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A linear programming input–output model for mapping low-carbon scenarios for Vietnam in 2030

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ABSTRACT

The intended nationally determined contribution (INDC) of Vietnam to the 2015 United Nations Climate Change Conference (COP21) is a 25% reduction in greenhouse gas (GHG) emissions relative to the business-as-usual (BAU) scenario by 2030. There are various measures proposed in the INDC, but studies to assess their potential effectiveness are still needed. An input–output based linear programming model is developed in this work to evaluate the maximum GHG emission reductions which can be achieved, given various climate change mitigation strategies. Six scenarios are considered to identify the highest GHG emissions reduction that can be achieved by the year 2030. These scenarios include BAU, the consideration of two different levels of differentiated sector growth, the adoption of a low-carbon electricity mix, energy efficiency enhancement for final consumption, and energy efficiency enhancement in the agriculture, transport and waste sectors. Each scenario quantifies the sector final demand, sector gross output, sector GHG emission load and the impact on human health. Results show that the best strategy is to simultaneously implement all of the identified low-carbon measures, which achieves a 24.6% reduction in overall GHG emissions in comparison to BAU levels.

1. Introduction

The impact of economic activities on climate has caused serious global concerns. Rising atmospheric levels of greenhouse gases (GHG), and particularly CO_2, from the continued consumption of fossil fuels are driving climate change, which in turn poses a serious threat to humans and ecosystems (De Schryver et al., 2009). The Kyoto Protocol developed by the 1992 UN Framework Convention on Climate Change (UNFCCC) to reduce GHG emissions including CO_2, CH_4 and N_2O (UNFCCC, 1998) urged countries to commit to explore various strategies to reduce GHG emissions. Countries have thus explored various strategies to meet their emissions reduction targets. For example, decarbonized electricity emerged as the dominant strategy in the simulations of Williams et al. (2012) for meeting the GHG reduction targets in California, while Cohen (2017) focused on GHG emissions reduction strategies in solid waste management. Recent work has recognized that too much focus on GHG emissions reduction might result in adverse unintended consequences, such as the increase of other environmental impacts (Kouloumpis et al., 2015) or negative effects on economic growth and social welfare. These effects differ from country to country, depending on the state of economic development and structure (Fan et al., 2010).

Vietnam is currently in the process of rapid industrialization (Mazyrin, 2013). Since the year 2000, the Vietnamese economy has prospered, with an average annual economic growth rate of more than 5% (PricewaterhouseCoopers, 2017). As a result of this rapid economic development, energy consumption in the country has also grown (MNRE, 2014) along with GHG emissions. In addition, the agricultural and industrial sectors (including waste treatment activities) also contribute large amounts of GHG emissions (MNRE, 2014). Nguyen and Nguyen (2014) reported that total GHG emissions generated from energy sectors, agriculture, forestry and other land use (AFOLU) and waste sector are projected to quadruple by 2030 relative to the year 2005, reaching 686.5 million tons of CO_2 equivalent ($MtCO_2e$) under the business-as-usual (BAU) scenario. As a non-Annex I country under Kyoto Protocol, Vietnam is not required to reduce GHG emissions. It has, however, ratified the agreement to make an effort to reduce emissions from the energy, agriculture and the transportation sectors (KEPA and GreenID, 2014).

In the 2015 Paris Climate Conference (COP21), Vietnam's intended nationally determined contribution (INDC) commitment is to reduce its GHG emissions by 25% by the year 2030. This reduction is evaluated relative to the emissions projections under

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the BAU scenario (UNFCC, 2015a). However, this commitment is dependent on the availability of international support. Various measures have been proposed to reduce GHG emissions to meet this target (UNFCC, 2015b). The measures focus on either reducing GHG emission intensity from electricity and other energy sectors, or applying energy efficient technologies to promote energy conservation throughout the economy. The former involves increasing renewable and clean energy in the national electricity mix, and the application of low-carbon technologies in transport, waste treatment and agriculture. As mentioned above, these measures to reduce GHG emissions may constrain the growth of Vietnam's economy, especially if the most productive economic sectors are also the most pollutive (KEPA and GreenID, 2014). Hence, it is particularly relevant for decision-makers and the government to evaluate how pollution mitigation strategies influence economic growth (Oliveira and Antunes, 2004).

Input–output (IO) analysis (Leontief, 1936, 1970) provides a framework for linking economic activities with their associated environmental impact. IO analysis captures the interdependencies between various sectors of an economy through aggregated supply chain linkages (Miller and Blair, 2009). The basic IO model can be extended to capture other aspects of an economic system. Hoa et al. (2016) for example, applied the inoperability input–output model (IIM) proposed by Haimes and Jiang (2001) and the vulnerability index developed by Yu et al. (2014) to develop a multi-criteria model for disaster vulnerability assessment resulting from the implementation of a biofuel policy in Vietnam. The extension of IO analysis, which takes into account environmental impacts, has been used for fuzzy multi-objective optimization of multi-regional bioethanol supply chains (Tan et al., 2008, 2009); in optimizing supply chains under water footprint constraints (Aviso et al., 2011); and in identifying the role of sectors as pollution contributors (Nguyen et al., 2018).

The value of IO analysis is further enhanced when it is coupled with linear programming (LP) to allow optimization to be performed instead of mere analysis (Vogstad, 2009). A recent review of the LP-IO approach outlines the advantages of this hybrid framework in comparison to the traditional IO model (Oliveira et al., 2016). The LP-IO can identify the appropriate level of sectoral activity to optimize a given objective function (e.g., to maximize gross domestic product) while satisfying the balance of sectoral production levels. Furthermore, LP-IO may provide a more complete evaluation of efficient production possibilities and economic effect of potential policies and allow for the study of trade-offs between conflicting objectives (Oliveira et al., 2016). For example, Quaddus and Holzman (1985) used LP-IO for economic planning in Bangladesh, while Hsu et al. (1987) applied it for assessing trade-offs between GDP and energy use to support energy planning in Taiwan. The LP-IO framework has been employed to investigate the effect of mitigating CO_2 generation in Taiwan while maximizing gross domestic product (GDP) (Chen, 2001). It has been used for estimating the macroeconomic costs of CO_2 emission reduction in China's economy (Fan et al., 2010), and for assessing the trade-offs between economic, energy and environmental (E3) objectives in Brazil's economy (De Carvalho et al., 2016). This model was also applied to optimize the gross domestic output (GDO) in the Greek economy in consideration of energy, GHG, and final demand constraints (Hristu-Varsakelis et al., 2010); and later extended to integrate the impact brought by solid waste (Hristu-Varsakelis et al., 2012). Recently, Cayamanda et al. (2017) developed a fractional programming (FP) IO model, which aims to minimize the carbon intensity of the Philippines in consideration of economic growth and climate policies outlined in the Philippine INDC. Their work also considered the potential CO_2 emission reductions measures for the Philippines. However, other GHGs such as methane (CH_4) contribute to climate change as well, and a clearer picture of global warming potential can be derived when other GHG emissions are considered in the evaluation. In addition, it has been shown that GHG emissions are also linked with other impacts, such as those which affect human health (West et al., 2013).

There has been limited work on evaluating how GHG emissions eventually impact human health. According to McMichael et al. (2003), the GHG generation, which contributes to climate change, causes an increase in various diseases such as diarrhea, malaria and heat stress. This may decrease peoples' longevity, or may contribute towards reduced levels of health. The evaluation of the effects of GHG generation can be conducted by looking at midpoint and endpoint impact indicators (Forster et al., 2007). At the midpoint, GHG emissions are assessed using the radiative forcing indicator or global warming potential (GWP), while the impact of GHG emissions is converted into damage indicators at the endpoint. The most common endpoint indicator for human health damage is measured in terms of Disability Adjusted Life Years (DALY), which is defined as years of life lost due to premature death and years of life spent with disability (Murray and Lopez, 1996). Goedkoop et al. (2009) has found that the application of DALY has been useful for assessing the human health impact from GHG emissions.

Macro-economic and sectoral levels studies on assessing the economic impacts of climate policies in Vietnam have not been done comprehensively. Such policies may include promoting cleaner and more efficient technologies. To address this gap, this paper develops an LP-IO optimization model to determine how to achieve minimal GHG emissions in kg of CO_2 equivalents. In addition, this work extends the evaluation to account for human health using DALY as an indicator. Different scenarios based on given climate policies and economic growth targets are considered against the BAU scenario. The modeling framework is applied for the 18-sector IO model of the Vietnam economy, looking at its growth trajectories to 2030. The rest of paper is organized as follows. The modeling framework is discussed in Section 2. Section 3 mentions the six different scenarios considered. Results and discussions from these scenarios are then analyzed in Section 4. Section 5 then discusses some implications of the results with regards to the development of national policies. Finally, the conclusion and recommendation for future work are given.

2. Modeling framework

The implementation of climate policies which aim to reduce GHG emissions will have an impact in the development of economic sectors. There may be a need to readjust the economic productivity of certain sectors due to limitations imposed on the growth of sectors with high emissions. This can constrain a country's macroeconomic development. The conflict between economic growth and GHG emission mitigation is something that a decision-maker needs to contend with. In this work, LP-IO is developed to minimize the total GHG emissions in consideration of Vietnam's continued economic growth amidst the implementation of low-carbon measures. To implement optimization, this model allows economic sectors to achieve different levels of productivity.

The LP-IO model parameters and variables are defined as follows:

Model parameters:

$\mathbf{A}$ technical coefficient matrix
$\mathbf{I}$ identity matrix
$\mathbf{x_L}$ column vector for the minimum level of total sector output
$\mathbf{x_U}$ column vector for the maximum level of total sector output
$\mathbf{y_L}$ column vector for the minimum level of the sector final demand
$\mathbf{y_U}$ column vector for the maximum level of the sector final demand