A Theoretical Frameworks to Link a Computational General Equilibrium Model with an Energy Model
An Application to New-Zealand

[1*] Hossein Ehteshamnia , [2] Nathaniel Robson

[1]Research fellow, Department of economics -ESSEC Business School -France

(*Corresponding Author) Email:hossein.ehteshamnia@essec.edu, ORCID ID: 0009-0004-6573-4993

[2] Economist, School of Economics and Finance - Victoria University of Wellington, New Zealand
Email:nathaniel.robson@vuw.ac.nz, ORCID ID: 0009-0001-0775-0408

ABSTRACT

This paper proposes a methodology to link a CGE model with an Energy model. Specifically, an iterative procedure ; linking the CLIMAT-DGE model with the TIMES-NZ model is introduced. The linking methodology benefits from a precise representation of energy and technology choices offered by TIMES-NZ, incorporated into CLIMAT-DGE`s coherent macroeconomic structure. By adopting a two-way linkage, we not only seek to increase the model`s consistency but also to add methodological value to this study. Finally, potential applications of this methodology in studying the structural changes in New Zealand`s energy system and their implications for the economy are discussed.

JEL Classification : Q5,Q4,Q43, Q50

Keywords: Energy system models, Climate and Energy Policy, Soft-linking models

[1] Postal Address : 3 Av. Bernard Hirsch, 95000 Cergy, France, PO BOX:111
Tel-Fax : 00989913792089 , Mobile : 00989046658532 ,correspondence email :ehtesham.n.h@gmail.com

1. INTRODUCTION

New Zealand's first Nationally Determined Contribution (NDC1) sets a headline target of a 50 % reduction of net emissions below the gross 2005 level by 2030. Energy technologies are at the heart of emission mitigation strategies and are likely to face a structural change. Moreover, the increased climate policy emphasis is likely to affect the entire economy and the interactions between the sectors as well. It is therefore crucial to have a precise representation of technology choices in achieving NDC1 and access the macroeconomic effects of energy transitions.

The interactions between the economy, energy sectors, and climate policies can be modeled either by bottom-up engineering approaches, often in partial equilibrium, involving detailed representations of the energy sector, or using top-down energy-economy models representing the aggregated effects of energy and climate policies in monetary units. One major advantage of top-down energy models is the endogenous assessment of economic and societal effects which facilitates the understanding of energy policy impacts on the economy. On the other hand, top-down models suffer from a lack of technological detail and deliver rather generalized information.In contrast to macroeconomic modeling, bottom-up modeling approaches incorporate a high degree of technological detail which enables them to present very detailed pictures of energy demand and energy supply technologies, as well as plausible technology futures (,.Labriet et al 2015). However, they fail to capture region-wide or sectoral effects not directly related to the energy sector (Lanz et al., 2011).

Top Down and Bottom Up are also frequently linked with each other in the so-called "hybrid" models to allow for more detailed assessments. currently energy system modeling is moving toward hybrid modeling (,.Labriet et al 2015). According to Hourcade et al. (2006), a high-quality hybrid model system should incorporate at least three properties: i) technological explicitness, ii) microeconomic realism, and iii) macroeconomic completeness.

In the context of hybrid modeling, this work introduces a methodology to link a CGE model with an energy model. Our integrated model benefits from addressing repercussions across sectors and regions, offered by the CGE model, without losing the sectoral detail. In other words, the linked energy model provides additional quality assurance and credibility of CGE-based assessment by more robust sectoral foundations and explicit technologies.

In the context of New Zealand`s economy, Diukanova et al. (2008) and Fernandez et al. (2015) have used the CLIMAT-DGE model, Energy Efficiency and Conservation Authority (EECA, 2021) has used the TIMES-NZ model, and Fernandez et al. (2018) and Wanget al. (2021) have linked a CGE to a bottom-up agricultural model. However, we are not aware of any studies that adopt model-linking frameworks in the context of energy studies in New Zealand. To fill this void, we propose linking CLIMAT-DGE to TIMES-NZ. This framework allows us to benefit from each model`s strength; a consistent description of the interactions between all sectors of the economy, offered by CLIMAT-DGE, and the technological richness of TIMES-NZ. Moreover, we adopt a two-way linking approach not only to increase the consistency of our model but also to add additional "methodological value ", since there is little work done using the two-way linkage method in the context of national CGE models. In terms of applications, CLIMAT-DGE, with TIMES-NZ, will specifically enable to study of structural changes in New Zealand`s energy system along the low carbon transition path and analyze the response of the economy to such energy transition.

Section 2 provides a brief discussion of the methodological aspects of the linking framework by looking at the general and specific challenges of this approach and proposes a method to overcome them. Section 3 introduces the details of the models. Section 4 discusses the methodology used to link the models. Section 5 provides scenarios to reflect the potential applications of our proposed method and the final section concludes.

2. METHODOLOGY

Two general approaches can be distinguished in model linking. In a one-way linkage, the information is shared in one direction, i.e. the outputs from one model serve as exogenous parameters or variables in another model. Conversely, a two-way linkage takes into account the feedback between models. The two-way linking approaches are based on the iterative or sequential calibration methods which consist of repeatedly interchanging certain variables between models until mutual consistency is achieved. (Delzeit et al., 2020).

Best practices depend on the modeling objective: one-way linking is sufficient if the focus is on an economy-wide picture based on given sectoral pathways/constraints. Two-way linking is a better choice if modelers seek a broader PE/CGE consistent picture with multiple dimensions.

Furthermore, if the interest is in the results of key variables in all models involved in the linking rather than in the "receiving" model alone, a two-way link is preferable over a one-way link. (Delzeit et al., 2020). This is the case in this research proposal, since we aim to capture the emissions and energy mix variables from the PE model and the general equilibrium effects of policy interventions from the CGE model. Based on the above discussion, we adopt a two-way linking approach corresponding to the fourth type in the figure below.

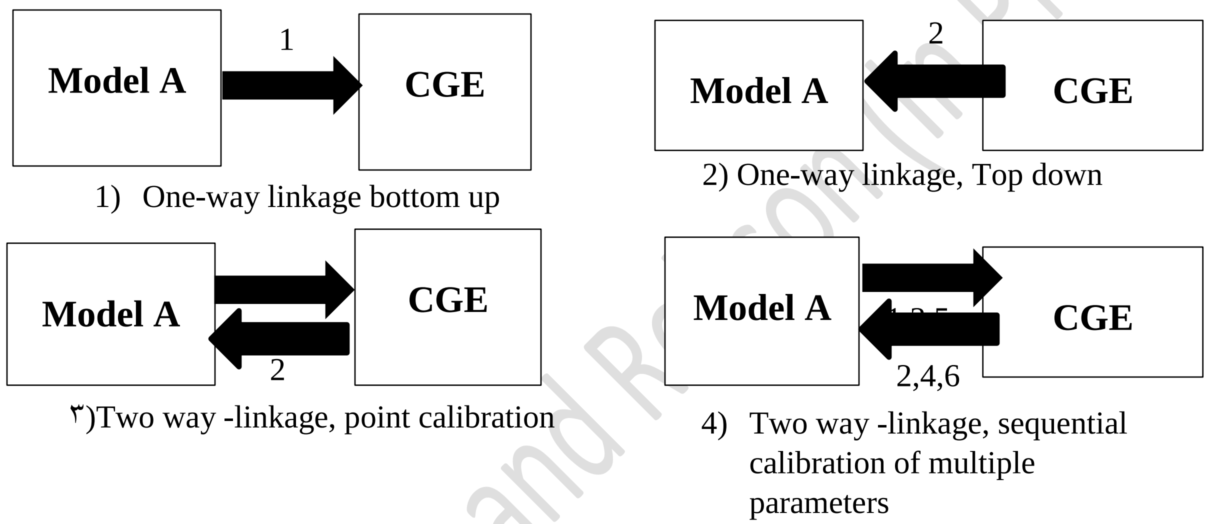

Fig. 1. Overview of PE-CGE linking approaches (Delzeit et al.,2020)

Moreover, the literature sometimes distinguishes between soft and hard linkages, albeit with different connotations: Wene (1996) focuses on the technical link by distinguishing between data exchanges controlled by model users versus computer programs (Delzeit et al., 2020).

Regarding soft links versus hard links, what matters is the degree of convergence of the overlapping variables between the two-way linked models, whatever the method used to compute the combined solution (Delzeit et al., 2020). The advantages of soft-linking can be summarized by practicality, transparency, and learning. Likewise, the advantages of hard-linking can be characterized by productivity, uniqueness, and control. (Wene,1996).

3. THE MODELS

The models of this study are selected in a way that they can be a good representative of their respective model type; they both have been developed quite recently and they have both been applied to study the impacts of low-carbon developments and policies.

Moreover, the preference given to a regional model over a global model in this study is mainly due to policy analysis considerations since most of the policy-making takes place at the national level important features of several key sectors concerning energy, environment, and economy, are typically well described. The availability of reliable and detailed data facilitates a more complex model representation (e.g., more detailed sector representations), and since the linking[2] approach can address more complexity, it provides advantages from a national policy perspective (Riekkola et al., 2017). There are examples in Riekkola et al., (2017) and Helgesen et al., (2018) of national studies on climate policy, using linking procedures.

3.1 CLIMAT-DGE

The Climate Mitigation, Adaptation and Trade in Dynamic General Equilibrium (CLIMAT-DGE) model, developed by Land Care Research, is a top-down dynamic, multi-sectoral, and multiregional CGE model that describes the global economy and generation of greenhouse gas (GHG) emissions with a strong focus on New Zealand as a distinct region. (Fernandez et al., 2015)

CLIMAT-DGE uses the Global Trade Analysis Project (GTAP) dataset that accounts for 129 regions and 57 economic sectors. The base year of the benchmark projection is 2007 (the latest year included in GTAP); the model then develops a benchmark projection of the economic variables and GHG emissions (from human activities), and simulates scenarios to evaluate the impacts of mitigation policies. Based on long-run conditions and constraints on physical resources that restrict the opportunity set of agents, the model predicts the behavior of the economy, energy use, and emissions by region and sector. CLIMAT-DGE is coded using the

[2] Krook et al., 2017, use a different definition for soft and hard link. Our hard linking approach matches the soft linking definition of Krook et al., 2017.

Mathematical Programming System for General Equilibrium (MPSGE) package in GAMS. (Fernandez et al., 2015).

CLIMAT-DGE is based on the dynamic version of the MIT-EPPA model (Babiker et al., 2008). The equilibrium is maintained under the following conditions:

a) Zero profit: The satisfaction of this condition is assured concerning aggregate consumption, investment, capital, and level of production respectively, using the following equations.

$$E_t^{c}(p_{it}, p_{jt}) - p_t \geq 0 \,, C_t \geq 0 \,, [E_t^{c}(p_{it}, p_{jt}) - p_t]\, C_t = 0 \quad (1)$$

$$E_t^{I}(p_{it}, p_{jt}) - p_{t+1}^{K} \geq 0 \,, I_t \geq 0 \,, [E_t^{I}(p_{it}, p_{jt}) - p_{t+1}^{K}]\, I_t = 0 \quad (2)$$

$$r_t^{K} + (1 - \sigma)p_{t+1}^{K} - p_t^{K} \geq 0 \,, [r_t^{K} + (1 - \sigma)p_{t+1}^{K} - p_t^{K}]\, K_t = 0 \quad (3)$$

$$E_{jt}^{Y}(p_{it}, p_t^{F}) - p_{it} \geq 0 \,, Y_{it} \geq 0 \,, [E_{jt}^{Y}(p_{it}, p_t^{F}) - p_{it}]\, Y_{it} = 0 \quad (4)$$

Where E_t^{c} is the unit expenditure function, p_t is the consumer price index, C is the aggregate consumption level , E_t^{I} is the unit investment cost function, I_t is the level of investment , p_t^{K} is the price of capital , K_t is the level of capital stock and r_t^{k} is the rate of return on capital , E_{it}^{Y} is the unit production cost function, Y_{it} is the level of output and p_{it} is the output price. Please note that subscripts i , j and t stand for commodities , sectors and time respectively while σ is depreciation rate of capital .

b) Market Clearing : Supply equals demand in the commodity market ,primary factors markets (labor,capital,energy) and in capital accumulation respectively,according to the following equations :

$$\sum_j D_{ijt}^{ID}(p_{jt}, y_{it}) + D_{it}^{C}(p_{it}) + D_{it}^{I}(p_{it}) + D_{it}^{M}(p_{it}) - D_{it}^{X}(p_{it}) - y_{it} \geq 0 \,, p_{it} \geq 0$$

$$[\sum_j D_{ijt}^{ID}(p_{jt}, y_{it}) + D_{it}^{C}(p_{it}) + D_{it}^{I}(p_{it}) + D_{it}^{M}(p_{it}) - D_{it}^{X}(p_{it}) - y_{it}]\, p_{it} = 0 \quad (5)$$

where D(.) are the compensated demand functions, and where the superscripts ID denotes intermediate demand, C final demand, I investment, X exports and M imports.

$$\sum_j D_{jt}^{F}(p_t^{F}, y_{it}) + F_t^{F} \geq 0, p_t^{F} \geq 0 \,, [\sum_j D_{jt}^{F}(p_t^{F}, y_{it}) + F_t^{F}]p_t^{F} = 0 \quad (6)$$

Where D_{jt}^F are factor demand functions, F_t^F is factor supply, and p_t^F is the price of factor service (wages and resource rents).

$$I_t + (1-\sigma)K_t - K_{t+1} \geq 0, p_t^K \geq 0, [It + (1-\sigma)K_t - K_{t+1}]p_t^K = 0 \quad (7)$$

c)The income-expenditure balance conditions: This condition states that the present value of the stream of incomes over the agent's lifetime equals the present value of the agent's expenditures over their lifetime and the sum of the agent's income and their borrowings in any current period must equal the sum of their expenditures and savings.The following equations assure the satisfaction of the income-expenditure condition:

$$p_0{}^K K_{0+} \sum_{Ft} p_t{}^F F_t{}^F - P_{t+1}{}^K K_{t+1} = \sum_t P_t \ C_t \ (8)$$

$$P_t + C_t + E_t I_t + S_t = \sum_F p_t{}^F F_t{}^F - r_t{}^K K_t + B_t (9)$$

Where S is saving and B is borrowing.

3.2 TIMES-NZ

The Integrated MARKAL-EFOM2 System (TIMES), developed by the International Energy Agency is an energy-economic model generator for local, national or multi-regional energy systems, and provides a technology-rich basis for calculating energy dynamics over a long term, multi-period time horizon (Riekkola et al., 2017).

TIMES-NZ is a technology-based optimization model that represents the entire New Zealand energy system, encompassing energy carriers and processes from primary resources to final energy consumption.it is a bottom-up model which requires a detailed description of energy technologies, processes and costs, plus additional infrastructure such as transmission and distribution systems, fuel production and processing, and energy security considerations. TIMES uses a linear-programming solver to minimize the total discounted energy system cost over the entire modeled time horizon. The cost minimization is achieved by choosing between technologies and fuels to meet expected energy demand.

4.LINKING THE MODELS

The major challenges of linking the models are twofold: i) Differences in model scope and concepts ii) Differences in data aggregation and data definition .

We refer to steps outlined by Wene (1996) to identify the differences of CLIMAT-DGE and TIMES-NZ: i) identifying basic differences between the models; ii) identifying overlaps; and iii) identifying and deciding upon common exogenous variables. (Riekkola et al., 2017).

The main differences between the two models are that i) CLIMAT-DGE is a general equilibrium model while TIMES-NZ is a partial equilibrium model ii) CLIMAT-DGE represents the flows of materials, capital labor and energy in monetary terms while TIMES-NZ is based on physical energy flows (in energy units) with a representation of materials (in mass or volume), renewable energy credits (in number) and taxes (in monetary terms). iii)in TIMES-NZ the production of goods is exogenous while in CLIMATE-DGE they are endogenously determined by model.

The main overlap of the models is that they drive the energy demand for each sector in the economy, and these variables will in turn determine the resulting emissions. This variable will be governed by TIMES-NZ since it offers a more detailed picture of the energy sector.

Moreover, since models use different statistical sources, harmonizing the variables that are exogenous to both models is crucial as the baseline assumptions have a great impact on model results. However, some variables are not possible to fully harmonize such as biomass or hydrogen resources which have limited representation in the CLIMAT-DGE model.

Finding common measuring points at which the macroeconomic model and the energy system model can interact is the first step in linking the two models. Mappings should be defined in geographic regions, sectors and commodities between the two models. In identifying the connection points we refer to the methodology suggested by Riekkola et al., (2017); focusing on improving the assumptions required by the receiver model through the results generated by the sender model, Riekkola et al., (2017) suggest using "direction-specific "connection points i.e. one direction when transferring information from CLIMAT-DGE to TIMES-NZ and one direction when transferring information from TIMES-NZ to CLIMAT-DGE.

4.1 The linking procedure

This section briefly describes a procedure inspired by Riekkola et al., (2017) and Helgesen et al., (2018) to overcome the linking challenges. Generally speaking, demand projections from CLIMAT-DGE will be fed into TIMES-NZ while the energy system feedback into CLIMAT-DGE is based on the results from TIMES-NZ.

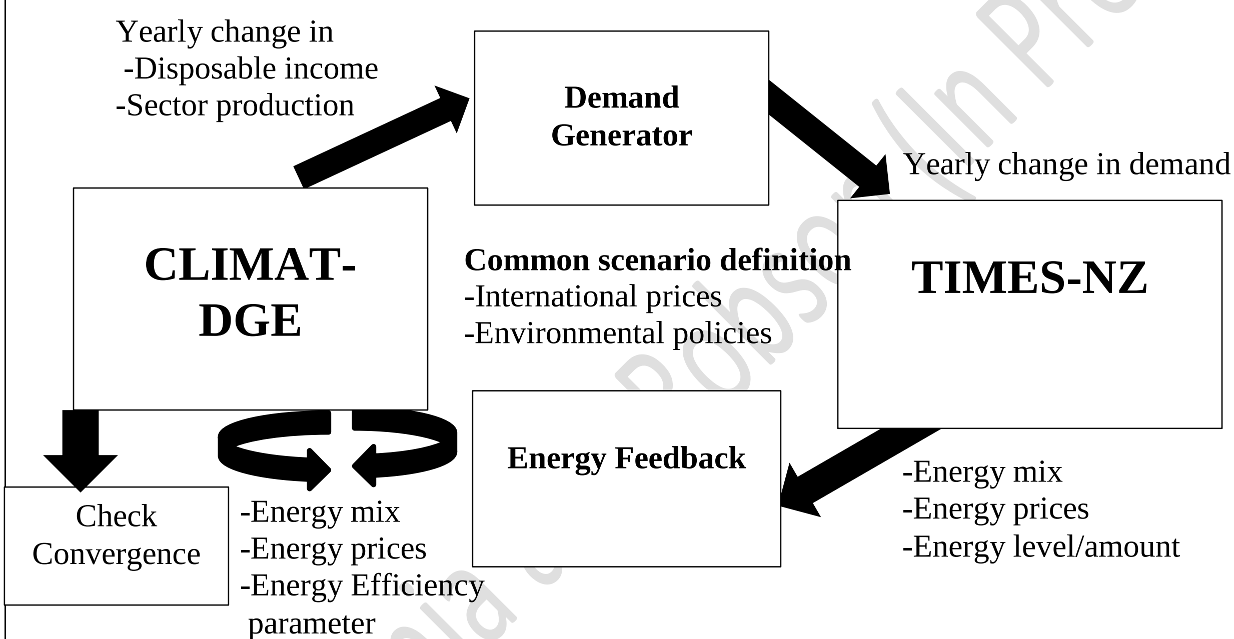

Fig. 2. Overview of the linked model – adapted from Riekkola et al., (2017) and Helgesen et al., (2018)

The demand generator translates economic development parameters from the CLIMAT-DGE model to demand for energy incentive goods in the TIMES-NZ model. Many approaches have been suggested in the literature. For instance, Riekkola et al., (2017) use the historical correlation between the demand for a commodity in physical units as described in TIMES and the corresponding sector growth in monetary units according to the national accounts. Helgesen et al., (2018) assume specific energy intensities for each industry and region, measuring the input of energy service per production quantity. Moreover, the household expenditure from CLIMAT-DGE will be used as a driver for energy service demand in TIMES. Regarding transportation, the amount of interregional trade combined with inter-regional transport and trade margins and direct consumption of transport services by households and firms will determine the demand.

The energy feedback from TIMES-NZ makes the energy efficiency parameter endogenous to CLIMAT-DGE which is normally exogenous. Moreover, the energy mix in CLIMAT-DGE is determined completely by the results from TIMES-NZ. To facilitate this transformation, the production function in CLIMAT-DGE needs to be changed so that the substitution elasticity between different energy inputs is set to zero i.e. Leontief representation.

Moreover, changes in investment flows due to large structural changes in the energy system might not be captured satisfactorily since there is no link between investment demand and the rest of the economy. To overcome this limitation Labriet et al., (2010) and Helgesen et al., (2018) suggest incorporating a technical progress parameter into capital consumption while Riekkola et al., (2017) suggests disaggregating the powers sector to generate a link between power technologies and the demand for capital investment.

Each model needs to be modified before being linked. More precisely, the price elasticity of the energy demand of TIMES-NZ should be deactivated since it must use the demand vectors provided by CLIMAT-DGE. The major modification of CLIMAT-DGE is to introduce new energy forms not present in the model such as hydrogen, biomass, etc. This requires re-writing the nested CES functions of the model.

Finally, we need to define a convergence criterion by calculating the relative changes of variable values between iterations and comparing them it against a chosen tolerance. If all changes are below the tolerance, the iterations have converged.

5. APPLICATIONS

Our proposed methodology can serve best as a structure to assess scenarios regarding structural changes in New Zealand`s energy systems and the economic implications of such energy transition. The former could be analyzed using the outputs from TIMES-NZ and the latter could be analyzed using the outputs from CLIMAT-DGE.

In exploring structural changes in New Zealand`s energy system Luke et al., (2018) propose a good research question: Given all low-emissions generation technologies present either social, commercial, or technological risks that could prevent their deployment, what is the impact of pursuing a narrower set of technological options? Moreover, in exploring the implications of energy transitions, one can think about how the chosen emission-reduction pathway affects economic activity and employment of the nation as a whole. To this aim one can consider a baseline scenario, as benchmark, which does not include any climate policies and a scenario consistent with the NDC1 target.

Another interesting theme to explore is the implications of alternative emission trading schemes and their implications on the economy. Hence, one can consider several scenarios with different ETS (Emissions Trading Scheme) configurations to examine their macroeconomic effects. Specifically, examining the macroeconomic impacts of incorporating the energy sector in an ETS. Finally, to assess the two-way linking methodology one can compare the analysis obtained by the linked model with standalone CLIMAT-DGE and TIMES-NZ models. These scenarios are reflected in the table below. Note that an extra ambitious scenario is also included which reflects the 2050 zero emissions case.

Scenario	Climate Policy	ETS
Baseline	No	NZ-ETS
Commitment	YES(NDC1)	a) NZ-ETS b) Incorporating Electricity sector in ETS c) Incorporating Transport sector in ETS d) Incorporating Manufacturing sector in ETS
Ambitious	YES (2050 Zero Emissions)	

Table 1. Applications of the linking methodology: Climate scenarios for New Zealand
(Model assessment scenarios proposed by authors)

The NZ ETS (NZETS) is among the world's earliest market-based emission trading systems operated at a national level (ICAP, 2019). The scheme covers six gases, namely, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons. (Wang et al., 2021). Table 2 summarizes the NZETS impact studies that adopted computable general equilibrium (CGE) approaches.

Author(s)	Model class	ETS coverege
Diukanova and Andrew (2008)	Static CGE	All the ETS sectors and agriculture, no cap-and-trade, captures CO2e that involves CO2, N2O and CH4 emissions
Fernandez and Daigneault (2015)	Dynamic CGE	Primary sectors, manufacturing and value-added sectors, and energy sectors, global cap-and-trade, captures CO2 and non-CO2 GHGs that include CH4, N2O and 14 fluorinated gases .
NZIER (2008)	Static CGE	All the economic sectors and agriculture, no cap-and-trade, captures CO2e that involves CO2, CH4, N2O, HFCs, PFCs, and SF6 .
NZIER (2018)	Dynamic CGE	All the economic sectors and agriculture, no cap-and-trade, measures CO2e .

Table 2. Applications of CGE models in studying New-Zeeland`s emission trading scheme (adapted from Wang et al., 2022)

6. CONCLUSIONS

This study proposes a methodology to link a CGE model with an energy model using an iterative procedure. The linking methodology combines the precise representation of energy and technology choices, offered by the energy model, with the coherent macroeconomic structure, offered by the CGE model. The benefits of our proposed two-way linkage not only increase the model`s consistency but also add methodological value. Moreover, this methodology is applied to two models for the New-Zealand, namely CLIMAT-DGE and TIMES-NZ. Furthermore, applications of this methodology have been suggested by discussing several climate scenarios.

FUNDING

No funding support.

AUTHOR`S CONTRIBUTION

Conception, design, and writing of the manuscript: Ehteshamnia. H; supervision and edit: Robson. N.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

ACKNOWLEDGMENTS

We want to express our gratitude regarding suggestions for improvement of earlier versions of the manuscript by three anonymous reviewers.

REFERENCES

[1] Babiker, M., A. Gurgel, S. Paltsev & J. Reilly (2008): A Forward-Looking Version of the MIT Emissions Prediction and Policy Analysis (EPPA) Model. *Joint Program Report Series Report* 161, 18 pages (http://globalchange.mit.edu/publication/15538)

[2] Château, J., Magné, B., & Cozzi, L. (2014). Economic implications of the IEA Efficient World Scenario. *OECD Environment Working Papers*. https://doi.org/10.1787/5jz2qcn29lbw-en

[3] Delzeit, R., Beach, R., Bibas, R., Britz, W., Chateau, J., Freund, F., Lefevre, J., Schuenemann, F., Sulser, T., Valin, H., Van Ruijven, B., Weitzel, M., Willenbockel, D., & Wojtowicz, K. (2020). Linking global CGE models with sectoral models to generate baseline scenarios: Approaches, opportunities and pitfalls. *Economic Analysis*, 5(1), 162–195. https://doi.org/10.21642/jgea.050105af

[4] Diukanova, O., Andrew, R., & Lennox, J. (2008). Emission trading in New Zealand: Computable general equilibrium model and evaluation. Auckland, New Zealand: *Landcare Research*.

[5] Diukanova, O., & James, R. L.(2008). Emission trading in New Zealand: Computable general equilibrium model and evaluation. *Landcare Research . prepared for the Ministry for the Environment*

[6] Energy Efficiency and Conservation Authority 2021 New Zealand Energy Scenarios TIMES-NZ 2.0 - *A guide to understanding the TIMES-NZ 2.0 model*, Wellington, New-Zealand ,ISBN: 978-1-99-115220-6 Published in May 2021 by Energy Efficiency and Conservation Authority (EECA) Wellington, New Zealand .

[7] Fernandez, M., and Adam Daigneault. "The climate mitigation, adaptation and trade in dynamic general equilibrium (CliMAT-DGE) model." *Landcare Research Contract Report LC2156 prepared for the Ministry for the Environment* (2015).

[8] Fernandez, M. A., & Daigneault, A. J. (2018). MONEY DOES GROW ON TREES: IMPACTS OF THE PARIS AGREEMENT ON THE NEW ZEALAND ECONOMY. *Climate Change Economics*, 09(03), 1850005. https://doi.org/10.1142/s2010007818500057

[9] Helgesen, P. I., Lind, A., Ivanova, O., & Tomasgard, A. (2018). Using a hybrid hard-linked model to analyze reduced climate gas emissions from transport. *Energy*, 156, 196–212. https://doi.org/10.1016/j.energy.2018.05.005

[10] Koutsandreas, D., Spiliotis, E., Doukas, H., & Psarras, J. (2021). What is the macroeconomic impact of higher decarbonization speeds? The case of Greece. *Energies*, 14(8), 2235. https://doi.org/10.3390/en14082235

[11] Krook-Riekkola, A., Berg, C., Ahlgren, E. O., & Söderholm, P. (2017). Challenges in top-down and bottom-up soft-linking: Lessons from linking a Swedish energy system model with a CGE model. *Energy*, 141, 803–817. https://doi.org/10.1016/j.energy.2017.09.107

[12] Labriet, M., Drouet, L., Vielle, M., Loulou, R., Kanudia, A., & Haurie, A. (2015). Assessment of the Effectiveness of Global Climate Policies Using Coupled Bottom-up and Top-down Models. Fondazione Eni Enrico Mattei *(FEEM).* http://www.jstor.org/stable/resrep01141

[13] Lanz, B., & Rausch, S. (2011). General equilibrium, electricity generation technologies and the cost of carbon abatement: A structural sensitivity analysis. *Energy Economics*, 33(5), 1035–1047. https://doi.org/10.1016/j.eneco.2011.06.003

[14] NZIER. (2008). The impact of the proposed emissions trading scheme on New Zealand's economy. Retrieved from *https://nzier.org.nz/static/media/filer_public/fa/9a/fa9a8658-fe6a4dcb-b00c 099604e60209/nzier_-_quantitative_evaluation_of_proposed_ets.pdf*

[15] NZIER. (2018). Economic impact analysis of 2050 emissions targets. Retrieved from https://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/NZIER%20report%2020 Economic% 20impact%20analysis%20of%202050%20emissions%20targets%20-%20FINAL.pdf

[16] Reedman, L. J., Kanudia, A., Graham, P. W., Qiu, J., Brinsmead, T. S., Wang, D., & Hayward, J. A. (2018). Towards zero carbon scenarios for the Australian economy. *In Lecture notes in energy* (pp. 261–276). https://doi.org/10.1007/978-3-319-74424-7_16

[17] Wang, Y., Sharp, B., Poletti, S., & Nam, K. M. (2022). Economic and land use impacts of net zero-emission target in New Zealand. *International Journal of Urban Sciences*, 26(2), 291–308. https://doi.org/10.1080/12265934.2020.1869582

[18] Wene, C. (1996). Energy-economy analysis: Linking the macroeconomic and systems engineering approaches. *Energy*, 21(9), 809–824. https://doi.org/10.1016/0360-5442(96)00017-5