He Tangata, He Taiao, He Ōhanga

a values-based biosecurity risk assessment framework for Aotearoa

NEW ZEALAND'S BIOLOGICAL HERITAGE

Ngā Koiora Tuku Iho

National Science Challenges

Future developments of the MPI TERM CGE model: a review of the literature

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Lincoln University: Agribusiness and Economics Research Unit

AERU Client Report
June 2023

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Client Report for AgResearch
June 2023

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Suggested citation for this report:

Saunders, J.T. (2023). *Future developments of the MPI TERM CGE model – a review of the literature*. AERU Client Report for AgResearch. Lincoln University: Agribusiness and Economics Research Unit.

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Acknowledgements

This work was funded by NZ's Biological Heritage National Science Challenge.

Definitions

AgMIP – The Agricultural Model Intercomparison and Improvement Project

AEZ – Agro-ecological Zones

CBA – Cost Benefit Analysis

CES – Constant Elasticity of Substitution

CGE – Computable General Equilibrium

ESM – Earth System Model

FAO – Food and Agriculture Organization of the United Nations

IAM – Integrated Assessment Model

LENZ – Land environments of New Zealand

MPI – Ministry for Primary Industries

PE – Partial Equilibrium

Model Definitions

AIM – Asia Pacific Integrated Model (IAM)

AgLU – Agriculture and Land Use model (Land-use)

DSSAT – Decision Support System for Agrotechnology Transfer (Crop)

EC-MSMR – Environment Canada's Multi-Sector, Multi-Regional model (CGE)

ENVISAGE – Environmental Impact and Sustainability Applied General Equilibrium model (CGE)

GIAM – Global Integrated Assessment Model (IAM)

GLOBIOM – Global Biosphere Management Model (IAM)

GTAP – Global Trade Analysis Project (CGE)

GTEM – Global Trade and Environment Model (CGE)

HadGEM2-ES – Hadley Centre Global Environment Model version 2 (Climate)

Hector – (Climate)

IMAGE – Integrated Model to Assess the Global Environment (IAM)

IMPACT – International Model for Policy Analysis of Agricultural Commodities and Trade Model (PE)

Joanna - The Business and Economic Research Limited CGE model of the NZ economy (CGE)

LPJmL - Lund-Potsdam-Jena managed Land (Crop & Vegetation)

LTEM – Lincoln Trade and Environment Model (PE)

MAGICC – Model for the Assessment of Greenhouse Gas Induced Climate Change (Climate)

MAgPIE – Model of Agricultural Production and its Impact on the Environment (IAM)

MMRF – Monash Multi-Regional Forecasting Model (CGE)

1 Introduction

This review explores the literature on economic models and their application, in relation to the potential avenues for the development and expansion of the Ministry for Primary Industries' TERM CGE model. As such, the review will focus primarily on CGE modelling and the potential linkages or expansions available for consideration. The TERM CGE model was developed in Australia, where it is primarily used, although other variations of the model exist for other nations (including New Zealand). This literature review will therefore also address some of the existing variants and modifications on the TERM model as potential avenues for the MPI-based model. The GTAP (Global Trade Analysis Project) model (and its variants) is one of the most well-known, well established, and well documented CGE models. While not all of the body of literature on the GTAP model is necessarily applicable to the TERM model, many of the underlying equation structures, features and limitations are common to CGE models, thus this body of literature will also be drawn upon.

Integrated assessment models (IAMs) are also a key part of the economic modelling literature as they are multi-component models which integrate climate and bio-physical models with economic modelling frameworks (such as partial equilibrium (PE) or computable general equilibrium (CGE) economic models). IAMs offer a potential for linking CGE models, like the MPI TERM CGE model, to climate or land models in order to broaden the range of topics which can be analysed. In particular, IAMs are used for assessing the impacts and changes under climate change and climate scenarios.

Expanding or further developing the MPI TERM CGE model will be resource intensive in researcher time and expertise. The question of where best to invest these resources depends on MPIs strategic aims and the potential expansions of the MPI TERM CGE model which may shed light onto these aims. First, as the model is New Zealand focused, specific issue which are of particular interest to New Zealand's economy, industries, land, values and political goals will be salient in a way they are not for other CGE models. Thus, the applicability of any potential expansion will be considered with its relevance for New Zealand in mind. Second, the strategic aims of MPI (2021; 2022) and the policy and research questions which are relevant to them will be considered. With these interests in mind the following review of the modelling literature also aims to highlight modifications which are possible given the TERM framework and with the data available in the New Zealand context.

2 TERM

This section addresses previous literature which utilises the TERM model and modifications therein. The two key papers address droughts and agricultural water-use, both of which are relevant to MPI's 'Sustainability| Kauneke' & 'Visible Leadership| Ngā Manukura' strategic aims as they would contribute to improving water quality and the resilience of the agricultural industry in the face of climate change.

Horridge, Madden & Wittwer (2003), use functions mapping change in agricultural production with weather data for rain deficit days in order to simulate the associated losses in agricultural production with drought conditions in Australia. Separate estimations were made for different types of crops and for livestock. The estimation was made on the relationship of regional dry-day's impact on agricultural productivity. This approach of integrating the projection of weather into the production framework, would be valuable in the New Zealand context, where increases in extreme weather under climate change will have significant impacts on the future of the agricultural sector. Wreford, Saunders & Renwick (2022), for example, indicated that the increase in frequency of severe drought due to climate change between 2030 and 2050, could potentially cost the New Zealand pastoral industry 3 billion USD on average per annum.

In a 2010 paper, Dixon, Rimmer and Wittwer utilise TERM-H20, a variant on TERM which incorporates a complex accounting of water systems in Australia. The modelling of water accounts is done primarily around the use of water for irrigation schemes for agricultural production. The paper focuses on the Murray-Darling basin which has experienced extreme water scarcity. The scarcity of water has led to a degradation of wetlands and lakes, as well as pressures on irrigators, who are unable to obtain their minimum requirements of water to continue cropping or farming. This issue is also exacerbated by an over-allocation of irrigation extraction consents, which were based on periods of higher average rainfall. The policy reform to address these issues is a government buyback of irrigation consents and the TERM-H20 modelling exercise is attempting to inform the implications and optimality of buybacks. The policy aims to balance the competing pressures and uses of the water resource, as well as address water quality and salinity.

The water trading constraint is constructed as a complimentary condition, meaning the constraint is only binding once the limit is met.

This version of TERM has 17 farm sectors and 10 irrigation sectors. The model has also been set up to include water trading. Irrigation water can be sourced from water allocations, trading of water allocations or rainfall (on land which would otherwise use irrigation). Dry land, irrigation water and unwatered irrigable land are the specific additional inputs used to map water-use in agricultural production. Unwatered irrigable land is determined by usually irrigated land that is unwatered due to shortfalls in available water (i.e., in droughts or overallocation of water resources). This allows for dryland industries to utilise unwatered irrigable land, where the change in rental values is due to whether a parcel of irrigable land is watered. This allows for a transfer of land between dry and irrigated land-uses depending on water availability.

Structurally, irrigated land uses a nested leontif specification with the inputs of irrigation water and irrigable land. This version of TERM also distinguishes between operator labour (farm family labour) and hired labour, incorporating operator labour with land as a primary factor. Dryland production can also utilise cereals as an intermediate input to substitute land (i.e., higher stocking rates using brought-on feed).

The split between dryland and irrigated land uses is performed based on data on irrigation by commodity and region taken from the Australian Bureau of Statistics.

3 GTAP

The Global Trade Analysis Project (GTAP) model is a long-standing and well documented CGE model for which there has been extensive work on the database and alternative versions for addressing different research questions, making it a fruitful source for potential modifications for CGE models.

A version of the GTAP-Bio model, GTAP-BIO-W, also features a CGE framework which takes irrigated and non-irrigated land into account (Taheripour, Hertel & Liu, 2013). Land is separated into pastureland, cropland and forestry, with water as an input into irrigated crop production (The GTAP-BIO-W does not include water use for pastureland). All agricultural industries can compete for land and land can shift from rainfed to irrigated if the biophysical constraints allow it. THE GTAP-BIO-W model divides regions into separate river basins and AEZs. Water demand and use is then mapped and tracked at the river basin level. River basin locations and outlines were taken from the Impact Water Simulation Model (Rosegrant et al., 2012), and the demands for water by crop type from Siebert and Döll (2010). Such an approach would have to be adapted for New Zealand to include water as an input for certain pastoral land-uses. This could be achieved in the same way irrigated cropland is treated. Furthermore, the IMPACT model's approach to water defines 126 global water basins, in which New Zealand as a whole is treated as a single water basin. More detailed specification at the catchment level for New Zealand would be necessary in order to track demand for water at the regional scale. Data on water use by industry would also be valuable in understanding the relative impacts of water policy by sector in New Zealand.

Portmann, Siebert and Döll (2010) also created a land-use database which defines rainfed and irrigated croplands for 29 crops in 160 regions. Taheripour, Hertel and Liu (2011) explore constraining water resources in this framework. An unconstrained model showed an underestimate of conversion of forestland into cropping and an understatement of land-use impacts. A constrained water scenario had 2.4 million less irrigated hectares globally, compared to a scenario without constraints. This demonstrates the potential difference in not including measures for mapping irrigation in crop production.

In terms of applicability for a New Zealand model, the data constraints could be restrictive. The Australia Bureau of Statistics has data on the value of irrigation production, water use for different farm types and total output. The price for water was set using the average price reported for temporary trades for water in Victoria and New South Wales. With no water trading schemes in place in New Zealand another source for water pricing would have to be used. Although unitary pricing could be assumed under Leontif production functions.

4 Trade

Exports of primary products are of high importance to the New Zealand economy, with agricultural and fishery exports accounting for around 62 per cent of total goods exports (StatsNZ, 2023). MPI's 'Prosperity| Tōnuitanga' strategic objective also references a prosperous economy based on the export of high value goods and growing Māori agribusinesses. Both of these aims are dependent on strong trade relationships, the development of global markets, and New Zealand trade policy and the trade policy of other key nations trading primary products. Thus, the potential for the MPI TERM CGE or the suite of tools available to MPI, to be able to understand global markets and be used for analysis of trade would be of significant value. Some options of how trade might be better incorporated into the MPI TERM CGE model and some relevant examples are provided below.

Wittwer and Horridge (2007) details the creation and use of *Indo*TERM, a version of the TERM model based on Indonesia. The TERM framework has also been applied to other countries including Brazil, China, Finland, South Africa, Poland, USA, and Japan (Horridge, 2011). Due to the importance of trade for exports of New Zealand's primary products, further coverage of key export markets for New Zealand is important. Utilising aggregate versions of other countries' TERM databases could help inform a more accurate picture of New Zealand's global markets. Incorporating other regions in a TERMS framework would also allow the modelling of foreign demand, rather than an aggregate of global export demand.

Alternatively, hard linking the MPI TERM CGE model with a partial equilibrium framework to map demand and trade for key commodities and markets could better represent exports and imports in a TERM framework. Partial equilibrium models focus on a particular sector of the economy (usually agriculture) and have a more detailed disaggregation of commodities within that industry. One example is the Lincoln Trade and Environment model (LTEM) (Saunders, Kaye-Blake & Turner, 2009; Saunders et al., 2016; Saunders, Guenther & Saunders, 2019), which has a focus on New Zealand agricultural policy and trade. The LTEM includes production, consumption and trade data for 23 countries and 23 agricultural commodities (which can be expanded or disaggregated given sufficient data). The LTEM could provide production and consumption projections for key export markets and trade competitors for New Zealand's primary production, which would better account for New Zealand's position in global markets, as this context is lacking from the current TERM structure.

Another example is the linking of a PE and CGE model performed in Narayanan, Hertel, and Horridge (2010), where the point is made that aggregation bias in tariffs can impact the modelling of trade policy. Aggregate sector tariff lines might give the appearance of competition where there is none, if two regions trade specific and distinct goods which are grouped at the sector level, for example. Additionally, trade policy is often targeted at the individual tariff line level, causing a high variance in tariff rates and barriers, which may be combined at the sector level. Some alternative index measures have been created to represent a more accurate index of aggregate tariff barriers (Anderson & Neary, 1996;2003; Bach & Martin, 2001).

Narayanan, Hertel and Horridge (2010) nest a simplified PE model within the GTAP structure, by splitting domestic consumption into sub-sections. They assume the ratio of domestic consumption to imports from GTAP is shared across the sub-sectors but caution this assumption as a limitation of the work and recommended estimating different ratios for each sub-sector.

Another approach to disaggregating sectors in order to perform trade analysis at the tariff line level, is shown in Aguiar, Corong & van der Mensbrugghe (2021). Building on the hybrid version of GTAP which includes a partial equilibrium component for trade analysis, GTAP-HS can examine trade flows and tariffs at the 6-digit HS level. The model utilises trade and tariff data from the TASTE program (Horridge & Laborde, 2008) which can quickly extract data from the massive ITC Market Access Map dataset. In comparative scenarios the GTAP-HS model shows differences at the HS6 level, compared with the standard GTAP framework (even with minimal levels of disaggregation), demonstrating the value of using disaggregated analysis for trade and tariff analysis.

In terms of specifying the model for incorporating trade at the HS6 sub-sector level, the framework of the GTAP-HS model required a new specification of demand to account for disaggregated products. Demand for the sub-sectors was made equivalent to the price of that sub-commodity and the aggregated price for the overall sector. Trade equations are maintained, just at the sub-sector level, and new slack variables are introduced to ensure sub-sectors add up to the sector level.

5 Land-use

As with the importance of trade in understanding New Zealand's markets for its exports of primary products, understanding land-use is important for understanding the production potential of New Zealand's primary products, as well as the ecological and environmental limits on primary production. Understanding the trade-offs within land-use is important for MPI's 'Sustainability| Kauneke Tauwhiro' strategic aim as reducing New Zealand's greenhouse gas emission will involve land-use change with an evolving agricultural sector and increased carbon storage in forestry.

The Brazil version of TERM has a focus on different land-uses (Horridge, 2011). Similarly, land-use classes could be defined for New Zealand based on the NZLRI Land Use Capability maps (Lynn et al., 2009; Landcare Research, 2021) to constrain the potential use of land resources for different types of agriculture. This would quantify the limits of certain arable, horticultural and high productive pastoral systems by region. This would also constrain the options for conversion in low-productive high-country land being, especially relevant with potential land-use changes in sheep and beef systems.

An alternative sub-classification of land could use the Agro-ecological Zones (AEZs). The AEZs are classification of land on the basis of climate, soils and other physical attributes. The AEZs have been used to give broad potentials for the productivity of different crop types depending on these factors (FAO, 1996). They can also be used to map the change in productivity over time. A number of models use the AEZs, including GTAP-BIO (Plevin et al, 2014). There are also more New Zealand specific approaches to define AEZs such as the Land Environments of New Zealand (LENZ) (Leathwick et al., 2002), although this approach has a greater focus on resource management and conservation issues than the FAO's AEZs. A New Zealand case study of the Targets for Sustainable and Resilient Agriculture model, shows an approach for integrating a number of New Zealand land-use and agricultural systems data, including the LENZ (Vibart et al., 2017).

In terms of land-use trade-offs with the forestry sector, the AgLU model used in Sands & Kim (2008), is an equilibrium model designed to allocate land between different productive uses (crops, pasture, and forest), based on the average per hectare economic returns for each land-use type. The paper also presents the AgLU approach for mapping forestry growth rates, optimal timber rotation, and optimal timber rotation given carbon pricing for carbon sequestration in productive forests (taken from van Kooten, Binkley & Delcourt, 1995). A method for accounting for ethanol from switchgrass is also presented but is of limited relevance to New Zealand. The AgLU model's framework is useful for assessing the transfer of land between different uses given different product and carbon prices. The AgLU is incorporated in a simple global equilibrium model and is intended to be incorporated in a PE framework as well. A similar separate forestry land-use module could be of use to assess the impacts of carbon pricing policy or forestry specific policy questions.

One potential drawback of the constant elasticity of substitution (CES) framework utilised in most CGE models, and of course TERM, is that changes in different factors do not necessarily equate to the total sum of factors, this is relevant when these factors are measured in the same units. This would be an issue for accounting for particular subsets of one input, such as land-use. Fujimori et al. (2014) tested this discrepancy with a version of the AIM model using a CES specification for land and a version using a logit specification. The difference in total land use between these versions was 1.3 per cent for cropland and 0.2 per cent for pastureland. The discrepancies were larger however at the regional level, with differences of over 15 per cent for some crops in some areas. This points to there being some value in recognising this limitation for regional analysis.

One, alternative framework for the usual CES specification used in most CGE models which preserves the additivity of different inputs is the 'additive constant elasticity of substitution' and the 'additive constant elasticity of transformation', which have been used in the ENVISAGE CGE model to map land-use (van der Mensbrugghe & Peters, 2020). Whether this approach would be compatible with the TERM equation structure would require further investigation.

6 Labour

The current version of the TERM model has a homogenous labour supply with cross-region mobility. The labour market could be disaggregated by either skill or source (i.e. migrant labour). This change would support MPI's 'Prosperity| Tōnuitanga' strategic aim as it would lead to a better understanding of labour market dynamics and the impacts of policies and shocks which effect immigration or education/worker training.

A 2008 paper by Horridge and Wittwer on SinoTERM, the version of TERM developed for the Chinese economy, also discussed disaggregating the labour market into skilled and non-skilled labour as a potential modification of the model. Here it is discussed in the context of being a necessary step in modelling income inequality as the low wages associated with low-skilled work are a key driver of income inequality. The point is made that this disaggregation would also allow for the modelling of skill shortages.

Migrant workers form a key part of New Zealand's labour force, with temporary migrants making up almost five per cent of New Zealand's total labour force in 2016 (NZPC, 2021); and this percentage increases in some key industries, with work visa holders making up 22 per cent of dairy employees or almost 10 per cent of all employment in the dairy industry in 2020 (DairyNZ, date unknown). This influx of labour was interrupted by the COVID-19 related restrictions on international travel.

Furthermore, the percentage of migrants with tertiary education is also higher than native-born New Zealanders and outnumbers the number of tertiary educated emigrants (NZPC, 2021). This indicates the issues of skilled and non-skilled labour and migrant labour are interconnected issues, indicating the need for a disaggregation on both factors in order to understand these impacts fully. A Department of Labour paper (2009) shows one approach to assessing immigration effects on labour market outcomes using a CGE framework. The approach used Joanna, The Business and Economic Research Limited (BERL) CGE model of the New Zealand economy, which included immigrant labour of differing skill levels. The various skill levels are based on data for labour by occupation (i.e., managers; professionals; Machine operators and labourers), which includes 'Primary sector workers' as a classification. In the studies, shocks to the immigration rate are made in total quantity of immigration and in the skill level of the immigrating workers.

7 Biosecurity

CGE and PE models have been used to support cost benefit analysis (CBAs) and help quantify the economic damages associated with current and potential biosecurity outbreaks. This form of analysis would help the MPI strategic aim of 'Protection| Whakangungu' as quantifying the economic risks of pest and disease outbreaks can help inform an appropriate and commensurate policy and industry response or preventative measures.

Two examples of this biosecurity analysis using the TERM model and its predecessor, the MMRF model, are presented in two Wittwer, McKirdy & Wilson papers (2005;2006). The 2005 paper examines an incursion of *Tilletia indica* (causing Karnal bunt) while the 2006 paper examines the potential regional costs of a pierce's disease outbreak in Australian viticulture, given a novel incursion of glassy winged sharpshooter. The modelling of these scenarios does not require any particular modifications of the TERM model. For example, the damage from Pierce's disease is modelled as a lagged decrease in production as vines are damaged or as a decrease in yields as existing vines are affected; and the exogenous decrease in capital stocks in the viticulture industry as vines are removed. The Karnal Bunt scenario shocks intermediate inputs in fungicides, a reduction in produce quality and a loss of export markets, all possible within the standard model framework.

Other people have used utilised PE/CGE models to assess the impacts of production and trade losses associated with disease outbreaks such as Avian Influenza in the US (Çakir, Boland & Wang, 2017); the risk of economic damage and welfare effects of trade with potential to spread fire blight in Australia (Cook et al., 2011); giant buttercup in New Zealand's pastoral industry (Saunders et al., 2017); and foot and mouth disease in Australia (Hafi et al., 2022) and the US (Boisvert, Kay & Turvey, 2012).

This style of analysis does not require modifications to the MPI TERM CGE model, but rather the construction of scenarios which plausibly reflect the potential damages and impacts of a given incursion, on the basis on expert analysis. Welsh et al. (2021) provides a summary of the approach and methodologies used in this style of analysis, and Kompas et al., (2017) of biosecurity CBAs using economic models.

8 AGMIP

The Agricultural Model Intercomparison and Improvement Project (AgMIP) (Rosenzweig et al., 2013) provides a range of research and comparisons of the outputs of different models. The project includes 11 models, including six CGE and five PE. Some of the tested models, such as AIM, GLOBIOM, IMPACT, IMAGE and MAgPIE combine economic and bio-physical components in their modelling. This combining of land-use and crop models with an economic framework allows for a better understanding of the drivers of trade and supply. While the majority of these approaches use a PE framework due to their focus on agricultural and climate change impacts, the integration of land-use in some models could be of value. Some of these models are also open-source (Dietrich et al., 2018).

These models have also been used incorporating the projections from the DSSAT and LPJmL crop models (Delincé, Ciaian & Witzke, 2015). Such a link would make possible the inclusion of different shared socio-economic pathways and representative concentration pathways from various global circulation climate models. The impact of these projections on average agricultural yields could be used to inform the potential change in production in New Zealand and overseas.

9 Climate Change and IAMs

Climate change is and will continue to be one of the defining issues of the 21st Century. Climate change will impact on socio-economic issues globally, impacting trade and policy. Gradual climate change will impact on agricultural production, water availability and sea-level rise. Outside of the gradual change in mean temperatures, and precipitation, climate change is also expected to increase the severity and frequency of extreme weather events, which will have further implications in increasing the volatility of agricultural markets and will impact global supply and demand (Wreford, Saunders, Renwick; 2022). These impacts intersect with MPI's strategic aims of 'Prosperity| Tōnuitanga', 'Sustainability| Kauneke' & 'Visible Leadership| Ngā Manukura' as modelling these outcomes under climate change will aid in understanding the relationship between climate change and primary production in New Zealand as well as the global market environment New Zealand will be trading into, given the global changes in supply and demand for primary products.

There are several approaches for integrating the impacts of climate change within CGE analysis such as linking CGE model frameworks with integrated assessment models (IAMs) or earth systems models (ESMs). The following section will describe some of these potential linkages.

Zhang, Liu & Wang (2021) propose a method of calculating a damage function for extreme weather events from an ESM and incorporating it within a CGE framework. The damage function is based on the Nordhaus damage function and tracks the economic impact of droughts, floods and low temperature events based on temperature, precipitation, extreme weather and climate events from the HadGEM2-ES model. The proposed damage function expands on the Nordhaus damage function by including extreme weather events and precipitation.

Van der Mensburgghe & Chepeliev (2021) convert a CGE model into an IAM by incorporating emissions datasets, marginal abatement curves (and their underlying implications for producer substitution given prices on emissions), and climate models. The paper explains the linking of the FAIR model (Smith et al., 2018) into the GTAP model. The paper also cites the simple MAGICC (Meinshausen, Wigley & Raper, 2011) and Hector (Hartin et al., 2015) climate models as potentials for linking into a CGE framework.

The approach uses U.S. Environmental Protection Agency marginal abatement curves which track the intersect between emissions prices and percentage reduction of emissions, and the share parameters of the greenhouse gas output function of the model. The CES elasticities are then calibrated to incorporate the trade-offs implied by the abatement curves. In order to implement this approach, similar marginal abatement curves for emissions pricing in the New Zealand context would have to be calculated or sourced.

Garnaut (2008), used a combination of models in their analysis modelling the costs of imposing mitigation policies in Australia, including the potential beneficial impacts from lessening some of the impacts of climate change. The models used were the Monash Multi Regional Forecasting Model (MMRF), the Global Trade and Environment Model (GTEM), and the Global Integrated Assessment Model (GIAM). Multiple models were utilised as there was no one model deemed to be able to capture all the salient factors in addressing this topic. The GIAM model includes the interaction between climate and economic factors.

Another approach for linking IAMs with CGE frameworks is shown in Gilmore et al. (2023), who assess the potential energy mix used to reach different emissions pathways, while considering the uptake of net negative emissions technologies. This is achieved by integrating the national emissions pathways from the Global Change Assessment Model (GCAM) with a multi-regional CGE model, the Environment Canada's Multi-Sector, Multi-Regional CGE (EC-MSMR). The EC-MSMR model details multiple energy generation technologies in multi-level nested CES cost functions. The energy generation is dependent on the prices of capital, labour, energy and material. The model can then assess trade-offs between the multiple options for energy generation.

The energy mix is less critical to total greenhouse gas emissions in New Zealand, than for North America, due to the large percentage of hydro-electricity generated in New Zealand (82.1% of electricity generated by renewables in 2021; MBIE, 2022). Thus, it is of less importance to MPI's strategic aims, unless there is a need to consider overall emissions targets or emissions goals which include both agriculture and New Zealand's overall energy mix. The paper also explores, however, the use of net-negative energy generation options, such as biomass generators with carbon capture and storage, and direct air capture technologies. The EC-MSMR assumes biomass generators utilise agricultural goods as a feedstock (alongside the other inputs considered with other energy generation methods). Although as the model does not have an explicit land-use component the trade-off between the use of agricultural goods as feedstocks for energy generation and for food or feed is not considered. This approach may help in assessing the viability of these technologies as a component of New Zealand's overall emissions profile. This would be an important component of the analysis in the New Zealand context, given the size of the agricultural industry and the importance of primary exports to New Zealand's economy and terms of trade.

The GCAM (Calvin et al., 2019) is open-source and thus accessible to researchers. The GCAM model links land, energy, climate, water, and socio-economic systems. The Hector model is incorporated into CGAM as the basis for the climate carbon-cycle portion of the model.

10 Conclusion

This report summarises some of the salient literature on CGE models and the potential for expansions, modification or linkages with other models, with reference to the viability of use in developing the scope of research and analysis the MPI TERM CGE model could perform; the relevance to the New Zealand context; and MPIs strategic aims.

Key areas identified include existing expansions of the TERM model; the different version of the GTAP model; links with PE models for trade analysis; land-use modules; disaggregating the labour market; and the integration with climate models, ESMs or IAMs.

Of the presented options the most immediately feasible and valuable (dependent on changes in MPIs strategic aims and areas of research interest) would be detailing the water/irrigation use by region, as performed in the Australian context in Dixon, Rimmer and Wittwer (2010). Such an addition would help support regional councils in their water allocation decision-making and would help understand the links between water policy settings, agricultural production and nitrate leaching.

The linking of the MPI TERM CGE model with a PE framework for better understanding agricultural trade and trade policy, would help inform the potential for New Zealand agri-businesses to transition to high value goods, increasing New Zealand's export earnings and create a more sustainable and less resource/emissions intensive agricultural sector.

Finally linking the model with an open-source model which includes climate projections (such as GCAM), would be a low-cost method of incorporating the impacts of climate change on New Zealand production.

All of the developments listed above would greatly aid in the coverage and usefulness of the MPI TERM CGE model.

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