FUEL CONSTRAINTS ON NEW ZEALAND ECONOMY AND FREIGHT TRANSPORT: ANALYSING IMPACTS AND MITIGATION OPTIONS

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ABSTRACT

In the past few years, there has been convincing evidence of future fuel constraints due to supply limitations. The failure to address and plan accordingly to the seriousness of the issue might drastically impact on various national economies around the world. Nevertheless, there is limited knowledge about the impacts of reduced fuel availability to the economy and freight transport, which is essentially overlooked in studies, forecasts and planning. This paper presents the economic analysis of future fuel availability scenarios using Supply Constraint Input-Output models. The New Zealand economy is examined and more specifically the freight transport sector is studied. The paper also investigates potential mitigation options that could be adopted in terms of changes in technology, infrastructure and policy actions to promote sustainable freight transport. The results, achieved by the comparison of different scenarios of fuel constraints and economic growth, indicate that if no actions were taken to mitigate impacts of fuel constraints, and if they persist for several years, the total impacts on the fuel, freight transport and all other sectors would increase significantly and greatly affect the New Zealand economy. In this backdrop, technological mitigation options to reduce impacts of fuel constraints were investigated considering New Zealand's economy and geography. The analysis revealed that improvements of the existing technologies are necessary to provide a positive balance of saved energy.

Keywords: fuel constraints, impacts, economy, freight transport

INTRODUCTION

It is widely acknowledged that freight transport systems are dependent on fossil fuels availability. Goods movement is mainly performed by fuelled engines, predominantly with petroleum derivatives. Fossil fuel consumption is involved in most of the processes of the extended supply chain, from the extraction of raw materials to the final disposal of the produced goods, in particular on the transport stages of the supply chain. Every day decisions are made, in private and public levels, based on the assumption that oil and natural gas will remain plentiful and affordable.

However, there are signs of future fuel price increases and shortages. Lately, various governments have admitted the probability of fuel restrictions in the future (Dunlop, 2007; EIA, 2000; Lee, 2006). Others have also forecasted high likelihoods of increases in fossil fuel prices due to scarcity effects (IEA, 2008; MED, 2006). In the past few years, convincing evidence about the global world peak production of conventional oil ("Peak Oil") and the oil depletion issue (Campbell, 1997; Deffeyes, 2001) confirmed future fuel supply restrictions. The data suggests that "Peak Oil" is likely to happen soon. Despite the uncertainty of when peak oil may happen, a mapping of all predictions shows the probability of happening at 2015 (or before) is about 80% (Dantas *et al.*, 2007). Fuel specialists all over the world are completely convinced that in the next 20 years oil will become more difficult to find, locations will become more remote, drilling will be deeper and prices will rise, making cheap oil disappear (Lee, 2006). Additionally, the levels of carbon dioxide emissions and green house gases in atmosphere became an evident issue after the Kyoto Protocol. The solution for both problems is pointed to an urgent decrease of fossil fuel consumption, by means of shortages (Peak Oil) or reduction policies (Climate Change).

Despite the high risk of fuel constraints, there is limited knowledge about their real impacts. Passenger transport has received plenty of attention and some progress is noticed in this area (Krumdieck *et al.*, 2010; Schafer, 2000). Although freight is still less than passenger transport in terms of total energy usage and kilometres travelled, the growth in freight has been dramatic. Predictions anticipate that the energy use for freight transport will exceed that for people travel on a world-wide basis in the year 2020 (WEC, 1995). Even though there has been considerable interest in the European Union to decouple freight transport and economic growth (Kveiborg and Fosgerau, 2007; McKinnon, 2007; Schleicher-Tappeser *et al.*, 1998), freight transport is still mostly neglected by planning and policy making, and little genuine progress is observed.

Some scholars' efforts have focused in addressing the freight transport energy issues and presenting alternatives to reduce the freight fuel consumption (Ang-Olson and Schroeer, 2002; McKinnon, 1999). Researchers have also analysed how the road freight sector can rapidly save oil during a supply emergency, but do not include any quantitative assessment of policy measures (Noland and Wadud, 2009). However, the overall impact of reduced fuel availability on the freight transport sector and the economy has never been comprehensively evaluated. This lack of a systematic assessment of economic impacts contributes to a disregard of freight in the regional transportation planning (Seetharaman *et al.*, 2003).

The approach taken in this paper is focused on long-term continuous fuel shortages and assumes that the future of world oil supply is more critical than the challenges imposed by climate change. Without adequate energy supply, the world will not be able to cope with the negative effects of climate change (Lightfoot, 2006). Additionally, it is more likely that reductions in fuel availability will happen before effective policies to reduce fuel consumption are instituted as the effects of climate change become more pronounced. Recent disruptions to fuel supply, such as the fuel protests of 2000 in the UK, have confirmed their heavy impact on the economy and people's well-being and indicates a lack of resilience and preparation (Lyons and Chatterjee, 2002). However, there is little knowledge on the quantitative impact measures of fuel constraints to economy. Some have argued that there is a 1:1 relationship between percent decline in world oil supply and percent decline in world GDP (Hirsch, 2008), but this is not realistically proved.

This paper introduces a method to estimate the broader impacts of fuel constraints to the freight transport and the economy. A supply constraint Input-Output analysis is used to model the relationship between scenarios of fuel constraint and economic impacts. The New Zealand economy is studied and more specifically the freight transport sector is investigated. In the end of this paper mitigation options of vehicle and energy technologies for the New Zealand freight transport system are examined, based upon the options' energy consumption and implementation costs.

METHOD

Economic impact analysis is used to measure changes in economic activity resulting from specific program or projects (Hudson, 2001). It estimates potential economic benefits of interventions and helps in determining best value projects. It has been widely used in transportation decision making due to its ability to systematically quantify impacts to different kinds of resources, including scarce and valued resources.

There are many techniques to analyse economic impacts and they can be divided in partial equilibrium models and general equilibrium models. General equilibrium models take into account the interrelationship between sectors and markets. They have an appropriate framework to conduct economic impact analysis. Among the available techniques to apply general equilibrium models, Input-Output (I-O) models have the smaller data requirements. They also suit well this research's objectives and do not involve a great number of secondary data. Moreover, there are many commercially available I-O models and they have been widely applied to transportation analysis.

Input-Output Analysis

Input-output model, developed by the Nobel Prize winner Wassily Leontief, is a well established technique to undertake an economic impact analysis. It is, in fact, the most commonly used tool to do such analysis. Within an I-O model, each industrial sells its output to other sectors and buys inputs from the other sectors (Seetharaman *et al.*, 2003). Its popularity is based on the ability to not only compute the direct effects of a project, but also to estimate secondary indirect and induced effects, through inter-dependence relationships among sectors (Seetharaman *et al.*, 2003).

Among the different variations of I–O analysis, the supply constraint or mixed I-O model was selected. It was initially proposed by Stone (1961) to improve the evaluation of economic impacts in a case of supply constraint. Mixed I-O was designed to trace the economic implications of a reduction in productive capacity on one or more industries of the final demand. It is based on the purchase coefficients A, which shows how one sector is dependent on the others, calculating how much each sector needs to purchase from the other sectors to produce one dollar of output.

The mixed I-O approach allows the final demand of the constrained sectors and the gross output of the remaining sectors to be specified exogenously. The model is then partitioned in constrained and unconstrained sectors; represented by the indexes r and s, respectively. The new outputs of the unconstrained sectors (X_s) and the final demands of the constrained sectors (Y_r) are estimated by Equations 1 and 2. To do so, it is necessary to specify the values for the outputs of the constrained sector ($\overline{X}_r$) and final demands of the unconstrained sectors ($\overline{Y}_s$).

$$X_s = (1 - A_{ss})^{-1}(A_{sr}\overline{X}_r + \overline{Y}_s) \quad (1)$$

$$Y_r = (1 - A_{rr})\overline{X}_r - A_{rs}X_s \quad (2)$$

Where,
A_{ss} = direct requirement matrix of transactions between the s unconstrained industries;
A_{sr} = direct requirement matrix of coefficients of inputs by the s unconstrained industries of the r constrained industries outputs;
A_{rs} = direct requirement matrix of coefficients of inputs by the r constrained industries of outputs by the s unconstrained industries; and
A_{rr} = direct requirement matrix of transactions between the r constrained industries.

Model Assumptions

The assumptions that support this model are an unchanged matrix of purchase coefficients, and unchanged vector of final demand for the unconstrained sectors. The first assumption means that the input distribution patterns are constant in an economic system even after an initial constraint, and the second assumption implies that the unconstrained sectors will keep the same level of sales to final markets (households, government, private investments and exports). Even though earlier applications of the model have not indicated any problems regarding its use and have validated the technique (Davis and Salkin, 1984; Giarratani, 1976; Hubacek and Sun, 2001; Subramanian and Sadoulet, 1990), these assumptions underpin some of the model's limitations.

The first assumption indicates that there would be no input substitution and technology change, which are likely to occur as a result of an increase in fuel prices relative to other inputs. However, input substitutions and technological innovations take a long time to be developed and implemented. The second assumption suggests that the final demand of products would remain constant even after a fuel constraint, meaning that there would be no substitution effects (buying less fuel and more of other commodities, because the relative price of fuel rises) or income effects (changing households consumption pattern in face of having less money available to spend in total due to higher fuel costs).

These assumptions are particularly concerning, if the objective is to study impacts of increases in fuel prices. This paper, though, aims to analyse the impacts of peak oil translated as a reduction in the availability of fuel to the production processes, as stated before. It is expected that a reduction in fuel quantity would lead to an increase in fuel prices, at a rate determined by the price elasticity of supply (normal supply-demand behaviour).

However, oil prices have oscillated widely over the last few years, and mostly in response to short term factors such as wars, crisis, natural disasters and speculations (Williams, 2008). Amongst these causes, probably the most relevant are the geopolitical tensions and uncertainties in the OPEC's countries (Brook *et al.*, 2004) and the natural disasters, which are almost unpredictable. The previous attempts to model future fuel prices have failed to predict fuel prices for one year ahead (for a summary of these forecasts see Donovan et al. (2008)). Also, most of these models forecast that future fuel prices will remain almost constant in the next 20 years, around USD 100/barrel. Surely the future of fuel prices is highly unpredictable.

On one hand, price fluctuations are considerably important and there are many interesting discussions on this topic (Davis and Haltiwanger, 2001; Hamilton, 2003; Jiménez-Rodríguez and Sanchez, 2005; Keane and Prasad, 1996) . Jones *et* *al.*(2004) summarized many theoretical and empirical developments in the understanding of the macroeconomic consequences of oil price shocks. They are:

- Positive and negative oil shocks generate asymmetric impacts and intra- and inter-sectoral reallocations of labour, noted only in highly disaggregated models;
- Post oil shock recessionary movements of GDP are largely attributable to the oil prices and could not been avoided by alternative monetary policies;
- There is a stable, nonlinear, relationship between oil price shocks and GDP, but this relationship has been weakened with time and it is quite complex to estimate;
- The extent to which an oil shock impacts on GDP is around -0.055, as an oil price-GDP elasticity. Thus, a 10% fuel price high of 3 years would cause the GDP to reduce about 0.55% in a two year period; and
- There is still much to learn concerning price changes and economic impacts, and that there are many contradictory results that need further examination.

On the other hand, supply constraints are more effective to motivate behavioural changes than fuel prices rises, because people prefer functionality over feasibility (Krumdieck *et al.*, 2004). Thus, the discussion on how prices will behave when fuel constraints occur and how fuel prices will impact on the economy and transport system is likely to become a fierce debate, which is not of the interest of this paper. Also, despite the existence of many studies about the impacts of fuel price shocks, the effects of supply variations have not been broadly covered. Therefore, the approach taken in this paper is to examine the effect of supply constraints, ignoring fuel price increases or assuming that fuel prices would remain constant.

ANALYSING FUEL SUPPLY CONSTRAINTS ON NEW ZEALAND

When "Peak Oil" happens, there will be no excess capacity on the economy, neither there will be a perfect substitute to fuel in a short or medium term. Available renewable energy sources, such as solar, wind and biofuels will not produce enough energy to economically and environmentally substitute the use of traditional fossil fuels (Lightfoot, 2006). Also, the reduced fuel supply will not be instantly adjusted within the economic system. A likely scenario would be the continuous consumption of fuel stocks which will be quickly extinct. Subsequently the production of the other sectors will be affected. Finally, the reduced production of goods and services will impact on the whole economic system.

The mixed I-O model accounts for economic impacts in cases of supply constraints and assumes that supply is inelastic for some sectors (Miller and Blair, 1985). It considers the sector that is causing the disruption as exogenous to the system. After estimating the reduction on the constrained sector it can then calculate the impacts on the unconstrained sectors.

Context

New Zealand was chosen as a case study to analyse fuel constraint impacts due to a number of reasons. The country is mall and isolated, extremely reliant on fossil fuels. The nation is greatly dependent on international trade, mainly with Australia, the USA and Japan. Also, there are not many options to shift from traditional fuels, for instance biofuels. In addition, because of the country geography, the rail and maritime networks are underused. At last, 95% of fossil fuels used internally are imported from three main locations: the Middle East, the Far East and Australia. Thus, instabilities in fuel supplies in these places would probably cause disruptions to the national economy.

The current distribution of goods in New Zealand is mostly made by roads. In 2006/2007 approximately 92% of tonnage and 70% of tonne-km is transported by the roading network. Rail has 6% of tonnage and 15% of tonne-km, and coastal shipping has a corresponding share of 2% of tonnage and 15% of tonne-km (Paling, 2009). New Zealand has become particularly reliant on cheap air travel. The primary industries are agriculture, forestry, milk and livestock. These four industries have a significant share of total freight movements, corresponding to approximately 25% of the total tonne-km. The economy is also tourism based.

The trip-end-estimated total freight in tonnes occurs over 71% in North Island. Only the regions of Auckland, Waikato, Bay of Plenty and Manawatu-Wanganui correspond to more than 50% of tonnage. There are several courier and freight companies spread throughout the country and the goods distribution system is considered inefficient, mostly in terms of delays and operational costs; and unsustainable.

The Transaction Table

In an Input-Output analysis, New Zealand's economy is represented by its transaction table. The original table of 54 industries of the year 2005/2006 was consolidated into seven industries, three final-payments sectors (households, other payments and imports), and three final-demand sectors (private consumption, other local final demand and exports) to facilitate reproduction and analysis, as depicted in Table 1. Furthermore, the table was roughly updated to the year 2009 considering the national accounts and other statistical data (Infometrics, 2009; SNZ, 2009). It was considered that the technology available in 2006 is the same as the currently available.

The freight transport sector includes road freight, rail and water transport. Air transport and transport services, and passengers transport were added to the service sector, which incorporate all services sectors plus finance and insurance, government and administration, defence, and education. The fuel sector embraces oil and gas extraction, production and distribution; petroleum refining and product manufacturing. Sector 3 (Supply and Construction) denotes the construction sector combined with electricity generation, electricity transmission and distribution, water supply, sewerage, drainage and waste disposal services. Trade (sector 4) embraces wholesale and retail trade, as well as accommodation, cafes and restaurants. The other industries were grouped according to the 1996 ANZSIC (Australian and New Zealand Standard Industrial Classification).

Table 1 – Inter-industry transactions of New Zealand – 2008/09 (NZD millions)

Industries	Extraction (1)	Manufacturing (2)	Supply and Construction (3)	Trade (4)	Freight Transport (5)	Service (6)	Fuel (7)	Total industry demand (8)	Private Consumption (9)	Other local final demand (10)	Exports (11)	Total final demand (12)	**Total demand (13)**
Extraction (1)	4,082	11,206	284	1,094	33	635	73	17,407	724	387	3,532	4,642	**22,049**
Manufacturing (2)	1,733	13,158	5,637	6,123	113	4,274	79	31,118	11,499	2,791	29,524	43,814	**74,932**
Supply and Construction (3)	607	1,953	14,789	790	38	4,969	201	23,346	2,453	15,869	323	18,645	**41,990**
Trade (4)	1,475	3,114	2,015	3,637	478	3,571	63	14,354	21,099	4,751	7,368	33,218	**47,572**
Freight Transport (5)	745	2,040	138	1,023	1,341	497	77	5,863	412	90	101	603	**6,465**
Service (6)	2,540	6,009	3,484	9,332	995	34,777	227	57,363	37,144	33,721	9,682	80,547	**137,910**
Fuel (7)	498	796	850	323	292	511	1,055	4,324	1,211	272	638	2,121	**6,445**
Total local inputs (8)	11,681	38,276	27,197	22,323	3,290	49,233	1,775	153,775	74,540	57,881	51,167	183,589	**337,364**
Household (9)	5,088	11,612	5,176	12,340	1,360	36,936	174	72,686	0	0	282	282	**72,968**
Other Payments (10)	3,507	14,909	7,032	9,331	1,536	44,080	3,060	83,456	8,987	1,660	1,227	11,875	**95,330**
Imports (11)	1,774	10,134	2,586	3,578	280	7,660	1,436	27,447	15,060	8,811	0	23,871	**51,318**
Total final payment (12)	10,369	36,656	14,794	25,249	3,175	88,677	4,670	183,589	24,047	10,472	1,509	36,027	**219,616**
TOTAL INPUT (13)	**22,049**	**74,932**	**41,990**	**47,572**	**6,465**	**137,910**	**6,445**	**337,364**	**98,587**	**68,353**	**52,676**	**219,616**	**556,980**

As shown in Table 1, New Zealand's economy is dominated by the service and manufacturing industries, together they represent more than 63% of the total economy. Even though, New Zealand is not a major manufacturing economy comparing to other international patterns. Other representative sectors are sector 4 and 3. But the final demand and final payment sectors (12) are predominant.

It was considered that Table 1 represents the most efficient technology to produce the goods and services in New Zealand and that it cannot be quickly changed. Therefore, it is assumed that the purchase coefficients will remain constant (or optimal) even if there are variations in the composition of final demand in the near future.

The Fuel Constraints

The exact fuel constraint to be caused by peak oil is still uncertain. Past oil crisis, such as the Iranian revolution, the Persian Gulf War and the Suez Crisis had a reduction of world oil output of between 7.2% and 10.1% (Hamilton, 2003). To determine the real fuel constraint of peak oil, it would be necessary to know the exact world oil's reserves. However, OPEC's true reserves are unknown (Tverberg, 2008). The constraint analysed here is assumed as a disruption on the main New Zealand fuel supplies and an international oil scarcity. The entire fuel sector of New Zealand is considered to be affected, and the reduction on the supply of the sector is initially set to 10%. A key assumption of the model would be that the reduction of supply on the constrained sector would be evenly distributed to all purchases of that sector from other sectors. So, the fuel sector would sell 10% less to all other sectors. The final demands of the non-constrained sectors would remain stable after the fuel constraint

Thus, the total output of the fuel sector would be subject to a 10% reduction, which is equivalent to $\overline{X}_r$ equal 0.9 multiplied by New Zealand Dollars (NZD) 6,445 million. This reduction on total output of the fuel sector would represent an initial 0.12% decrease in the total economy's output.

The Impacts

Using Equations 1 and 2, impacts were calculated for the unconstrained sectors and for the national economy. Considering a fixed purchase coefficient, a transaction table for after fuel constraints was computed, as shown in Table 2.

Table 2 – New Zealand Transactions after Fuel Supply Constraints (NZD million)

Industries	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Final Demand (12)	**Total Output (13)**
(1)	4,080	11,203	284	1,094	33	635	65	17,394	4,642	**22,036**
(2)	1,732	13,154	5,632	6,122	113	4,273	71	31,097	43,814	**74,911**
(3)	607	1,952	14,776	790	38	4,967	181	23,310	18,645	**41,955**
(4)	1,474	3,113	2,013	3,636	478	3,570	57	14,342	33,218	**47,560**
(5)	744	2,039	138	1,023	1,339	497	70	5,851	603	**6,454**
(6)	2,538	6,007	3,481	9,330	993	34,766	204	57,319	80,547	**137,866**
(7)	498	796	849	322	292	511	949	4,217	1,584	**5,800**
(8)	11,673	38,265	27,174	22,317	3,284	49,218	1,598	153,529	183,052	**336,581**
Final Payments (12)	10,362	36,646	14,781	25,242	3,170	88,648	4,203	183,052	36,027	**219,079**
Total Input (13)	**22,036**	**74,911**	**41,955**	**47,560**	**6,454**	**137,866**	**5,800**	**336,581**	**219,079**	**555,660**

The 10% reduction on total output of the fuel sector would initially cause a 25.3% decrease of its final demand, from NZD 2.1 billion to NZD 1.6 billion. This change would affect the non-constrained sectors, because fuel is an input factor to all other industry sectors. Thus, non-constrained sectors would reduce their total outputs due to backward linkages, which would affect the entire economy. Comparing the total input of New Zealand before and after the constraint, the cutback would be of NZD 1.3 billion. This corresponds to a 0.24% contraction of the total economy. This might seam insignificant, but the absolute value corresponds to more than the entire coal mining and other mining and quarrying sectors' output (consolidated into the extraction sector).

The reductions of output of the unconstrained sectors would not be too significant in absolute and relative value terms. In relative terms the mostly affected sector (excluding fuel) would be the freight transport sector with a reduction of 0.18%, because freight transport is highly dependent on fossil fuels. However, in absolute values the freight transport sector would have the smallest reduction in the total output (only NZD 12 million). This is due to the freight sector's small share on the total money flow of the economy. On the other hand, the service sector would have the second highest output decrease in absolute values (NZD 44 million), but it would be subject to a small percentage reduction. This is because the service sector has considerable participation on the total output of the economy, but it has limited exposure to changes in the fuel sector.

Sector 3 (construction and supply) would have the second largest percentage reduction. Probably this is explained by the sectors' direct backward linkage to the fuel sector, as electricity generation can be reliant on fuels. It is also observed that the trade sector would have a contraction in absolute values smaller than the extraction sector, even though trade is more than twice bigger than extraction. This is because the extraction sector has high levels of fuel consumption. the service sector would have the smallest percent decline, even though it has the most expressive total input of the endogenous sectors. This is explained by the fact that fuel is not a significant input to the service sector. Hence, the economic contraction of sectors is related to the interdependency each sector has with the fuel sector and vice-versa.

Some inferences could be drawn by observing the economic structure of New Zealand regarding the allocation of the impacts to the final demand sectors. The fuel's final demand was the only one affected by the fuel constraints, due to the model assumptions. This final demand includes exports of fuel; household consumption of fuel (heat houses, fuel cars and other domestic uses); and other local final demand, which comprise government consumption, stock change and gross investment. Considering that unfinished projects would likely continue even after an initial reduction in fuel supply, plans for other investments would not immediately change and government expenditures would continue as planed beforehand. It can be argued that government consumption and investments would have the smallest reductions of output. On the other hand, the stocks probably would have greater reductions in comparison to the previous year changes. This would reduce the risks of maintaining high fuel stocks during a shortage. Thus, it is plausible that the exports and private consumption of fuel would be the most affected final demand sectors. Due to international scarcity of fuel, the exports would probably be reduced to zero to protect the internal market. Also, the household consumption of fuel would be significantly reduced, since domestic consumption generally has a higher capacity to adapt than industry demand. It is likely people would become more thoughtful on the number and distance of car trips, and shift to other forms of energy to maintain their lifestyle.

All the analyses done so far were for an open economy. If the households sector were included as an endogenous sector, a common practice in many cases, the impacts would be significantly bigger. . Closing New Zealand economy with respect to households and imposing the same 10% fuel constraint would cause the total economy to decline by 11.2%. The exalted impacts in the closed economy are explained by the fundamental role household plays in buying outputs of the entire economy and are also related to the fact that this model is highly aggregated.

Finally, it is useful to perform a sensitivity analysis of the model to different fuel constraints. Scenarios of fuel constraints were investigated, 20%, 40% and 80% reductions of fuel availability were compared to the previous 10% reduction. The results of the sensitivity analysis are illustrated on

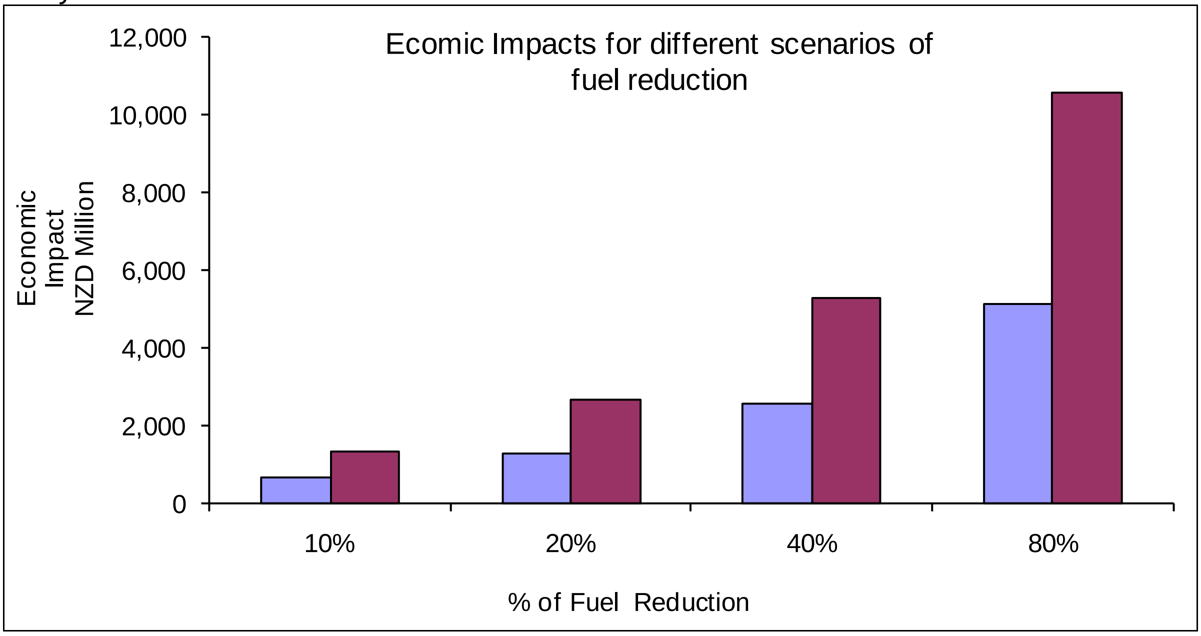

Figure **1**.

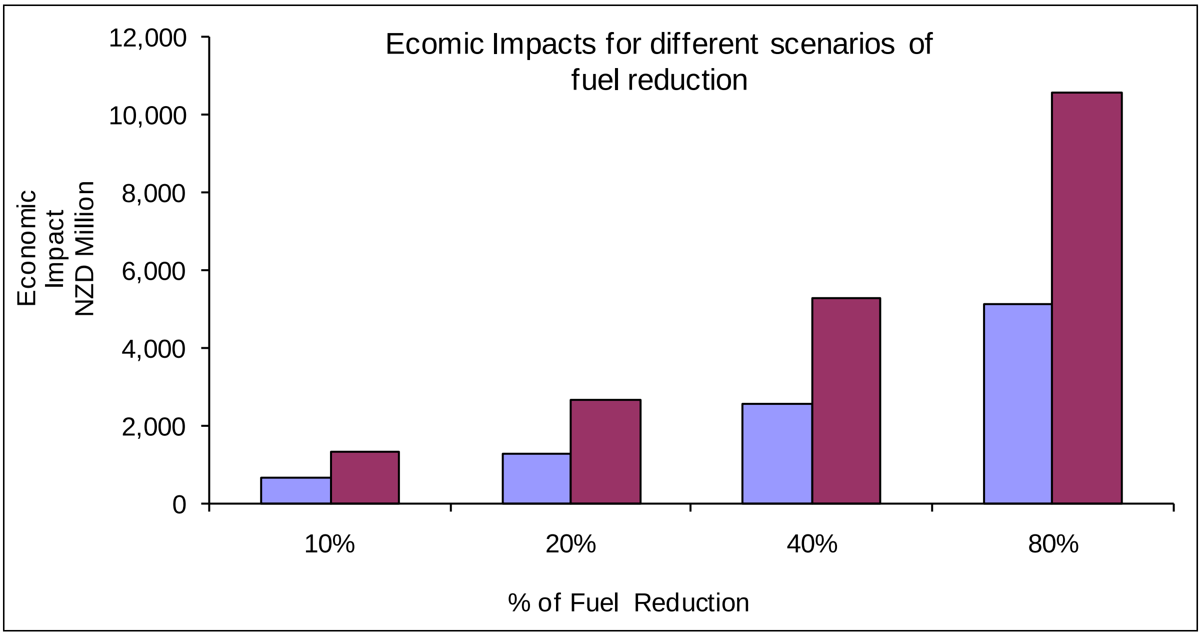

Figure 1 – Impacts of Different Scenarios of Fuel Reduction (NZD million)

A straightforward direct linear relationship between impacts and fuel constraint is revealed in

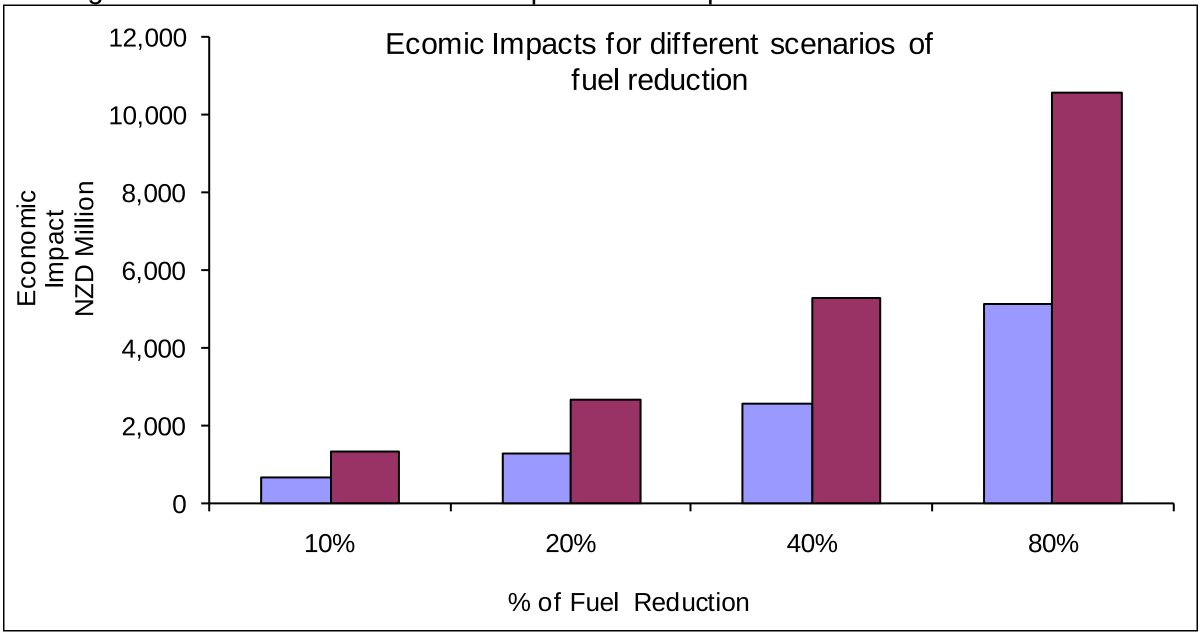

Figure **1**. Thus, the 40% fuel constraint would produce impacts two times higher than the impacts caused by the 20% constraint. However, in a closed economy, the impacts do not vary significantly with variations of fuel constraint. This is due to the most important factor affecting the economy would be actually the relationship the household sector has with the other sectors of the economy.

The Future

The analysis done so far focused on the present economic conditions. To analyse policies it is necessary to determine future consequences of decisions made today. In addition to assessing the current situation, future impacts of fuel constraints are also computed. To calculate the long term impacts it is necessary first to forecast the future economic system. The changes and adjustments of the economy can happen in terms of people's tastes, technologies, productivity, international markets, the relative size of sectors etc. In input-output modelling these changes are called structural changes, because they modify the structure of the I-O tables, more specifically the coefficient matrix. However, for a certain period of time the coefficients can be expected to remain roughly static, because changes occur slowly and relatively stable. Therefore, the model can be used, even though it may appear outdated (Carter, 1970). In previous studies, the forecast error of economic impacts for 22 years analysis was approximately 3% and the 14 years results had a 0.6% error (Miller and Blair, 1985). Thus, although individual elements can be poorly estimated, forecasts at high levels of aggregation can be reasonably precise (Parikh, 1979).

Considering a business as usual (BAU) scenario it is assumed a stable economic structure. Inferring that after the original 10% fuel constraint no changes were made to the present system and lifestyles, the subsequent years would be also subjected to 10% fuel constraints. Considering that this pattern will persist for the next 15 years, the impacts of this conjecture are shown in Figure 2. The main assumption behind this scenario is that the economic structure would not change and the fuel constraints would be the only responsible for the economic decline.

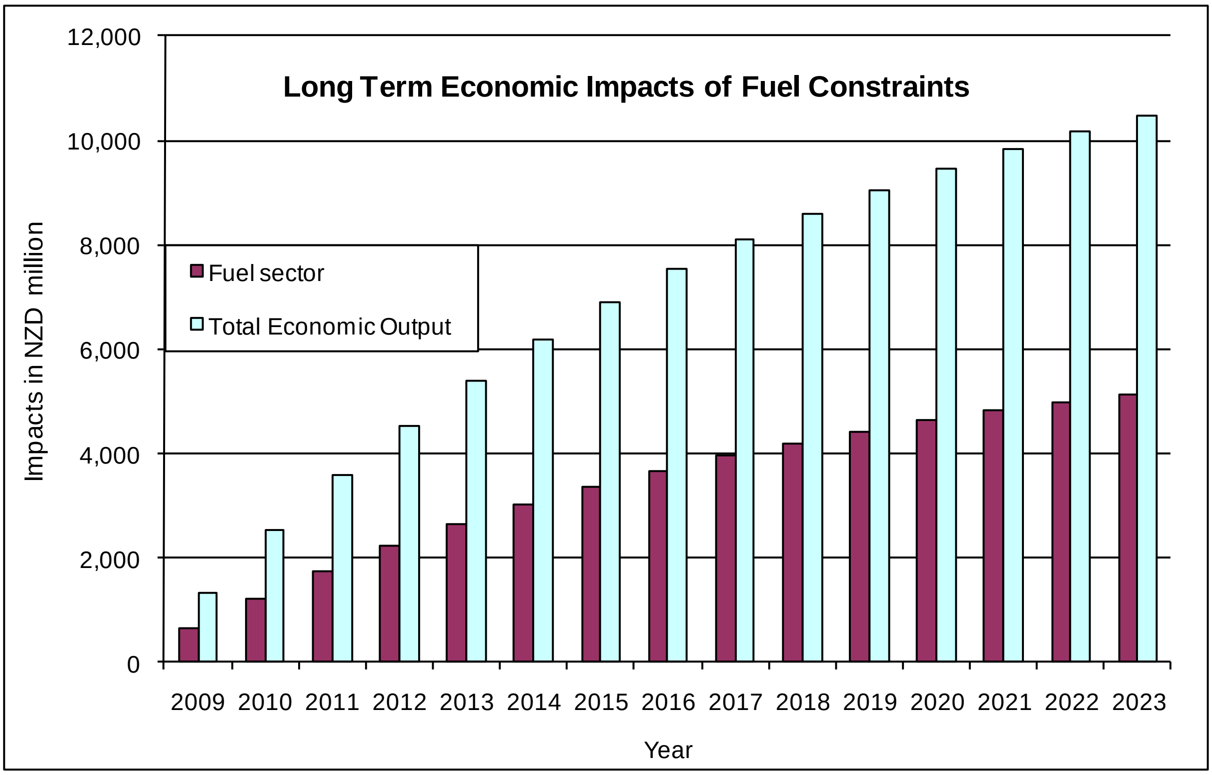

Figure 2 – Impacts of 10% Fuel Constraint on the Fuel Sector and Total Output – BAU Scenario

As displayed in Figure 2, the impacts of the 10% fuel constraint have a logarithmic temporal evolution. The total impact on the economic output after 15 years is about NZD 10,481 million and the reduction of output of the fuel sector compared to the initial year of analysis is NZD 5,118 million.

Comparing the BAU to an unconstrained scenario in which the economy follows a growth pattern, the impacts could be enormous. The growth for the initial five years were forecasted by using the production-based GDP growth projected by Infometrics (2009). The other ten years were estimated by using an average growth of 2.1%, which is the same average of the five years forecast. The difference between these two scenarios for the fuel and freight transport sectors is shown in Figure 3.

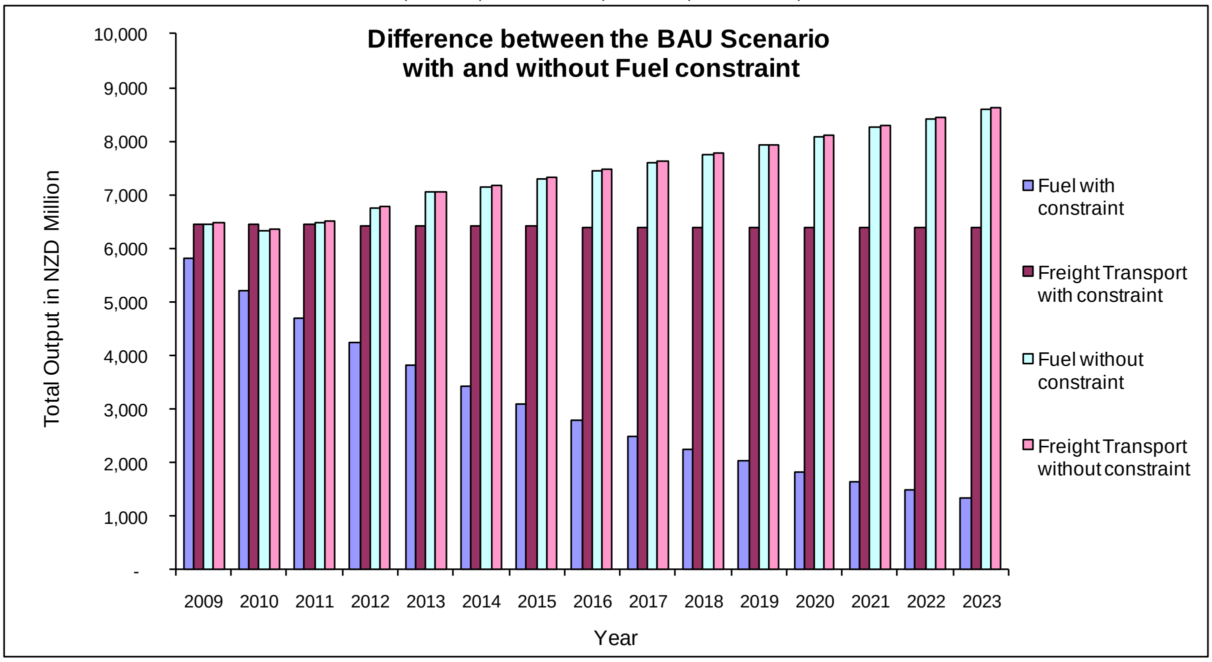

Figure 3 – Difference of Total Inputs between BAU with Fuel Constraint and without Fuel Constraints for the Fuel and Freight Transport Sectors (NZD million)

Fuel and freight transport sectors have similar outputs for the non-constrained scenario. If fuel constraints do not happen for the next 15 years, these sectors would have a constant growth and their total output would reach approximately NZD 8.6 billion. However, if continuous fuel constraints were observed, the long term impacts would be exacerbated. For instance, the 2022/2023 total input of the fuel sector with the 10% fuel constraint would be NZD 1,327 million, compared to NZD 8,597 million without constraints. Figure 4 shows the difference between the constrained and non-constrained total economies of New Zealand.

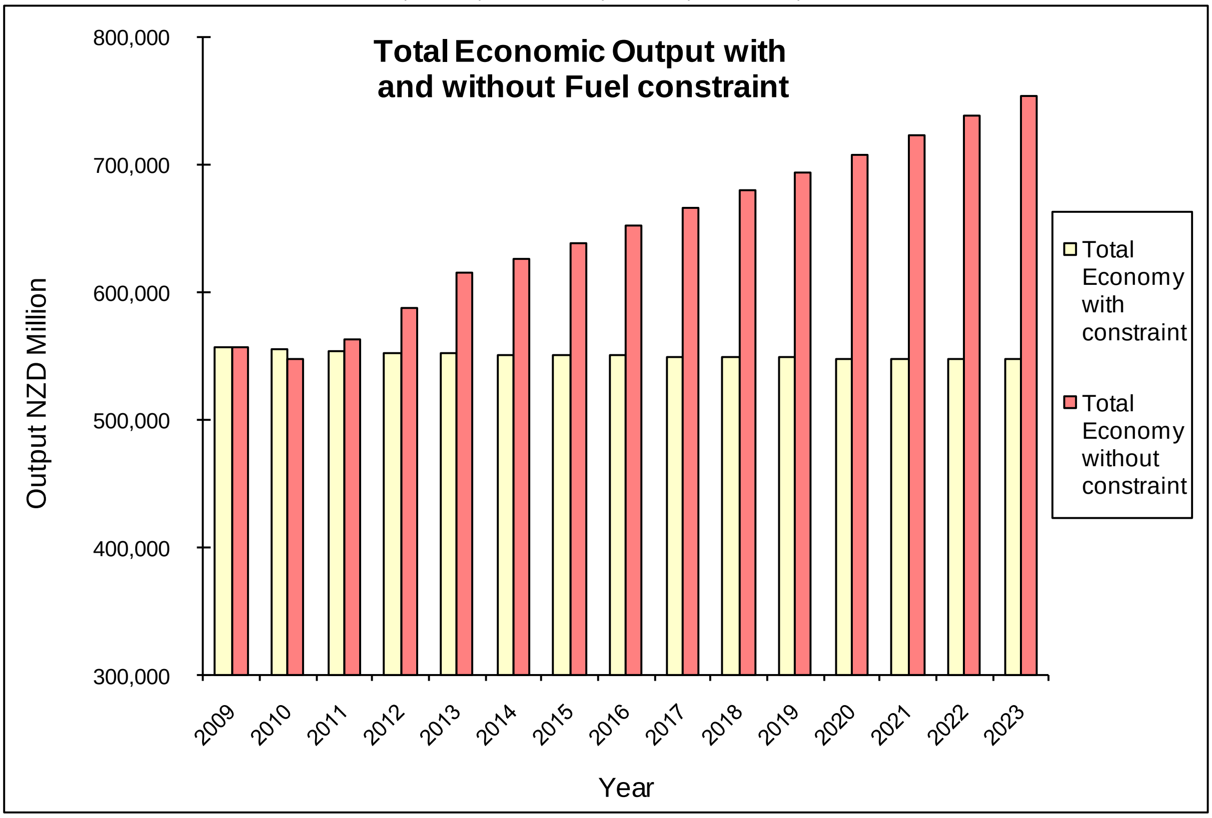

Figure 4 – Total Economic Output with and without Fuel Constraint (NZD million)

The total economy would be subject to a slight reduction over time when fuel constraints are imposed. Such a reduction would lead to almost a stagnation of the economy. However the longer term total impact of the fuel constraint scenario compared to the non-constrained scenario is significant, due to the lack of economic growth. At the end of the analysis period, the total difference between these two scenarios would be NZD 206,419 million, which represents 27.4% reduction in the economy size.

This model is not completely taking into account the responses of industries and population. It is expected that with a long term fuel shortage, such as the one here analysed, companies and population would be sensitized to reduce their fuel use and find alternative ways to substitute fuel. These changes could lead to future growth a few years after the initial shock, as new technologies and mitigation options are employed.

Mitigation Options

There are alternatives that could help to reduce the impacts of fuel constraints. Mitigation Options (MO) could be implemented at all economy levels to reduce fuel consumption. MOs to reduce fuel use of freight transport may include: reduction of vehicle speed, increasing loading rates and space utilisation, reducing empty-running, advancing vehicle routing, changing the delivery times, changing the supplier of the products to more locally produced, using alternative fuels, information technology, using more efficient vehicles (engine), enhancing vehicle technology (aerodynamics, tires, lubricants, etc), improving driver behaviour (through training and monitoring programs), using vehicles with greater capacity (less vans and small trucks), changing the land-use, adopting superior logistical trends (such as reverse logistics, rationalization of the supply chain, etc). Some of these MOs can reduce not only the fuel consumption of the freight transport but also help other sectors.

The mitigation options investigated in this study were mechanical and technological alternatives: biofuels (for ships, trucks and trains), regenerative brake (for trains and trucks), wheel motor technology (for trucks), electrification of the rail network, electric hybrid vehicles, fuel cells and hydrogen engines and skysail technology. The selection of the best alternatives should include an analysis of the options that consume less energy and are also available sooner for the three most representative freight transport modes in New Zealand: trucks, trains and ships. Data was collected in terms of vehicles energy consumption, price of energy, EROI, Mton-km carried per year and implementation costs of the mitigation options. The EROI which stands for the Energy Return On Investment is the ratio of the energy delivered by a process to the energy used directly and indirectly in that process. This case study also considers geographical and geopolitical characteristics of New Zealand.

Some of the proposed mitigation options would require significant infrastructure investments. However, the implementation costs of the mitigation options could not be calculated, especially because some are not yet available and others have not had their costs estimated elsewhere.

Biofuels

Biofuels offer the possibility of producing energy without a net increase of carbon into the atmosphere. The biggest advantage of biofuels is that they can be used with all classic engines. Trucks manufacturers as Daimler, Daf, Renault, explore various fuel types, and pride their selves for being able to produce trucks to run on bio-diesel, or bio-gas, a bio-diesel/bio-gas combo, DME (dimethyl ether), hydrogen/bio-gas and methanol/ethanol. At the same time, existing biofuels alternatives are controversial due to the use of food crops and soil resources to produce fuel.

The production of biofuels can be made by different ways, the most common way being by growing crops high in sugar and produce ethanol through fermentation, as it is observed in the USA with their corn ethanol and the sugar cane ethanol produced in Brazil. Another common method is to grow plants that contain high amounts of vegetable oil, after these oils are heated they can be burned directly in a diesel engine, or they can be chemically processed to produce fuels such as biodiesel.

The literature review studied showed that biodiesel is not an option for New Zealand, because it would require a great amount of effort to improvethe efficiency of this fuel. For instance, it was found that the energy return in one Mega Joule (MJ) of biodiesel is 0.334, or when one MJ of biodiesel is used, three MJ of energy have been consumed through the process. The price of one litre of biodiesel is about 1.76 times higher than the price of normal diesel, albeit diesel has higher taxes than biodiesel. The average fuel efficiency of a biodiesel truck is similar with a diesel one. Therefore, biodiesel uses the same amount of energy than the normal diesel engine, but it costs about 45% more. Finally, even though New Zealand has a strong potential for biofuels, its current infrastructure to produce biofuel is almost non-existent (Clark *et al.*, 2001).

Considerable improvement has been observed in the technology to produce biofuels. The traditional first generation of biofuels, produced from food crops, has been substituted, at least in the theoretical ground, to the so called second, third and fourth generation of biofuels. Second generation of biofuels are produced from the whole plant and non-food crops, but they are still carbon positive, for instance the BTL-fuels (biomass-to-liquid). Lately some analysis has been made towards different plants or genetically modified crops to produce carbon neutral (third generation), such as algae, and carbon negative biofuels (fourth generation), such as electrofuels. Still, there is no established concept for these technologies. While new generations of biofuels can be promising, they will take many years to produce acceptable results and most importantly to reduce their capital and production costs (Lane, 2010).

Electrification of the Rail Network

The topography of the North and South Islands dictates that rail network features many sinuous and hilly sections. This characteristic suggests that electric rail systems would not be very efficient and quite slow. Additionally, it is important to consider the nature of the electricity production in New Zealand, mostly supplied by hydraulic dams. (52.3%). The remaining electricity generation comes from gas (23.7%), coal (10.5%), geothermal (9.4%) and wind (2.5%), the remaining sources include wood, biogas, oil and waste heat (MED, 2009). New Zealand is nuclear free, i.e. it is prohibited to produce electricity from nuclear sources, leaving the country only with the current sources of energy. All the hydro generation is already currently exploited and the government does not intend to approve new dams to mass electricity production, due its environmental impacts. Thus, to electrify its rail network, New Zealand would have to find other means to generate electricity.

Another daunting point is the cost of the network electrification. For this calculation, the costs of a 50km electrification project of the Auckland rail network were extrapolated for the 3898 km of the New Zealand rail network. This project has shown that electrification would cost about NZD 10 billion/km. Thus, considering only the electrification costs, this alternative would take an absurd time to pay off and a huge investment. For the financial reasons electrification of New Zealand railway network was also found not to be a good option. However, this analysis has not taken into account the implementation costs of a new power plant, as well as the benefits of pollution and congestion reduction, which indicated that further analysis is required for a more accurate conclusion.

Regenerative brakes and In-Wheel motor technology

A regenerative brake is a mechanism that reduces vehicle speed by converting some of its kinetic energy into a storable form of energy instead of dissipating it as heat, as with a conventional brake (Cheng *et al.*, 2009). The captured energy is normally stored for future use in battery packs, but may also be stored by compressing air or by a rotating flywheel (Trabesinger, 2007). Two types of regenerative brake are currently employed on vehicles; the KERS (Kinetic Energy Regenerative System) is a hydraulic system and the electric system with storage of energy in a battery pack. Both systems are applied on few new trucks such as the Class8 Volvo truck and the USB Hybrid Truck, and also on hybrid trains.

The KERS is an extremely efficient process, enabling over 70 percent of the energy normally wasted during braking to be used, minimising the load on the engine and reducing fuel consumption. Previous applications in rubbish collection trucks showed that the fuel reduction could be over 40 percent, plus lower brake wear. It is also possible to reduce the size of the vehicle engine as this can be sized for peak speeds, by up to 25 percent. For original equipment manufacturers, hydraulic hybrid systems can be incorporated into existing vehicles without major modifications, minimising the cost of new technology while adding value to the product. Similarly, for end users, the technology can deliver real savings in fuel consumption and brake use while reducing both emissions and noise pollution.

The other type of regenerative brake is the electric systems, which is currently used on electric vehicles, such as the Toyota Hybrid and the Venturi fetish. The hybrid electric vehicles (HEVs) are vehicles that combine a conventional propulsion system with a Rechargeable Energy Storage System (RESS) to achieve better fuel economy than a conventional vehicle (O'Donnell, 2007). Modern mass-produced HEVs prolong the energy stored in their batteries by capturing kinetic energy by means of regenerative braking.

Regenerative brakes can also be used in trains, in which the energy put into accelerating a train and into moving it uphill is “stored” in the train as kinetic and potential energy. In vehicles with electric traction (this includes electric, diesel-electric and hybrid stock) a great part of this energy can be reconverted into electric energy by using the motors as generators when braking. The electric energy is transmitted “backwards” along the conversion chain and fed back into the catenaries. Similarly, rotating flywheels can also be used in trains.

The electric regenerative brakes can easily be coupled with another technology, the wheel motor. The wheel motor is an electric motor that is incorporated into the hub of a wheel. Thus, the internal combustion engine normally found under the hood is simply not necessary; it is replaced with at least two motors located in the hub of the wheels. These wheels contain not only the braking components, but also all of the functionality that was formerly performed by the engine, transmission, clutch, suspension and other related parts. With In-wheel technology, more batteries can be installed in the space, which would otherwise be occupied by the transmission and differential gear. It provides a significant weight and manufacturing cost economy by eliminating mechanical transmission, gearboxes, differentials, drive shafts and axles.

To apply the in-wheel motor technology it is important to notice that this is effective only for electric vehicle or hybrid vehicle. However, there is not any hybrid truck on the freight network. Thus, the study was based on the efficiency of the Wheel motor system in comparison with a conventional truck engine and implementation costs could not be calculated as the technology is not yet available in the market. The conventional truck has an efficiency of 33% and the in-wheel motor engine has an efficiency between 85% to 92%.

The regenerative breaking which can be associated with wheel motor technology can save in average 25% of energy. The price of applying this system on a vehicle has not been set precisely by the supplier, but some publications suggest that it would cost about NZD 75 thousand to implement the KERS system on a truck. Again, the implementation cost here indicated only includes the price to apply it in the truck, ignoring the infrastructure to implement the system on trucks.

Hydrogen and fuel cells

Hydrogen could be an important energy solution because it is the most abundant chemical element of the universe and produces energy when combined with oxygen. The energy stored in the hydrogen can be harnessed with the help of technologies such as fuel cells. A fuel cell is an electrochemical conversion device which converts the chemical energy of fuel to electricity. However, hydrogen is not an energy resource, except if nuclear fusion is commercially developed. To use hydrogen as a fuel, it first has to be generated by electrolysis of water or another method, such as obtained from fossil fuel. The process of producing hydrogen normally consumes more energy than the energy released when it is used as a fuel.

Some believe that hydrogen is the fuel of the future. Yet, it may take another 20 years before hydrogen engines trucks can be widely available. Some key factors which prohibit the hydrogen engines from being widely available include producing the vehicles at a reasonable price, developing the product that meets customer's demands for power and fuel savings, finding ways to directly converse the chemical energy in the form of hydrogen into mechanical energy and integrating the technology into vehicle mass production.

The Hytruck is a hydrogen-powered prototype truck, based on a Mitsubishi Canter 7.5-tonner, but its manufacturer says its technology can be mated to other makes and models. To create the vehicle, the company replaced the existing diesel motor, gearbox, differential and fuel tanks with a completely new-concept driveline, called the Hytruck H2E (Hytruck, 2009). It has fuel cells mounted under the cab producing 16kW that draw hydrogen from the 227-litre fuel tank containing 5.8kg of hydrogen at a pressure of 350bar. The energy from the fuel cells is transferred to the batteries, which are mounted where the diesel fuel tanks used to be. The fuel cells provide continuous charge to the batteries.

Nevertheless, the Hytruck is just a prototype for the moment and it is very expensive (around NZD 4million). In addition it would be necessary to adapt the fuel stations to hydrogen and produce hydrogen in large scale. Finally, the EROI of the Hytruck was estimated as 0.25, meaning that 4 MJ of energy are required for each MJ of energy used in the Hytruck, making this only a dream of technology for the moment.

Wind for ships

When it comes to transporting freight around the world, ships move by far the greatest amount, but shipping has so far been exempt from emissions restrictions. Cargo ships emit about 2.7% of the global total of greenhouse gases. This equates to 800 million tones of emissions per year — a figure that could double by 2030 as global trade increases.

One of the easiest ways to make shipping more efficient would be to slow the ships down. Fuel consumption increases rapidly with speed: doubling a ship's speed means using eight times as much fuel. Nevertheless, with the amount of freight to be shipped on the rise, and shippers demanding quick transit times, ship owners are under pressure to accelerate their vessels (Corbett and Koehler, 2003). Another way would be to use the wind as a source of energy.

The sail is another example of how the shipping industry is trying to tackle the question of energy efficiency. Wind is a free energy source and is the most economic and environmentally sound source of energy on the high seas. Yet, shipping companies are not taking advantage of this attractive savings potential at present. The reason for this is that, so far, no sail system has been able to meet the requirements of today’s maritime shipping industry.

Skysail is a product developed by a German company that consists of a large kite that is affixed to large ships. It is based in the same system developed to kite surfing and other kite sports. The SkySails propulsion system consists of a large foil kite, an electronic control system for the kite and an automatic system to retract the kite. The control system is on the tower of the boat (super structure) and the towing rope is connected close to the bow, the system is designed in such a way that optimal aero-dynamic efficiency can be achieved. A multi-level security system and redundant components guarantee the highest possible safety during operation of the SkySails propulsion. The optional weather routing system provides shipping companies with a means to guide their ships to their destinations on the most cost-effective routes and according to schedule.

The profile of the towing kite is designed in such a way that optimal aero-dynamic efficiency can be achieved. Their double-wall profile gives the SkySails towing kites aerodynamic similar to the wing of an aircraft. Thus, the SkySails-System can operate not just downwind, but at courses of up to 50° to the wind as well. In case of very strong winds, the power of the towing kite is reduced by changing its position in the wind window (relative to the horizon), without having to minimize the towing kite area. Presently, SkySails is offering towing kites for cargo ships with kite areas of approx. 150 to 600m^2. An experience with a container cargo ship (MS Beluga Skysails) from Germany to Venezuela, then to the United States, and ultimately arriving in Norway have show that high propulsion power can be achieved on halfwind, reaching and downwind courses from 90° to 270°. While the kite was in use, the ship saved an estimated 10-15% fuel. Depending on the prevailing wind conditions, a ship's average annual fuel costs can be reduced by 10 to 35% by using the SkySails-System and under optimal wind conditions fuel consumption can be cut by up to 50%.

Even though the idea of having a huge kite attached to a ship seams completely crazy at first sight, this options has showed to be very efficient. The technology was studied for the New Zealand coastal shipping network, using the average speed and energy consumption of ships in the coastal waters. The analyses showed that the costs of implementing a Skysail to a ship were almost paid off in the first year of use of the system, only through the energy saved.

Final remarks for Mitigation Options

We have observed that is very difficult to collect data, even general values, specially in terms of costs of the technologies and implementation costs. Also, mitigation options have to take in account the country's geographical, political and economical situation. Therefore, some alternatives that had bad results in this study might have better performance if applied in different countries.

After studying the mechanical mitigation options, it has been observed that the available technology is probably not enough to reduce fuel constraint impacts in a timely manner, so it is also important to study the other mitigation options, such as logistics of freight deliveries, that could probably be put in practice in a shorter time.

Finally, after studying several mitigation options it would be necessary to include them into the I-O analysis framework. Each MO could be explored in several fashions. For example, a MO that focuses on the use of an alternative fuel could take scenarios of high, moderate or no improvements. To analyse MOs it would be necessary to use either a dynamic model or integrated I-O and econometric models. When dealing with future years where mitigation options and policies are implemented, probably major modifications on the structure of the economic system would occur due to behavioural changes of households and companies. These changes would have to be modelled on a case by case basis. Hence, the characteristics of the mitigation options should be previously defined.

In this study the mitigation options were not studied in a more detailed manner due to the lack of specific data. It is important to emphasize that structural changes and calculation of future impacts are particularly important for the analysis of mitigation options. We can not treat the economy as stable after the introduction of mitigation options. These MOs will change the economic systems by means of application of new technologies, behavioural changes, production patterns and changes on the international trade market.

CONCLUSIONS AND RECOMMENDATIONS

This paper has analysed the economic impacts of fuel constraints by means of long-term continuous fuel shortages, measured in terms of quantity restrictions. Nonetheless, fuel constraints could happen for several reasons, such as wars, natural disasters, hikes of oil prices, climate change policies, international crisis and others. A supply constraint input-output analysis was used to model the relationship between scenarios of fuel constraints and economic impacts to the New Zealand economy and to its individual sectors. Even though the model was applied for New Zealand, any country could be investigated, requiring mainly its transaction table and some secondary statistical data.

The investigated scenario was a 10% reduction of fuel availability. According to the mixed I-O technique this would cause the final demand of the fuel sector of New Zealand to drop 25.3%. The most affected sector in relative terms would be the freight transport sector due to its high dependence on fossil fuels. The total economy would decline about 0.2%, from NZD 556,980 million to NZD 555,660 million. This shows that a 10% fuel constraint would not cause an impact on the total economic output of 10%, as previously assumed by other authors.

A business as usual (BAU) scenario was compared to a scenario of economic growth on longer term. It was observed that if no changes were made to mitigate impacts of fuel constraints, the total impacts on the fuel sector, freight transport sector and on the total economy would tend to increase almost linearly. In a 15 years analysis period the BAU scenario with fuel constraint would have a total economic output of 27.4% smaller than the BAU scenario without fuel constraints.

Finally, mitigation options could be put in practice to potentially reduce the impacts of fuel constraints. This study has examined vehicle and energy technologies that could help to reduce the energy consumption of freight activities. The analysis of these mitigation options in the New Zealand Freight transport system reveals the complexity of their implementation. Considering the mitigation options' energy consumption and implementation costs as part of the New Zealand economic and geographic contexts is concluded that improvements of the existing mitigation options are necessary to provide a positive balance between benefits and costs. The results have shown that the best alternatives for the New Zealand freight transport system are probably regenerative brake systems for trucks and trains, wheel motor technology for trucks and the skysail for ships. The results have also shown that biodiesel and electrification are not good alternatives for New Zealand, due to the high cost of production of energy. It would also be interesting to evaluate if the energy savings provided by the mitigation options could eliminate the economic impacts caused by fuel constraints to the freight transport sector, which is a recommendation for future work.

The approach and results presented here indicated promising opportunities to further apply I-O to model fuel constraints scenarios in the context of freight transportation. Although limitations were observed in this work, a series of recommendations can be presented in order to improve and better specify the proposed methodology. Future modelling attempts could incorporate price fluctuations in order to improve the representation of the reality. Alternatively, the current method could be improved by developing a questionnaire survey with industries to compare estimated with foreseen impacts of fuel constraints. In addition, technical coefficients need to be dynamically addressed in Transaction Tables according to future projections. Nonetheless, it is envisaged that possible modelling refinements should consider parameters that express the highly complex environment in which economic systems operate, as well as the lack of an appropriate substitute to fuel. In this backdrop, this work revealed that there is potential for studying fuel constraints through a system dynamics methodology. The system dynamics approach would be able to incorporate the mentioned characteristics of consistent changes on the economic environment, household and industries after a fuel constraint.

Finally, an integration platform between the quantitative analysis provided by the I-O Method and qualitative assessments of mitigation options could be developed. Such platform would provide both academia and industry with a powerful tool to comprehensively analyse and make decisions towards the reduction of impacts of fuel constraints in national economic systems as well as in people's wellbeing. Ultimately, decision makers cannot be deprived from such a platform, because fuel constraints have already proved to significantly change societal behaviours and the economy. Therefore, sole quantitative or qualitative approaches would possibly not incorporate all complexities needed to understand future scenarios.

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