 15% -30% energy savings.

Price and Worrell (2000) classified seven types of programmes and policies for energy efficiency in industrial sectors around the world. Regulations / standards, fiscal policies, agreements/targets, reporting/benchmarking, audits/ assessments, information dissemination, and demonstration and research and development are policies aimed to improving energy efficiency. They concluded that the best way to increase energy efficiency is an integrated approach where a number of policies and programmes are combined together. Such policies are used in Denmark, Canada, the Netherlands and Norway.

Saidur and Mahlia (2010) investigated potential energy saving and emissions reduction in the Malaysian industrial sector by introducing high-efficiency electrical motors. They found that between 1940 and 892 GWh can be saved for 20 and 120 kW respectively electric motors in a 10-year period. Also, USD160 million will be saved for the same categories of motors in utility bills. Finally, they concluded that 1,789 million kg of CO_2 emissions could be avoided by using these technologies.

Worrell and Price (2001) examined three policy scenarios to improve energy efficiency in the industrial sector in the United States when they face energy, economic and environmental challenges. They found 7%-17% improvements in energy efficiency by 2020, compared to a " business as usual" scenario in medium and advanced situations. Their study showed that although there are substantial potential gains from improving energy efficiency in industry, an integrated policy framework is necessary.

Yuan et al. (2009) studied the main energy policies of China since 1982. They categorised them into three main groups. The first group consists of several suggestions for reinforcement of energy saving. A second group of policies are the legal issues relating to energy conservation, and the third group is a medium- and long-term plan for energy saving. They designed two methods for measuring energy saving in associated with these policies, with and without antithesis and linear regression. They concluded that with and without antithesis is useful for analysing short-term effects, and linear regression is a better tool for long-term effects evaluation.

3 Electricity sector

One of the most important parts in any energy system is the electricity sector. Electricity is a significant input in any economy and has specific characteristics. One significant feature of electricity is that it is difficult to store in large quantities. Another important feature is that the stable operation of the electricity grid calls for the demand and supply of electricity always to be in balance. This situation requires that there is always enough generation capacity to satisfy demand. Therefore, it is common that the grid operators, who are responsible for the stability of the grid, purchase balancing capacity in order to be able to balance the grid in case of unexpected developments, such as plant outages. If the gap between electricity demand and supply exceeds the available balancing capacity, the entire electricity system can break down. So, it is important to ensure that the electricity system creates enough generation and grid capacity in order to ensure the stability of the system in the long run (Sensuß et al., 2007). Therefore, if any changes happen in the electricity demand, the supply side should balance generation and vice versa. Consider an increase in generation capacity, this can lead to a decrease in prices given current demand. So cheaper electricity flows to the economy, possibly resulting in an increase in demand. Again, increased demand for electricity changes the price, and this process continues until it reaches a convergence in price between the electricity system and the economy. A change in the electricity price could result in changing the amount of sectoral outputs as well as imports and exports. So measuring the impact of any policy that affects demand or supply of electricity needs to consider both the electricity and the economic system.

3.1 An overview of New Zealand electricity market

Before 1994, New Zealand had a state owned and controlled electricity system consisting of generation, transmission, distribution and retailing. Since then, industry reform has moved the system from a state monopoly to a competitive market including generators and retailers. Distribution and transmission is still under the control of Transpower, which is a state owned enterprise. In addition, the government acts as a regulator in this market with a complex code of rules. The New Zealand electricity market is composed of generators, retailers, distributors and a national grid. All main retailers are vertically integrated with generators and called " Gentailers" . OnEnergy was the last big self-sufficient retailer in the market, but was bankrupted by drought crises in 2003 and its customers were taken over by Meridian and Genesis. Gentailers are the main players in the electricity market, and they are a part of the revenue in this market.

3.2 Generation

New Zealand has about 75 generators in total. There are five major generator companies : Meridian Energy, Contact Energy, Genesis Power, Mighty River

Power, and Trustpower. These companies are all gentailers and supply 92% of New Zealand's power.

- Meridian Energy (SOE): 28%
- Contact Energy: 23%
- Genesis Energy : 18%
- Mighty River Power : 17%
- TrustPower: 6%

Other companies generate electricity with a smaller share of the market: Nga Awa Purua JV, Tuaropaki Power, Alinta ENZ, Todd Energy.
Total generation capacity was about 10,000 MW in 2012, while Huntly (owned by Genesis Energy) has the greatest individual capacity, around 1,448 MW.
In 2012, 42,900 GWh or 154 PJ of electricity was generated in New Zealand, of which 53% comes from hydro, 20% from gas, 14% from geothermal, 8% from coal, 5% from wind and 1% from bio energy (ElectricityAuthority, 2013) .

3.3 Transmission

The national electricity transmission grid is owned, operated, maintained and developed by Transpower. New Zealand's transmission system is made up of over 12,000 km of high-voltage transmission lines, 25,000 towers, 16,450 poles, 174 substations, 1,000 transformers and 2,300 circuit breakers. This grid connects power stations owned by generating companies to substations feeding the local networks that distribute electricity to consumers. Some large industrial users of electricity also receive their power directly from the national grid. These companies are very large industrial electricity consumers such as Carter Holt Harvey (Kinleith Pulp and Paper Mill), Norske Skog Tasman (Tasman Pulp and Paper Mill in Kawerau), New Zealand Steel (Glenbrook Steel Mill), NZ Aluminium Smelter (Tiwai Point), Pacific Steel (Otahuhu steel mill), Pan Pac (Whirinaki pulp mill) and Winstone Pulp International (Karioi pulp mill near Ohakune).
The HVDC connects the North and South Islands transmission grids together. HVDC is the only High Voltage Direct Connect (HVDC) in New Zealand. The line connects to the South Island grid at the Benmore Dam in southern Canterbury and travels 535 kilometres via towers to Fighting Bay in Marlborough. Then it crosses the sea by undersea cables for 40 kilometres to Oteranga Bay in the west of Wellington.
Twenty-nine companies distribute electricity from the grid exit points to final customers. Some of largest companies are publicly listed, but most of them are owned by trusts or local bodies.

3.4 Retailers

Retailers buy a large share of electricity from the wholesale spot market. Most end users purchase electricity from retailing companies, most of whom are owned by generators. Consumers can choose from up to ten electricity retailers for their energy supply, depending on their location. Currently there are 12 major retailer companies in the market: Genesis Energy, Contact Energy (including Empower Brand), Mercury Energy (a subsidiary of Mighty River), Meridian Energy (customer numbers include the smelter and Energy Direct ICPs), Trustpower, Energy Online (a subsidiary of Genesis Energy), Powershop (a subsidiary of Meridian Energy), Bay of Plenty Energy (a subsidiary of Todd Energy), Pulse Utilities (includes the Just Energy and Pulse Energy retail brands), Bosco Connect (a subsidiary of Mighty River Power, including the Tiny Mighty Power retail brand), King Country and Nova Energy (a subsidiary of Todd Energy).

3.5 Wholesale Market

Retailers and some large users of electricity buy electricity directly from the spot market. They typically enter into financial contracts like hedges to smooth out some or all of the volatility in spot prices. So, spot and hedge markets are the components of the electricity market, while there is an ancillary service market in the wholesale electricity market. Generators with a capacity larger than 10 MW compete in the spot market for the right to sell electricity to satisfy demand subject to transmission constraints. They submit offers to generate a specific quantity of electricity at a nominated price. Each offer covers a future half-hour period through the Wholesale Information and Trading System (WITS). Transpower (the system operator) uses a scheduling and dispatch system to rank offers in order of price, and selects the lowest cost combination of resources to satisfy the demand. Electricity prices can vary during different time periods, related to demand and supply, and they can be different in each location reflecting electrical losses and transmission constraints. There are 248 nodes, which are both Grid Injection Points (GIPs) and Grid Exit Point (GXPs) across New Zealand. Generators offer electricity prices in 52 nodes via GIPs, and consumers demand electricity in 196 GXPs on the national grid. Final prices at each node are determined by considering grid losses and constraints and confirmed as final prices the following day.

3.6 Current Electricity demand

Total electricity consumption was around 40,000 GWh in 2014. The industrial sector with 36%, residential with 35%, commercial with 24% and agriculture, forestry and fishing with 5% are the main sectoral consumers of electricity. There are 1.7 million residential consumers, 165,000 commercial consumers, 70,000 agriculture, forestry and fishing consumers, and 40,000 industrial consumers in New Zealand.

4 Our electricity intensive sector

As outlined in the introduction, the aim of this study is to shed light on the economy wide effects of the adoption of the new energy savings technology (SHE) on the industrial sector that is the most intensive user of electricity. Our CGE experiments (and presented results) are performed on a case inspired by New Zealand's light metal manufacturing sector. Our CGE model is solved for the status quo, and subsequently applied so that it captures the adoption of the new technology. For the targetted sector, electricity savings of the order of 30-40% are estimated and this is what we have implemented for the CGE model.

5 Methodology

There are two broad approaches for quantitative assessment of energy policies on the economy: bottom-up models, which focus on the technological detail of an energy system, and top-down models, which emphasise broader economy. Bottom-up models represent the energy system as a partial equilibrium. They include a large number of discrete energy technologies to supply to satisfy exogenous demand. These models utilise mathematical programming methods to select the lowest cost combination of primary energy subject to technological constraints. This approach well suited to measure the economic impact of changes in energy efficiency. The main weakness of these models is that they neglect the macroeconomic impact and income effects of energy policy on the economy. In contrast, top-down models study the broader economy and consider the interaction between markets by a change in price and income in one sector that is induced by policy. An energy sector is represented in these models as an aggregated sector, along with other sectors in the economy, by smooth production functions which capture substitution possibilities.

A shortcoming of these top-down models is that they typically do not capture the technological detail related to energy production and conversion. Top-down models cannot show how discrete technologies change as a result of energy policy.

Advantages and disadvantages of both approaches led to a hybrid approach which can use a technological detail of bottom-up models with macroeconomic interactions of top-down models (Hourcade et al., 2006). There are various types of hybrid models that use a link between both models. The hybrid models can be classified in three categories. The first group consists of those models that have a connection between an existing bottom-up model and a top-down model. The soft link approach has been used since the 1970s, but it has difficulties with consistency of assumption and accounting concepts (Hoffman and Jorgenson, 1977; Drouet et al., 2005; Schäfer and Jacoby, 2006).

A second group of hybrid models focuses on one type of model as a main model and uses a reduced form of another model in the core model. ETA-MACRO Manne (1977), and MERGE Manne et al. (1995) used a bottom-up energy system model and linked it with a high-aggregate economic model in a single optimisation framework. Bahn et al. (1999); Messner and Schrattenholzer (2000); Bosetti et al. (2006) used the same method for their hybrid modelling.

Completely integrated models, based on mixed complementarity problems, are the third class of hybrid energy models. By introducing a market equilibrium model as a mixed complementary problem and a combination of this with an optimisation problem of a bottom-up model, a modeller can use a single mathematical format to capture the technological detail and economic behaviour in a single framework Böhringer (1998).

Sue Wing (2008) applied a positive mathematical programming approach to develop a hybrid model of climate change to fill a gap between bottom-up engineering models and top-down macroeconomic models. By using United States data, he showed how electricity engineering costs can be integrated with the data of the electricity sector of a CGE model.

Frei et al. (2003) showed a dynamic formulation of top-down and bottom-up energy policy models. By presenting a complementary format of a CGE model, and including an endogenous formulation of investment decisions, this study represents the possibilities of capital stock and technology changing into an energy economy model in the long term.

Proena and Aubyn (2013) studied the feed-in tariff as a policy instrument in Portugal's economy for introducing renewable generated electricity under European Union directives on energy and climate regulation. They used a hybrid modelling approach to represent the complex interaction between energy and economic and environmental problems that are related to energy policies. Their results show that feed-in tariff policy is an effective and cost-efficient method in the generation of electricity by renewables in Portugal.

Although the integrated Mixed Complementarity Problem(MCP) is coherent and logical, complexity and dimensionality are two limitations, when faced with an optimisation problem of an energy system with lower and upper bounds. As complementarity has both dual and primal relationships, in many cases the number of equations and errors increased. In an optimisation model of an energy system, there are some upper and lower bounds on many decision variables, therefore in MCP formulation, a modeller faces robustness, efficiency problems and income effects . Böhringer and Rutherford (2006) present a decomposition approach of the integrated MCP formulation that allows a modeller to combine an energy system model and a general equilibrium model. An iterative algorithm settles the quantities and price between these two models, while general equilibrium uses the MCP format and an energy system utilises quadratic programming.

5.1 Arrow-Debreu equilibria

Complementarity between upper and lower bounds on equilibrium variables and weak inequalities is a feature of market equilibrium (Böhringer and Rutherford, 2006). Because of the complementarity feature of market equilibrium, a modeller can use a mathematical format of market equilibrium as a MCP. The MCP approach provides a general mathematical format that covers weak inequalities, i.e. a mixture of equations and inequalities, and complementarity between variables and functional relationships. It includes a wide range of mathematical problems, including systems of linear or nonlinear equations or mathematical programmes (Rutherford, 1995). The MCP formulation relaxes the integrability constraints for equilibrium conditions which emerge as first-order conditions from primal or dual optimisation problems. This permits the direct representation of market inefficiencies such as distortionary taxes or spillovers that cannot be readily studied in an optimisation framework (Böhringer and Rutherford, 2005).

To represent the algebraic format of an equilibrium, consider a competitive economy with

- n commodities (including primary factors) indexed by i,
- m sectors indexed by j,
- H households

Based on Mathiesen (1985), there are three categories of decision variables:

- p is a non negative n-vector of prices for all goods and factors,
- y is a non-negative m-vector for activity levels of constant returns to scale (CRTS) production sectors,
- M_h is a non-negative k-vector in incomes.

In this economy, the following conditions apply in equilibrium

Zero Profit Condition
No production activity makes positive profit:

$$-\Pi_j(p) \geq 0 \tag{1}$$

Where :

$\Pi_j(p)$ shows the difference between unit revenue and unit cost or the unit profit function for CTRS production activity in sector j

Market Clearance condition or Excess supply
Supply minus demand is non-negative for all goods and factors:

$$\sum_j y_j \frac{\partial \Pi_j(p)}{\partial p_i} + \sum_h w_{ih} \geq \sum_h d_{ih}(p, M_h) \qquad \forall i \tag{2}$$

where:
$\frac{\partial \Pi_j(p)}{\partial p_i}$ is the compensated supply of good i per unit operation of activity j by Hotelling's lemma.
w_{ih} denotes the initial endowment matrix by commodity and household.
$d_{ih}(p, M_h)$ is the utility maximizing demand for good i by household h.

Income Balance
Expenditure for each household h equals factor income, i.e. factor income equals the price of initial endowment

$$M_h = \sum_i p_i w_{ih} \tag{3}$$

In equilibrium there are three inequalities Eq.(1),(2)and(3), and two more additional conditions :

Irreversibility
All activities are operated at non-negative levels

$$y_j \geq 0 \qquad \forall j \tag{4}$$

Free disposal
Prices are always non-negative

$$p_i \geq 0 \qquad \forall i \tag{5}$$

Provided that underlying utility functions exhibit non-satiation, household expenditure will exhaust income, so:

$$\sum_i p_i d_{ih}(p, M_h) - M_h = \sum_i p_i w_{ih}$$

By substituting $p^T(d_h(p, M_h) - wh) = 0$ into Eq.(2), we have an inequality :

$$\sum_i p_i y_j \frac{\partial \Pi_j}{\partial p_i} = y_j \Pi_j(p) \geq 0 \qquad \forall j$$

Equation (1)and (4) show that $y_j \Pi_j(p) \leq 0 \quad \forall j$.
So, in equilibrium, any activity which earns negative unit profit is idle:

$$y_j \Pi_j(p) = 0 \qquad \forall j,$$

Moreover, any commodity in excess supply must have a zero price :

$$p_i \left[\sum_j a_{ij}(p) y_j + \sum_h w_h - \sum_h d_{ih}(p, M_h) \right] = 0 \qquad \forall i$$

5.2 Complementarity format of a general equilibrium

Complementarity between equilibrium variables and equilibrium conditions is a feature of economic equilibrium:

- Positive market prices imply market clearance, otherwise commodities are in excess supply and the respective prices fall to zero.
- Activities will be operated as long as they break even, otherwise production activities are shut down.
- Income variables are linked to income budget constraints.

General format of a complementarity problem is

$$\text{Given } f : R^N \to R^N, l, u \in R^N$$
$$\text{Find } z, w, v \in R^N$$

Subject to

$$f(z) - w + v = 0$$
$$l \leq z \leq u, w \geq 0, v \geq 0,$$
$$w^T(z - l) = 0, v^T(u - z) = 0$$

Now, we have formulated our market equilibrium as a mixed complementarity problem (MCP) by setting $l = 0$, $u = +\infty$, $z = [y, p, M]$, and letting $F(z)$ depict the equilibrium conditions.

5.3 Electricity Generation Model

An energy generation model is formed as a linear optimisation problem that seeks to find the least-cost schedule for meeting exogenous energy demand using a given set of energy technologies t.

$$Max \qquad p^T(e - x) \tag{6}$$

subject to

$$Ax + Bz \geq Ce$$

$$e, x \geq 0, l \leq z \leq u$$

Where:
$A, C \in R^{M\times n}$ and $B \in R^{M\times N}$: are technical constraints
$z \in R^N$: are decision variables of energy system which may be subject to lower bound $l \in R^N$ and $u \in R^N$ upper bounds.
By writing Kuhn-Tucker conditions and simultaneously solving with the equilibrium conditions, we have:

$$
\begin{gathered}
c^T\pi \geq p \quad, e \geq 0, \quad e^T(C^T\pi - p) = 0 \\
p \geq A^T\pi, \quad x \geq 0, \quad x^T(p - A^T\pi) = 0 \\
Ax + Bz \geq Ce, \quad \pi \geq 0, \quad \pi^T(Ax + Bz - Ce) = 0 \\
l \leq z \leq u, \quad \lambda^T(z - l) = 0, \quad \mu^T(u - z) = 0 \\
\lambda + B^T\pi = \mu
\end{gathered}
$$

By linear programming duality:

$$p^T(e - x) = \mu^T u - \lambda^T l$$

Therefore we can rewrite equation (3) as,

$$M_k = p^T\omega_k + \psi_k(\mu^T u - \lambda^T l) \tag{7}$$

So, the integrated bottom up model can be solved by equations (1)-(3),(6), (7).

5.4 Iterative Process

To link a CGE model with an optimisation model for electricity, we use an iterative algorithm which uses the demand for electricity and electricity inputs from the economy model (CGE), and then the electricity generation model shows the quantity of electricity supply subject to technological constraints to respond to the demand. Electricity supply flows to the economic model which generates new prices and demand for electricity. This process is repeated until the model converged; that is price and demand do not change.

6 Data and model

New Zealand input-output table used to build a social accounting matrix for the CGE model. NZ Statistics publishes input-output table for New Zealand, and the last version was released in 2007. There are 106 industries and 205 commodities groups in the table. We aggregate this classification to 11 groups of goods and industries. As the primary purpose of this study is to represent the role of electricity intensive metal manufacturing in the NZ economy, we consider this as a separate sector in the SAM. We divide data of metals sector into two

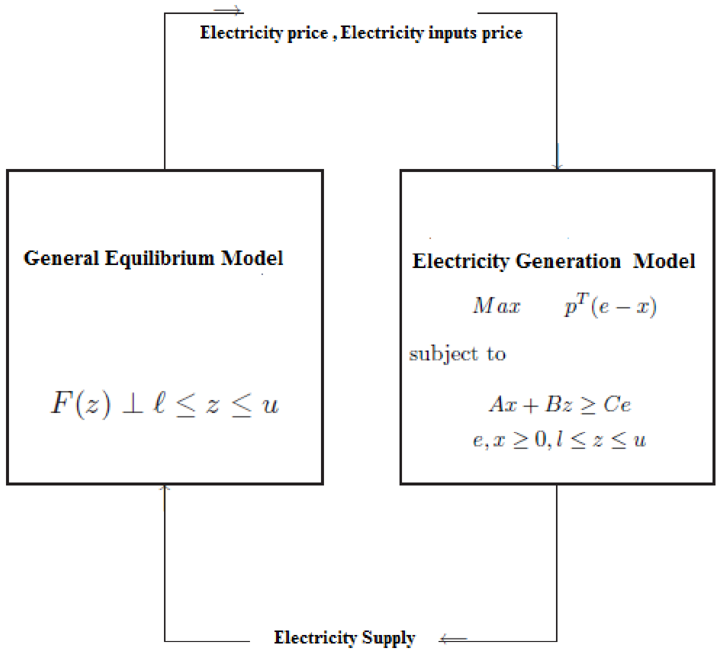

Figure 1: Iterative process between energy and economy models

categories, basic metals and light metals industry.
For the electricity sector, we use data of all active generators in New Zealand. We use marginal cost of per MW electricity generation the electricity sector based on the type of generator and the technology which employed in these turbines. There are 17 thermal plants consist of gas-fired turbines, coal, and gasoline. Most of these thermal generators located on the north island. Total capacity of thermal generation is 3230 MW. Hydro generation has 13 generators with 5196 MW capacity which mostly located in the south island. Geothermal by 11 generators and 748 MW capacity has a very low marginal cost of electricity generation. There are eight wind turbines by 601 MW capacity as well in the electricity system with marginal cost of almost zero (MED, 2012).

6.1 Computable General Equilibrium

In this section we describe the specification of a CGE model for analysing the impact of an industrial energy-saving technology in New Zealand, as a small open economy. we will show the detailed algebraic description of a CGE model and link it with the electricity generation model.
Our model is a static, multi-sectoral, applied CGE model for a small open econ-

omy formulated in the mixed complementarity format as a non-linear system of inequalities.

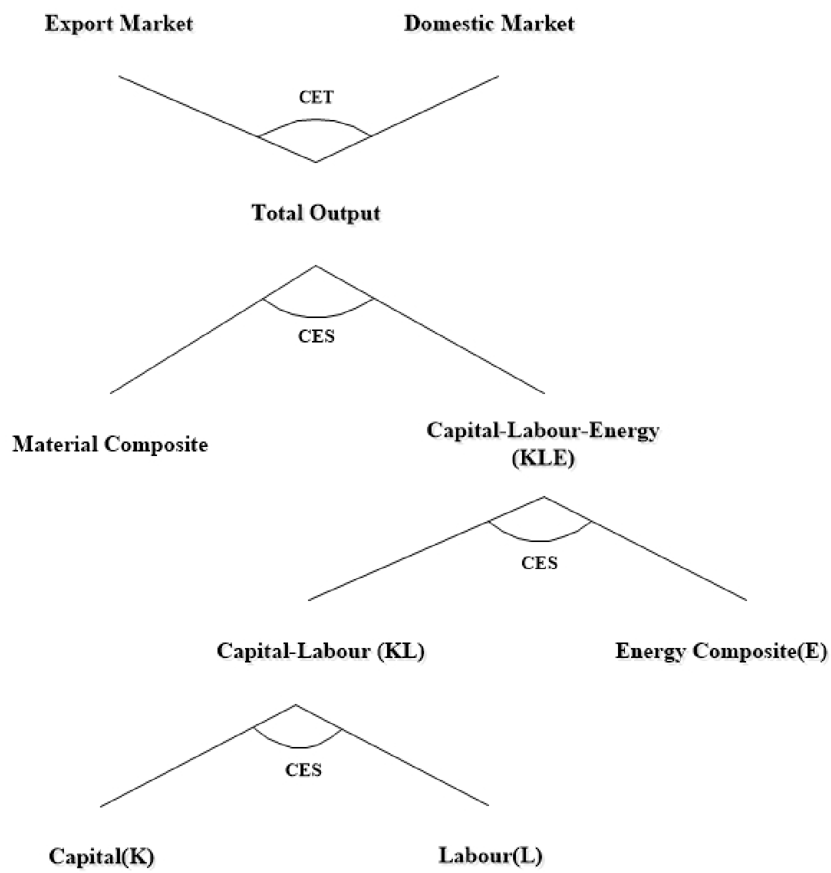

Figure 2: Nesting structure of non-energy production function

		CGE Model Dimensions			
Nr.	**Code**	**Production Sectors**	**Code**	**Primary Factors**	
		Non-Energy	1	CAP	Capital
1	AFF	Agriculture, forestry and fishing	2	LAB	Labour
2	MIN	Mining			
3	FOD	Food processing			
4	WPP	Wood, pulp, paper and printing			
5	CHM	Chemicals			
6	BAM	Basic metals	**Nr.**	**Code**	**Final demand**
7	ALZ	Ligth metals	1	HOS	Household
8	MAN	Manufactoring	2	GOV	Government
9	SER	Services	3	INV	Investment
		Energy	4	EXP	Exports
10	FOL	Fossil Fuels			
11	ELE	Electricity			

Table 1: CGE model dimensions

6.2 Factor Market

Capital and labour are primary factors of production. Initial factors endowments are exogenous. Factor markets are perfectly competitive and prices adjust, such that supply equals demand. Labour and capital are assumed to be perfectly mobile across sectors.

6.3 Production

The CGE production structure includes 11 sectors/commodities (two energy sectors, nine non-energy sectors). In this model the light metals sector is considered as a single non-energy sector. It is assumed that in each production sector a representative firm minimises the cost of producing output subject to the nested constant elasticity of substitution (CES) production functions, that reflect the substitution possibilities in domestic production between inputs of capital (K), labour (L), an energy composite (E) and a material aggregate (M). Each intermediate input represents a composite of domestic and imported varieties (Armington composite good). Production of goods other than the electricity generation sector to the domestic and the export markets is described by an aggregate production function which characterises technology through transformation possibilities on the output side and substitution possibilities on the input side. On the output side, production is split between goods produced for the domestic market and those produced for the export market, according to a constant elasticity of transformation (CET) function. On the input side, a three-level CES function captures the price-dependent use of inputs in production. At the top level, a CES material composite trades off with an aggregate of capital, labour and energy, subject to a constant elasticity of substitution. At the second level, a CES function depicts the substitution possibilities between the energy composite and a value-added aggregate. Finally, at the third level, capital is combined with labour, trading off at a constant elasticity of substitution. Aggregate material inputs to production of item g are a single-level CES function across all non-energy intermediate inputs (M). In the energy composite (E) production structure, energy input substitution possibilities are captured by a nested CES function. Fossil fuel aggregate (primary energy inputs) combines with electricity at a constant elasticity of substitution. The electricity generation sector is an exogenous parameter coming from the electricity generation model.

6.4 Final consumption

Final demand for this model involves households, governments, enterprise and export. Final consumption demand for households is derived from utility maximisation of a representative household, subject to a budget constraint given by the income level. Consumption demand of the representative agent is depicted as a CES aggregate of an energy composite and a non-energy composite good. Substitution patterns within the non-energy consumption bundle are reflected

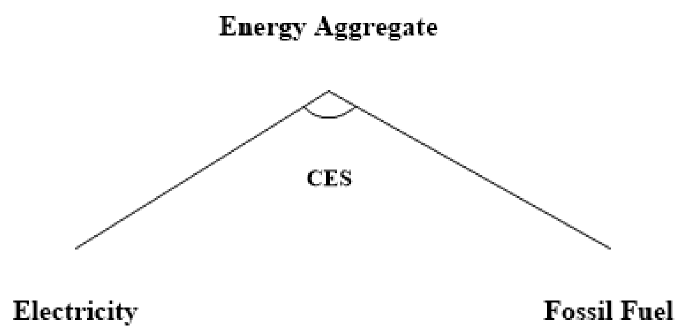

Figure 3: Nesting structure of energy production function

via a CES function with an Armington aggregation of imports and domestic commodities; the energy composite consists of the various energy goods trading off at a constant elasticity of substitution.

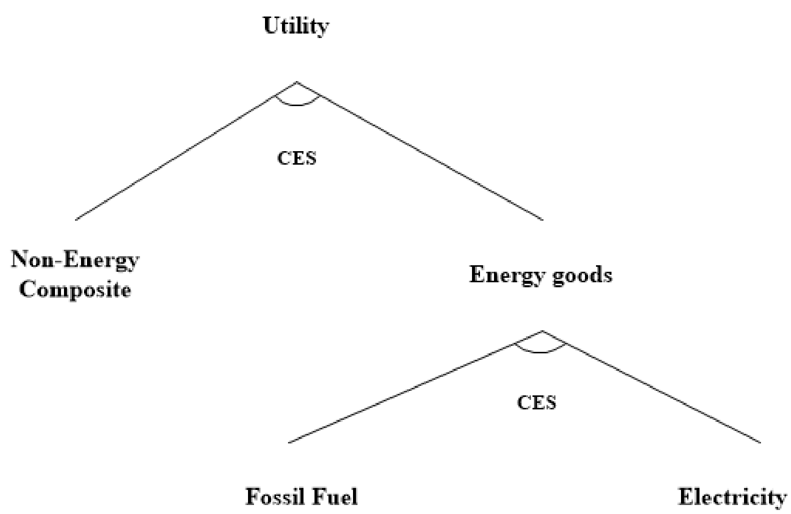

Figure 4: Utility nested function of representative consumer

6.5 International trade

We make two common assumptions when modelling international trade. First, the small economy assumption which means that the domestic market is too small to influence world prices and the world market can satisfy all the importing and exporting needs of the domestic economy. Second, based on Armington (1969), imported and domestically produced goods of the same type are imperfect substitutes; similarly, domestically produced goods may be supplied either to the domestic market or the export market by the constant elasticity of transformation function (CET). The Armington assumption of product heterogeneity means that all goods used in the domestic market in intermediate and final demand correspond to a combination of domestic production and ROW imports with a CES composite function, the so-called Armington composite good. Foreign trade closure requires that the value of imports to the rest of the world is equal to the value of exports from the rest of the world after including a constant benchmark trade surplus or deficit. A small open economy is assumed to be a price-taker with respect to world market prices (world prices are considered to be exogenous). So trade with the rest of the world is represented by perfectly elastic (horizontal) import-supply and export-demand functions.

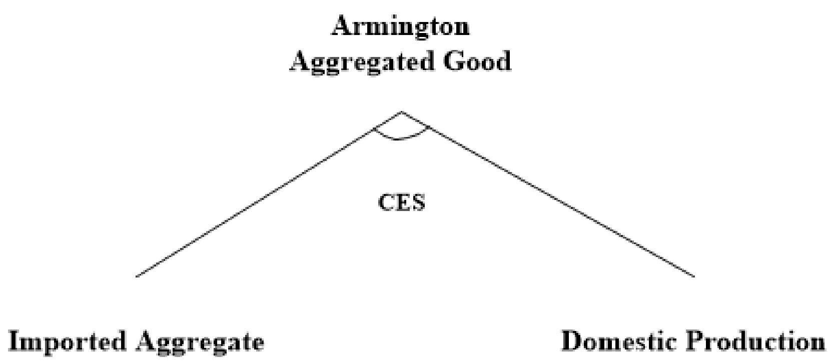

Figure 5: Nesting structure of Armington good

Activity Variables

- Y_i refers to the production of non-energy good i,
- E_i represents energy aggregate input in sector i,
- FF_i refers to the production of fossil fuel $i \in coal, oilandgas$,
- ELE denotes the production of electricity,

- A_t shows the Armington aggregate good i,
- U is the utility of aggregate household final consumption,
- M_i is the world import aggregate of good i.

Price Variables

- P_i is the output price of good i produced for domestic market,
- P_i^X is the output price of good i produced for the exported market,
- P_i^A is the price of Armington aggregate good i,
- P_i^E is the price of energy aggregate in sector i,
- w is the labour price,
- r_k is the capital price,
- r_i is the rent to natural resource i,
- P^{ELE} is the electricity price,
- P_U is the utility price index,
- P_i^M is the price of world import aggregate for good i.

Income variable

- M is the income of representative household

Unit profit function of non-energy output can be written as:

$$\Pi_i^Y = \left(\theta_i^X \left(p_i^X\right)^{1-\eta} + \left(1-\theta_i^X\right) p_i^{1-\eta}\right)^{\frac{1}{1-\eta}} - \left(\sum_{j\notin E} \theta_{ji} P_j^A\right) -$$
$$\left(\theta_i^{KLE}\right)\left[\theta_i^E \left(p_i^E\right)^{1-\rho_{KLE}} + \left(1-\theta_i^E\right)\left(w^{\theta_i^L} r_K^{1-\theta_i^L}\right)^{1-\rho_{KLE}}\right]^{\frac{1}{1-\rho_{KLE}}}$$

Where :

- θ_i^X is the value share of ROW exports in sector i,
- θ_{ji} is the cost share of non-energy intermediate input j in sector i,
- θ_i^{KLE} is the cost share of KLE aggregate in sector i,
- θ_i^E is the cost share of energy in the KLE aggregate of sector i,
- θ_i^L is the labour cost share in sector i,
- η is the elasticity of transformation between production for the domestic market and production for exported market,

- ρ_{KLE} is the elasticity of substitution between the energy aggregate and the value added in non-energy production,
- Y is the associated complementary variable.

The unit profit function for energy aggregate can be written as :

$$\Pi_i^E = P_i^E - \left\{\theta_i^{ELE}(P_{ELE}^A)^{1-\rho_{ELE}} + (1-\theta_i^{ELE})(P_{FOL}^A)^{1-\rho_{ELE}}\right\}^{\frac{1}{1-\rho_{ELE}}}$$

Where,

- θ_i^{ELE} is the cost share of electricity in energy demand by sector i,
- ρ_{ELE} is the elasticity of substitution between electricity and non-electricity energy goods in production.
- E is the associated complementary variable.

Unit profit function for Armington aggregate good is :

$$\Pi_i^A = P_i^A - \left[\left(\theta_i^A p_i^{1-\rho_A} + \left(1-\theta_i^A\right)\left(p_i^M\right)^{1-\rho_A}\right)^{\frac{1}{1-\rho_A}}\right] = 0$$

Where :

- θ_i^A is the cost share of domestic variety i in Armington aggregate good,
- ρ_A is the Armington substitution elasticity between domestic and imported varieties of the same good,
- A is the associated complementary variable.

The unit profit function for household utility is:

$$\Pi^C = P_c - \left\{\theta_C\left[\prod_{i\notin EG}(P_i^A)^{\gamma_i}\right]^{1-\rho_C} + (1-\theta_C)\left[\theta_{ELE}^C(P_{ELE})^{1-\rho_{ELE}^C} + (1-\theta_{ELE}^C)\left[P_{ff}\right]^{1-\rho_{ELE}^C}\right]^{\frac{1-\rho^C}{1-\rho_{ELE}^C}}\right\}^{\frac{1}{1-\rho_C}} = 0 \quad \forall_i \notin EG$$

Where :

- θ_C is the cost of non-energy composite in aggregate household consumption,
- θ_{ELE}^C is the cost of electricity in household energy aggregate demand,

- γ_i is the cost share of non-energy good i in non-energy household demand,
- ϕ_j is the cost share of fossil fuel i in non-electric household energy demand,
- ρ_C is the elasticity of substitution between energy and non-energy goods in household consumption,
- ρ^C_{ELE} is the elasticity of substitution between electricity and non-electricity energy in household consumption,
- C is the associated complementary variable.

6.6 Integration of electricity generation into the CGE model

The electricity generation sector and CGE model are solved based on an algorithm by Böhringer and Rutherford (2009). At the first step, we generate a consistent benchmark data set where electricity sector outputs and inputs are consistent with the aggregate representation of the Social Accounting Matrix (SAM). In the second stage, we simulate utilisation of technologies by calibrating the electricity generation model to observed demand for output at the market price. Then, for the electricity market, given the benchmark demand (d), we simulate the benchmark output of each generator $\bar{Y}_g$, as well as the benchmark price P_f, by solving following expressions as a mixed complementarity problem.

$$c^g + \mu^g \geq C \quad \perp \quad Y^g \geq 0$$

where

- Y^g is the output level.
- μ^g is the shadow value of installed capacity.
- C is the marginal cost of the generator used to cover the last unit of demand.

And it is the complementarity variable of the capacity constraint of each generator:

$$Y^g \leq \kappa^g \quad \perp \quad \mu^g \geq 0,$$

where :

- κ^g is the dependable capacity of generator g.

The equilibrium marginal generation cost C is determined by a market clearing condition:

$$\sum_{g \in G} Y^g \geq d \quad \perp \quad C \geq 0$$

where :

- G is the set of generators,
- d is electricity demand.

The price of electricity P, is given by the average generation costs

$$p = \frac{\sum_{g \in G} y^g c^g}{D}$$

where :

- D is the total demand for generation over the year.

The algebraic description of the electricity and economy model has represented in above sections. We now explain the algebraic description of the iteration process. This is similar to Lanz and Rausch (2011) strategy for their integrated model. Let $n = 1, ..., N$ shows an iteration index and consider first the economy-wide component. The electricity supply obtained from solving the electricity generation model in iteration $(n1)$ are used as input to parametrize the general equilibrium model in n. So, we can show the market clearing condition for electricity as:

$$\sum_g Y^{g(n-1)} \geq \sum_j x_j^n \frac{\partial \pi_j^{x(n)}(p)}{\partial p_i^{Y(n)}} \quad \perp p_i^{y(n)} \quad i = ele$$

So, the left hand side of the equation comes from electricity model and the right hand side is related to CGE model. In the electricity generation model, in each iteration our linear function re-calibrated to price and quantities that comes from CGE model. Therefore the demand function in iteration n is updated according to:

$$D^n = \bar{D}\zeta^n \left(1 + \epsilon \left(\frac{P^n}{\bar{P}\xi^n} - 1\right)\right)$$

$$\zeta^n = \sum_j x_j^n \frac{\partial \prod_j^{x^n} p}{\partial p_i^y} \bar{D}^0$$

$$\xi^n = P_{ele}^{Y(n)} \bar{P}^0$$

where ζ^n and ξ^n are scale factors on the n^{th} solution of CGE model and reference demand D^0 and price $\bar{P}^0$.

7 Results

In this section, the economic impact of introducing high efficient technology to the electricity intensive light metal sector is presented. Based on engineering estimation, new heat exchanger technology decreases the electricity demand

No	Commodity code	Commodity name
1	com1	Agriculture, forestry and fishing products
2	com2	Mining products
3	com3	Food and beverage products
4	com4	Wood, pulp and paper products
5	com5	Chemical products
6	com6	Primary metal products
7	com7	Ligth metals
8	com8	Electricity
9	com9	Manufacturing products
10	com10	Fossil fuel products
11	com11	Service goods

Table 2: Commodity groups

No	Industry code	Industry name
1	Ind1	Agriculture, forestry and fishing
2	Ind2	Mining
3	Ind3	Food and beverage
4	Ind4	Wood, pulp and paper
5	Ind5	Chemical
6	Ind6	Primary metal
7	Ind7	Light metal production
8	Ind8	Electricity
9	Ind9	Manufacturing
10	Ind10	Fossil fuel
11	Ind11	Services

Table 3: Industry groups

around 40 percent.

Table 4 shows the impact of large scale electricity demand reduction for households, government and investment in new Zealand. We can see there is not any change in these variables except household consumption.

No	Variable name	percent of change
1	Household consumption	-1
2	Government consumption	0
3	Aggregate investment	0
4	Household consumption price	0

Table 4: percent change in variables

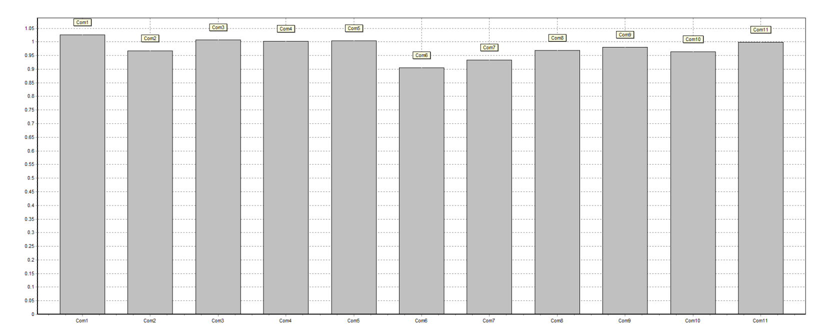

Figure 6: Aggregate supply

Figure 6 shows an increase in the aggregate supply (Armington Aggregate) in Agriculture, forestry and fishing, food and beverage and chemical products. However aggregate supply of Mining Primary metal products aluminum, electricity, manufacturing and fossil fuel slightly decreased compare to base scenario.

Figure 7 indicates that there is a huge decrease in ligth metal export as a result of decrease in the amount of aluminum production. Increase in Agriculture, forestry and fishing, mining, food and beverage, wood, pulp and paper and chemical products would also increase their export because of cheaper production cost.

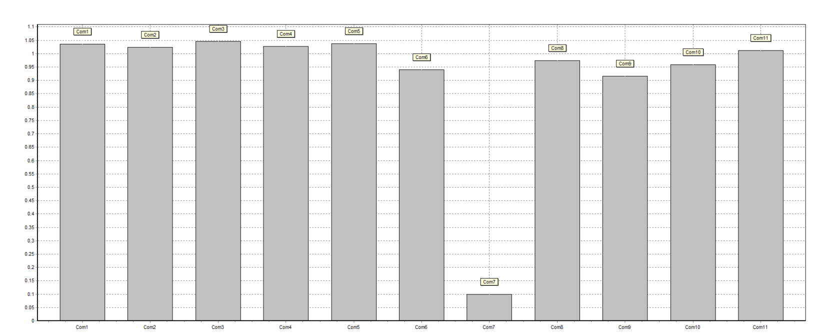

Figure 7: International export activity

Figure 8 indicates that international export prices in all sectors of the economy decreased in some extends.

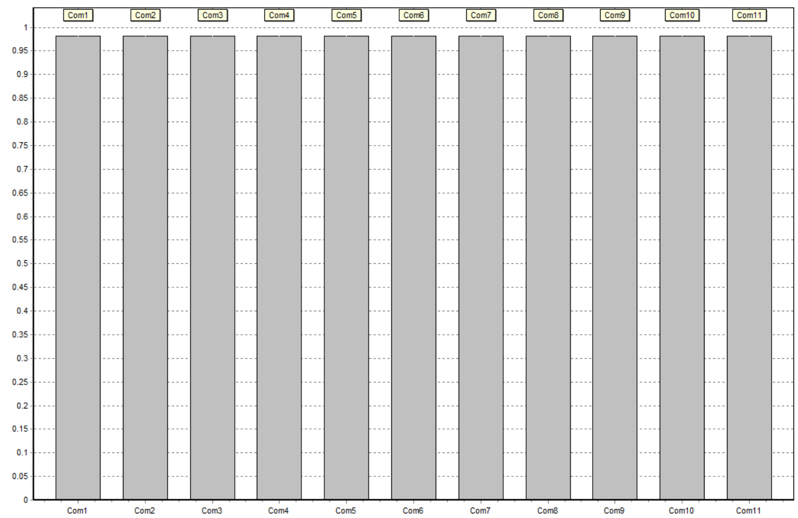

Figure 8: International export price

Figure 9 represents an increase in the price of light metals while the price of other commodities did not changed.

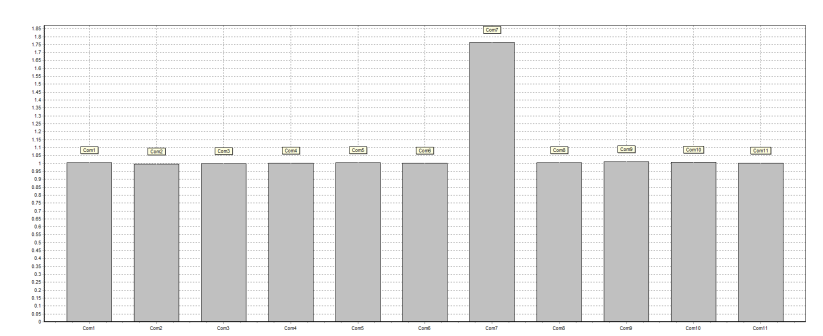

Figure 9: Composite demand price for marketed output

8 Conclusions

The economic impact of introducing new heat exchanger technology to the electricity intensive light metal production is not limited to the this sector. Electricity demand reduction from this sector, injects more electricity into the national electricity grid. This electricity surplus have two options for other sectors. First is using the same amount of electricity at a lower price decreases the marginal cost of product. Moreover, the second option is using more electricity at the same or lower price. So, more supply of electricity is an incentive for other

sectors to either increase their electricity demand and decrease their production costs. The economy can benefit from lower energy costs and compete with imported goods and has an advantage for export more into the international markets.
Some sectors are highly sensitive to energy price (e.g. metal production), and some other sectors are not affecting by a change in energy price(e.g. services). But they can benefit from cheaper intermediate input indirectly. Therefore, some sectors produce cheaper final goods that used to other sectors as an production input.
On the electricity sector, as long as demand declines there is no reason to turn on the expensive thermal generators. So, the marginal cost of electricity generation will decrease. The new equilibrium between electricity demand that comes from the economy and supply that extracts from the electricity system shows the new electricity price in the market. In this study we described the structure of a hybrid model between a top down CGE model and a bottom up optimization model for the electricity generation.
As a result, Aluminum sector can benefit from moving energy efficiency technology and other sectors in the economy will use the remaining electricity to decrease their production costs. Therefore introducing new heat exchanger technology has a direct and indirect impact on the New Zealand economy.

References

Bahn, O., Kypreos, S., Bueler, B., and Luthi, H. (1999). Modelling an international market of co 2 emission permits. *International Journal of Global Energy Issues*, 12(1/2/3/4/5/6):283–291.

Böhringer, C. (1998). The synthesis of bottom-up and top-down in energy policy modeling. *Energy economics*, 20(3):233–248.

Böhringer, C. and Rutherford, T. F. (2005). Integrating bottom-up into top-down: a mixed complementarity approach. Technical report, ZEW Discussion Papers.

Böhringer, C. and Rutherford, T. F. (2006). *Combining Top-Down and Bottom-Up in Energy policy analysis: A decomposition approach.* ZEW, Zentrum für Europäische Wirtschaftsforschung.

Böhringer, C. and Rutherford, T. F. (2009). Integrated assessment of energy policies: Decomposing top-down and bottom-up. *Journal of Economic Dynamics and Control*, 33(9):1648–1661.

Bosetti, V., Carraro, C., Galeotti, M., Massetti, E., and Tavoni, M. (2006). A world induced technical change hybrid model. *Energy Journal*, 27.

De Beer, J. (2000). *Potential for industrial energy-efficiency improvement in the long term*, volume 5. Springer.

Drouet, L., Haurie, A., Labriet, M., Thalmann, P., Vielle, M., and Viguier, L. (2005). A coupled bottom-up/top-down model for ghg abatement scenarios in the swiss housing sector. In *Energy and environment*, pages 27–61. Springer.

ElectricityAuthority (2013). Electricity in new zealand.

Frei, C. W., Haldi, P.-A., and Sarlos, G. (2003). Dynamic formulation of a top-down and bottom-up merging energy policy model. *Energy Policy*, 31(10):1017 – 1031.

Hepbasli, A. and Ozalp, N. (2003). Development of energy efficiency and management implementation in the turkish industrial sector. *Energy Conversion and Management*, 44(2):231–249.

Hoffman, K. C. and Jorgenson, D. W. (1977). Economic and technological models for evaluation of energy policy. *The Bell Journal of Economics*, pages 444–466.

Hourcade, J.-C., Jaccard, M., Bataille, C., and Ghersi, F. (2006). Hybrid modeling: New answers to old challenges introduction to the special issue of the energy journal. *Energy Journal*, 27.

Lanz, B. and Rausch, S. (2011). General equilibrium, electricity generation technologies and the cost of carbon abatement: A structural sensitivity analysis. *Energy Economics*, 33(5):1035 – 1047.

Manne, A., Mendelsohn, R., and Richels, R. (1995). Merge: A model for evaluating regional and global effects of ghg reduction policies. *Energy policy*, 23(1):17–34.

Manne, A. S. (1977). Eta-macro: A model of energy-economy interactions. *NASA STI/Recon Technical Report N*, 78:26612.

Mathiesen, L. (1985). Computation of economic equilibria by a sequence of linear complementarity problems. In *Economic equilibrium: model formulation and solution*, pages 144–162. Springer.

Mecrow, B. and Jack, A. (2008). Efficiency trends in electric machines and drives. *Energy Policy*, 36(12):4336–4341.

MED (2012). 2011 nz generation data update. Technical report, PARSONS BRINCKERHOFF, Ministry of Economic Development.

Messner, S. and Schrattenholzer, L. (2000). Message–macro: linking an energy supply model with a macroeconomic module and solving it iteratively. *Energy*, 25(3):267–282.

Price, L. and Worrell, E. (2000). International industrial sector energy efficiency policies.

Proena, S. and Aubyn, M. S. (2013). Hybrid modeling to support energy-climate policy: Effects of feed-in tariffs to promote renewable energy in portugal. *Energy Economics*, 38(0):176 – 185.

Rutherford, T. F. (1995). Extension of gams for complementarity problems arising in applied economic analysis. *Journal of Economic Dynamics and control*, 19(8):1299–1324.

Saidur, R. and Mahlia, T. (2010). Energy, economic and environmental benefits of using high-efficiency motors to replace standard motors for the malaysian industries. *Energy policy*, 38(8):4617–4625.

Schäfer, A. and Jacoby, H. D. (2006). Experiments with a hybrid cge-markal model. *Energy Journal*, 27.

Sensuß, F., Genoese, M., Ragwitz, M., and Möst, D. (2007). Agent-based simulation of electricity markets-a literature review. *Energy Studies Review*, 15(2):2.

Sue Wing, I. (2008). The synthesis of bottom-up and top-down approaches to climate policy modeling: Electric power technology detail in a social accounting framework. *Energy Economics*, 30(2):547–573.

Worrell, E. and Price, L. (2001). Policy scenarios for energy efficiency improvement in industry. *Energy Policy*, 29(14):1223–1241.

Yuan, C., Liu, S., Fang, Z., and Wu, J. (2009). Research on the energy-saving effect of energy policies in china: 1982–2006. *Energy Policy*, 37(7):2475–2480.