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A stronger energy strategy for a new era of economic development in Vietnam: A quantitative assessment

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ABSTRACT

Energy security has been a major concern in developing countries because of rapid economic development and population growth, low power generation capacity, and unwell-developed transmission infrastructure. Vietnam in this context has been under energy security threats for more than a decade and is currently having a new power policy to strongly develop power generation and distribution networks. It is expected that the country's economy is able to develop substantially due to massively additional energy supply once completing the plants and distribution networks but the likely impacts are still undefined. This paper extends an economic electricity-detailed model to examine the potential impacts of such a new power policy in Vietnam. We find that the policy will decrease the prices of both fossil-based and renewable-based electricity significantly by 40%–78% under a 2030 target scenario, benefiting all sectors in the economy to substitute for fossil fuels. Households are particularly benefited as evidenced by 5.64%–19.19% increases in per-capita utility. Overall, the Vietnamese economy is significantly advantaged with real GDP increasing by 5.44%–24.83% over different scenarios, which are much higher than the findings in other countries. More importantly, the policy moves the country to a low-carbon energy structure in the near future.

1. Introduction

Global warming and the sea level rise have become worldwide concern for decades, as increasingly frequent natural disasters are occurring in many regions around the world (Alexander, 2017). In this context, many countries have sought to implement climate change policies to mitigate greenhouse gas (GHG) emissions released into the atmosphere (Simshauser and Tiernan, 2018). New technologies have also facilitated the use of cleaner energy resources in electricity generation, production and transportation to lower the emissions levels (Kusumo et al., 2017; Silitonga et al., 2018). Many countries also regulate to strengthen power generation from renewable resources (Nelson et al., 2019; Simshauser, 2018). However, it is more challenging for developing countries, as having nationwide cleaner technology or renewable power plants is costly and beyond their financial capacity. Therefore, some countries, in the short term, have to facilitate both fossil-based and renewable-based power development to ensure national electricity security, while development of fossil-based power can be reduced and ultimately eliminated in the long term.

Vietnam has developed coal-fired and renewable power plants in the short term to sufficiently supply electricity for economic development, as well as the growth of its population. Only in the middle and long term will renewable energy be more focused for development as dependence on coal-fired power is mitigated. Specifically, Vietnam signed the United Nations Framework Convention on Climate Change and the Kyoto Protocol to contribute to the international effort in tackling climate change. The country has implemented energy policies to lower GHG emissions (Nong, 2018), as well as considered powerful climate change policies, such as an emissions trading scheme (Nong et al., 2020). However, Vietnam has experienced electricity shortages for years due to highly

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increasing demand of 8% per year (Danish Energy Agency, 2017). As a result, the Vietnamese Government has recently issued a Power Development Plan, aiming to increase electricity generation in the coming decade. The Plan has different milestones for capacity installation increases until completion in 2030 (Table 1).

In the short term, although the target is to considerably develop renewable energy, coal-fired power generation is also focused and targeted for development due to relatively low installation and operation costs compared to other technologies. However, massive development of renewables, excluding hydropower, will be pursued in the long run. Hydropower was developed strongly in the past decades due to the natural environment of the country (Nguyen-Tien et al., 2018). However, due to environmental issues, hydropower development has been declining. Nguyen (2007) estimated that Vietnam has a land area of 31, 000 km^2 for wind development of which 865 km^2 can generate a power of 3,572 MW at relatively low costs (i.e., less than $6 cents/kWh). Currently, wind power is only intensively developed in the south of Vietnam and only a few wind power plants are residentially constructed in the highly mountainous areas of the country (Nong et al., 2019). Offshore wind power technology (Hoseinzadeh et al., 2018) has also been applied to develop a farm with a capacity of 99MW in Bac Lieu, in the south of Vietnam (Tran and Chen, 2013).

Solar power development is also mainly feasible in the south due to the prevalence of hot temperatures and sunny conditions (Polo et al., 2015). Recently, a solar power plant in Tay Ninh with a capacity of 420MW has started generating electricity and joining the national electricity supply network.[1] Biomass-coal co-firing has also been used to generate electricity in some plants though the scale is not large (Truong et al., 2019). In addition, similar to the development of the production of cleaner energy sources, such as biodiesel in many countries (Silitonga et al., 2013), such a production is also being facilitated in Vietnam but the output level is currently relatively small (Hong et al., 2013). However, given the recent development of biodiesel production based on new technologies (Ong et al., 2019; Mahlia et al., 2020; Silitonga et al., 2020), Vietnam also has potential to foster the development of biodiesel production, which would be used for electricity generation. In this context, the multi-agent system in smart distribution network (Amini et al., 2013) has also been facilitated for additional electricity supply.[2] It is noted that all energy markets in Vietnam are regulated. Most energy companies related to crude oil, natural gas, and coal exploitation and electricity generation belong to the Government. Recently, they welcome private sector to invest into renewable power, such as solar, and distribution networks through Build-Operate-Transfer (BOT) projects to have certain periods of operation before transferring to the Government. The Government of Vietnam also controls the supply prices and quotas to stabilize the energy markets and ensure national energy security.

The additional electricity supplies shown in Table 1 would significantly affect both the economy and electricity market. The implications for the electricity price, as well as welfare would be substantial and complex, which are highly desirable in the public domain. In this regard, many studies have been conducted to examine the economic impact of renewable energy development in many regions around the world (for example, see De Arce et al. (2012) and Dai et al. (2016)). There are four common approaches to analyze the electricity market. The first method is a partial equilibrium modeling approach using electricity models. This approach encompasses a large number of studies, including those of Contreras et al. (2003), Nelson et al. (2012), Vithayasrichareon and MacGill (2012), Nelson and Simshauser (2013), Behrangrad (2015), and Nelson et al. (2018). While this method has the advantage of providing detailed impacts on the electricity market, it still has limitations not providing analyses of economy-wide impacts. The second method is to use the input-output models, such as in Machado et al. (2001), Martínez et al. (2013), da Silva Freitas et al. (2016), and Wang et al. (2020). This approach helps to address certain research questions; however, it presents major limitations in capturing price changes and interactions within economies (Meng and Siriwardana, 2016). The third group includes numerous studies using the electricity-detailed computable general equilibrium (CGE) models to examine the impact of a policy on different electricity sectors; for example, see Meng et al. (2013), Cai and Arora (2015), Peters (2016a), Nong et al. (2017), Tran et al. (2019); and Nong (2019). The fourth group consists of several studies using an integrated CGE and electricity modeling approach to obtain detailed impacts on various electricity sectors (Adams, 2007; Adams and Parmenter, 2013; Meng et al., 2018). This approach requires substantial resources and modeling inputs to study the impacts on the electricity market and the overall economy.

During the review of relevant literature, we have found the following research gaps. First, the models employed in the existing studies in this field do not consider different technology that would supply electricity differently subject to variable demands in different timelines.

Second, the impacts of such a policy have been well studied in other countries, mainly in major and/or developed countries (e.g., China and European countries), but there is still no empirical study on this issue in a small developing country, such as Vietnam. Hence, it is worth conducting a study to compare the impacts on a small developing country with the impacts found in other major and developed countries. In addition, the studies in most countries only account for renewable energy development, while the impacts of a policy that also includes fossil-based power development has not been considered.

Third, studies on energy/electricity market and policies in an emerging country like Vietnam are also highly scarce, as are the impacts of such a policy on the country's economy. In particular, in the last decade Nguyen (2008) employed the input-output model to examine the impact of increasing an electricity tariff on the prices of other commodities. Although this method contains numerous advantages, there are some major limitations. For example, the input-output method is not able to allow agents to respond to a price-induced shock in the economy (Meng and Siriwardana, 2016). Toan et al. (2011) reviewed energy supply, demand and policy in Vietnam, as well as projected electricity demand and supply in the country. It was estimated that electricity demand would considerably increase over the years until 2030. The studies that use the CGE modeling approach to assess the economy-wide impact of an environmental/energy policy in Vietnam are also scarce. In addition, these studies are dated, which do not reflect the current condition of the economy. For example, El Obeid et al. (2002) and Coxhead et al. (2013) used the CGE modeling approach to examine the impact of an environmental tax in Vietnam. There are only two recent studies conducted by Nong (2018) and Nong et al. (2019) that have attempted to examine the economy-wide impact of an environmental/energy policy in Vietnam.

Our objectives are therefore to fill the gaps in the modeling literature, as well as in empirical findings with comparisons of the impacts across countries. Specifically, this study has developed/extended an electricity-detailed CGE model to assess the potential impacts of the Vietnamese Power Development Plan on the whole economy with a focus on the electricity market and welfare. The model includes the base-load and peak-load technologies for supply of electricity for different demands during peak and normal time and seasons. The model was also extended in its database to include non-CO_2 emissions levels in order to enrich the capacity and accuracy for environmental policy studies. In the case of Vietnam, the CO_2 emission level in the GTAP-Power data in 2011 was only 127.25 Mt (Nong, 2020), while the country's non-CO_2 emission level in the same year was 148.6 Mt (Irfanoglu and van der Mensbrugghe, 2015). We also seek to address how the policy affects the country's economy: what are the costs or benefits compared to the plan

[1] https://e.vnexpress.net/news/news/southeast-asia-s-largest-solar-farm-begins-operations-in-southern-vietnam-3979068.html.

[2] https://www.adb.org/sites/default/files/project-document/189544/49175-003-cp.pdf.

Table 1
Electricity output growth in 2017–2030.

Electricity generation sector	Output capacity in 2017 (MW) (1)	Output capacity in 2020 (MW) (2)	Targeted output capacity in 2025 (MW) (3)	Targeted output capacity in 2030 (MW) (4)	Growth rate in 2017–2020 (% change) (5)	Growth rate in 2017–2025 (% change) (6)	Growth rate in 2017–2030 (% change) (7)
Hydro	18,004	21,600	22,201	31,315	20%	23%	74%
Coal-fired	14,595	26,000	47,600	55,300	78%	226%	279%
Oil-fired	1,242	1,287	2,144	2,716	3.6%	73%	119%
Gas-fired	7,446	7,713	12,856	16,284	3.6%	73%	119%
Other renewables	135	2,400	7,824	25,881	1678%	5696%	19071%

Source: The Vietnamese Ministry of Industry and Trade (2017).

developed in other countries, how the country transforms to a cleaner and low-carbon energy structure, and what are the policy implications for more sustainable development.

The rest of the paper is organized as follows: Section 2 highlights the modeling approach and simulations, while Section 3 provides the analysis of the impact of the Power Development Plan on electricity and other energy sectors, as well as the whole Vietnamese economy, and Section 4 includes some concluding remarks and policy implications.

2. Modeling approach

2.1. Model and database

The CGE modeling approach has been considered a powerful toolkit and widely used by policymakers and researchers to examine the economy-wide impact of a policy or economic activities (Adams and Parmenter, 2013; Garnaut, 2008; Siriwardana et al., 2013; Stern et al., 2006). A CGE model can be written in a static or dynamic framework (Dixon and Jorgenson, 2013). A dynamic model can include capital accumulation, financial asset/liability accumulation, lagged adjustment processes in the labor market, or land use change module depending on specific purposes of the study (Dixon and Rimmer, 2001; Wang et al., 2019). Nowadays, a dynamic model is preferable, as this modeling approach can generate the long-term impacts which deviate from the baseline in particular years. However, a dynamic modeling simulation would produce high uncertainty due to projections of certain variables in each yearly period, which are based on various other sources of projections. There are also multi-regional or multi-national CGE models (Dixon and Jorgenson, 2013). In any form, a CGE model includes most agents in an economy with their proper interactions in the commodity and income markets (Fig. 1). In particular, industries utilize capital, labor, intermediate inputs, and other resources in their production processes. Industries then pay households for their labor utilization and pay the central government production and consumption taxes. The central government also collects income and consumption taxes from households. In this structure, households and governments act as final users in each region, while industries are producers, which supply intermediate inputs for other industries and commodities for final users. Industries also use international transportation services, such as road and non-road transport to sell their commodities to households, governments, and industries in other countries.

In this study, we particularly employ a global static electricity-detailed CGE model, the GTAP-E-Power model developed by Peters (2016a). In general, the GTAP-E-Power model is the global economic GTAP-based model, which was constructed following the Walrasian general equilibrium theory/framework. The model assumes producers supplying commodities based on cost-minimizing behavior under constant returns to scale in competitive markets, while final consumers maximize their utility subject to given budget constraints. In each region, there is only a single representative household, supplying labor for industrial production, receiving factor returns, and paying taxes, such as income tax and consumption tax. The private demand for different commodities is based on the Constant Difference of Elasticities function, containing income and price changes. However, the public demand is modeled using the Constant Elasticity of Substitution function. In the model, trade flows are a key component and hence traded good and services are modeled via usual bilateral trade mechanisms.

While retaining the structures of the model, we add non-CO_2

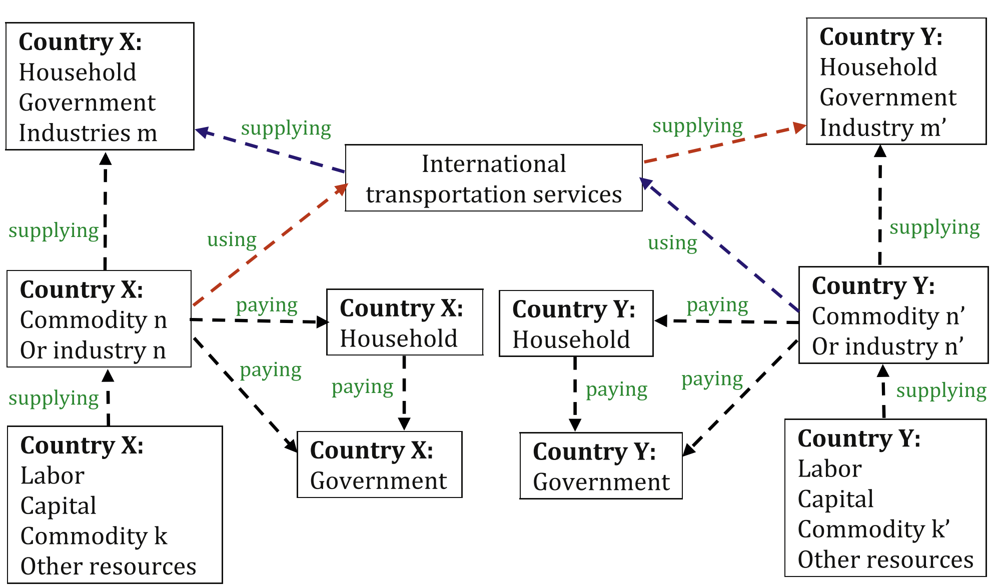

Fig. 1. The cycle of income and commodity flows in GTAP-E-Power.

emission variables in this model to capture most emission levels in countries/regions so that the model can increase its assessment capacity related to energy and/or environmental policy study. The GTAP-E-Power model was developed, based on the framework of the GTAP-E model (McDougall and Golub, 2007), which has been used in many policy studies, including Beckman et al. (2011); Cai and Arora (2015); Nong et al. (2018); Siriwardana and Nong (2018). The GTAP-E-Power model also includes an advanced technology component, which divides electricity generation into various sources based on the base-load and peak-load technologies. The peak-load technology is used to meet electricity demand during peak hours or high-demand seasons, whereas the base-load electricity generation is for regular uses. This structure of the model is particularly suitable to study an energy policy in Vietnam because demands for electricity in the country vary considerably depending on the time of days, weeks and seasons.

Details of the production structure in the GTAP-E-Power model are provided in Fig. 2. At the top level, industries use the endowment-energy composite and non-energy commodities via the Leontief function. At this level, these inputs are not substitutable. However, at lower levels, commodities are selected via various CES functions in order to minimize their costs. For example, the endowment-energy compositeis formed by selecting land, labor and the capital-energy composite. When one of these three commodities increases its price, industries will switch to use the other two commodities, which now become relatively cheaper. Other CES functions at lower tiers also act in the same way. It is noted that although there are 11 sources of electricity generation commodities in the GTAP-E-Power model, nuclear and oil-fired electricity generation using the base-load technology are not in practice in Vietnam. In addition, hydro and solar electricity generations using the peak-load technology are also not used in the Vietnamese electricity market.

In the GTAP-E-Power model, the CO_2 emission variables are inherently tied with fossil fuel consumption levels used by industrial sectors, government, and households. These CO_2 emissions are released from the combustion of coal, oil, natural gas, and petroleum products of which they correlatively fluctuate with changes in quantity of fossil fuel consumption. As a key improvement, this study extends the GTAP-E-Power model by incorporating non-CO_2 emission levels, according to data provided by the GTAP group (Irfanoglu and van der Mensbrugghe, 2015). For example, non-CO_2 emissions released from fossil fuel combustion by industrial and private sectors are incorporated into the model so that such emission levels also change according to the changes in the consumption levels of corresponding fossil fuels (eq. (1) for industrial sectors and eq. (2) for the private sector). Non-CO_2 emissions released from using land and livestock capital (Nong and Siriwardana, 2018) are tied with real quantity consumption of these endowment factors. That is, these emission levels vary according to the utilization levels of these factors (eq. (3)). In addition, non-CO_2 emissions released from production processes are tied with the real output level (eq. (4)).

$$I\_C\_NCO2_{c,s,j,r} = qfc_{c,s,j,r} \tag{1}$$

$$H\_C\_NCO2_{c,s,r} = qhc_{c,s,r} \tag{2}$$

$$I\_E\_NCO2_{e,j,r} = qfe_{e,j,r} \tag{3}$$

$$I\_O\_NCO2_{c,j,r} = qfo_{j,r} \tag{4}$$

where.

- *qfc* is the percentage change in real demands for fossil fuel *c* by industry *j* in region *r* from source *s* (domestic or import);
- *qhc* is the percentage change in real demands for fossil fuel *c* by the private sector in region *r* from source *s* (domestic or import);
- *qfe* is the percentage change in real demands for endowment factor *e* by industry *j* in region *r*;
- *qfo* is the percentage change in real production level of industry *j* in region *r*;
- *I_C_NCO2* is the percentage change in the non-CO_2 emissions released from corresponding consumption of fossil fuel *c* by industry *j* in region *r* from source *s*;
- *H_C_NCO2* is the percentage change in the non-CO_2 emissions released from corresponding consumption of fossil fuel *c* by the private sector in region *r* from source *s*;
- *I_E_NCO2* is the percentage change in the non-CO_2 emissions released from corresponding consumption of endowment factor *e* by industry *j* in region *r*; and
- *I_O_NCO2* is the percentage change in the non-CO_2 emissions released from production processes performed by industry *j* in region *r*.

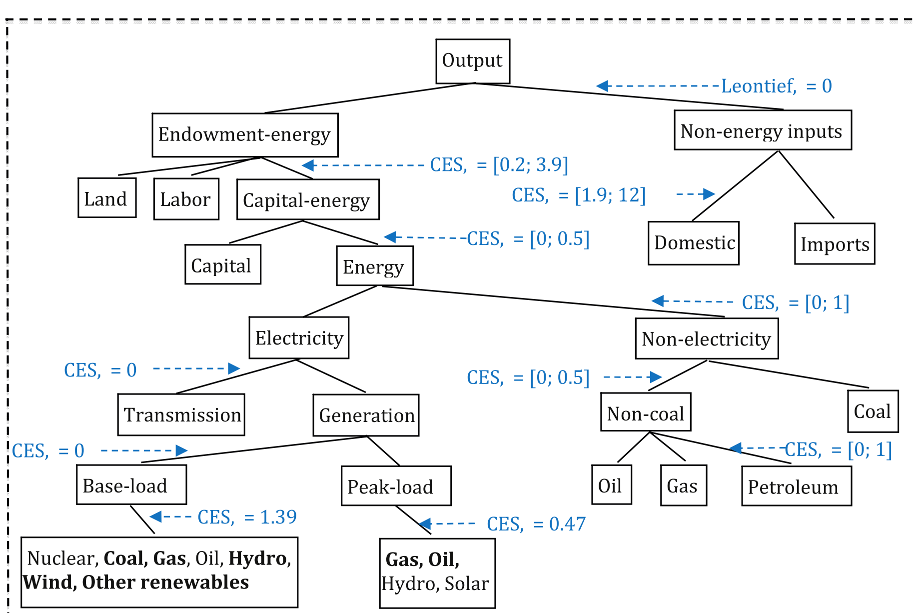

Fig. 2. The production structure in the GTAP-E-Power model.
Note: Words in bold indicate the electricity technologies in Vietnam.

We employed the GTAP-Power database (Peters, 2016b) and non-CO_2 emissions (Irfanoglu and van der Mensbrugghe, 2015) for this extended model. These databases have a base year of 2011 with 140 regions and 68 sectors. These regions and sectors have been aggregated into six regions and 33 industrial sectors, which have details of energy and electricity generation sectors in Vietnam. Since the database represents the world economy in 2011, such data has been updated to 2018 by using macroeconomic updates as shown in Fig. 3. The update includes investment, labor supply, capital stocks, and population provided by Diffenbaugh et al. (2012), while the real GDP growth rate updates are collected from the International Monetary Fund (2018). In addition to these updates, particular energy updates for Vietnam were also carried out to update the database to 2018 as shown in Fig. 4. The process for updating the database is to shock the corresponding exogenous variables with targeted values as aforementioned, then changes in endogenous variables will be determined following the simulation. The new database is also generated during this process, corresponding to changes in endogenous and exogenous variables.

2.2. Simulation design

This study examines the impacts of the Power Development Plan on the Vietnamese economy over three different scenarios.

In Scenario 1, the impacts on the economy are examined by considering the electricity targets in 2020. It is simulated in the short run framework, following the macroeconomic assumptions provided by Adams (2005), which established fundamentals for short run analysis. For example, real wage rate is fixed (exogenous), while labor supply is flexible in this framework. In addition, aggregate capital stock is constant, whereas the rate of return on capital can change.

Scenarios 2 and 3 take into account the electricity targets in 2025 and 2030, respectively. These two scenarios are set in a long run framework, following Nong et al. (2018). The closure settings for the two long run simulations are converted from those in the short run simulation provided in Scenario 1. For example, capital stock can change endogenously depending on the price of capital determined through the supply-demand mechanism, while the rate of return on capital is fixed (exogenous).

The target shocks in these three scenarios were implemented via the output-augmenting technical change variables with the values provided in columns (5), (6), and (7) in Table 1 for corresponding sectors. The methodology related to shocking this technical change variable has been adopted in various studies, including Diffenbaugh et al. (2012), and Bekkers et al. (2016). In particular, in Scenario 1, the output technical change variables of the corresponding electricity generation sectors were shocked with the percentage change values shown in column (5) of Table 1. This method was also applied in Scenario 2 and Scenario 3, by using the percentage change values shown in columns (6) and (7), respectively.

3. Impact of the Power Development Plan in Vietnam

This section provides an analysis of the results on the Vietnamese economy over different scenarios. The impact on the electricity and other energy sectors is provided first, followed by the results of the macroeconomic impacts.

3.1. Potential impacts on the electricity and energy market

The results show that the Power Development Plan adds a substantial energy supply to the country's economy (Table 2), which considerably alters the energy market. In particular, the wind and other renewable electricity generation sectors will expand strongly (e.g., an increase in wind power output by 747.5%–1014.9%, and by 444.7%–517.5% for other renewable energy output). These two sectors, however, account only for a small fraction in the Vietnamese energy market, the changes in dollar values are therefore not relatively high, ranging from $83.9 million to $251.1 million. However, their growth still indicates that they are considerably enhancing their role in the country's energy market of which low-carbon energy structure can be achieved. Since hydroelectricity is not highly targeted for development, it only grows at lower rates over the three scenarios (i.e., an increase in the output level by 2.31%–50.95%). However, this sector is a main electricity sector in the country with high output values in the baseline; hence, its output value increases substantially by $592–$5566 million corresponding to the percentage changes.

The gas-fired base-load electricity generation sector also increases its production level under the Power Development Plan policy. For example, its output increases by 11.39% (or $531.6 million) in Scenario 1, by 56.78% (or $2649.9 million) in Scenario 2, and by 111.4% (or $5198.9 million) in Scenario 3. The production levels of the gas- and oil-fired peak-load electricity generation sectors will also grow at similar rates due to similar installation capacity development. In this context, the highest value increase in electricity generation, however, belongs to the coal-fired electricity generation sector. A strong growth of this sector is targeted by the Vietnamese Government to ensure the national energy security and to lower the price of electricity. In particular, the output value of coal-fired electricity increases by $3621.6 million in Scenario 1, by $10327.2 million in Scenario 2, and by $12197.1 million in Scenario 3. With such strong growth rates of power generation sectors, the output level of the electricity distribution sector also increases greatly to support additional electricity supply. For instance, the electricity services increase its output by 162.05%–539.77% or by $10572.2–$35214.7 million.

Substantial growth rates in the electricity sectors have enabled industrial, private and public sectors to have abundant electricity to substitute for fossil fuels. Such substitution activities eventually have negative effects on demand for fossil fuels. However, the coal-, gas- and oil-fired power sectors still increase their demands for fossil fuels due to their expansions in production levels as aforementioned. This activity reduces unfavorable impacts on the fossil fuel sectors. Consequently, the net adverse impacts on the coal-mining, oil and gas extraction, and petroleum products manufacturing sectors are moderated. Their output levels only decline by below 5.5% (or below $500 million). It is also predicted that the energy-intensive industries will benefit from massively additional energy supply in the country. This is because the prices of energy, particularly electricity, will decrease, which eventually reduce production costs of utilization industries (i.e., the energy-intensive industries), resulting in strong growth rates of these sectors by 6.6%–21.99% or by $4100–$13694 million. These expansions are highly important for the country's development, as they are fundamental industries, which provide vast inputs for other industries and final users.

Large increases in the electricity supply also considerably affects the overall energy prices. In this context, such an additional supply significantly reduces the prices of most electricity-based technologies over the three scenarios. In other words, the decreasing rates of electricity prices are highly correlated with the increases of electricity supply (Table 3). In particular, considerable increases in the supply of coal-fired electricity and renewable electricity tend to accelerate the price decrease of electricity generated from these sources. For instance, the price of coal-fired electricity decreases by 39.68% in Scenario 1, by 62.91% in Scenario 2, and by 65.55% in Scenario 3. Similarly, the prices of electricity generated from using wind and other renewable resources will decline by 64.34%–78.13% over the three scenarios. These results for the electricity prices reveal that the elasticities of the supply and demand curves for electricity generated from wind and other renewable resources are much higher than those for electricity generated from combusting coal. This is because supplies of wind and other renewable electricity sources increase at much higher rates compared to the supply of coal-fired electricity in these three scenarios (Table 2).

The price of hydroelectricity decreases at relatively high rates from

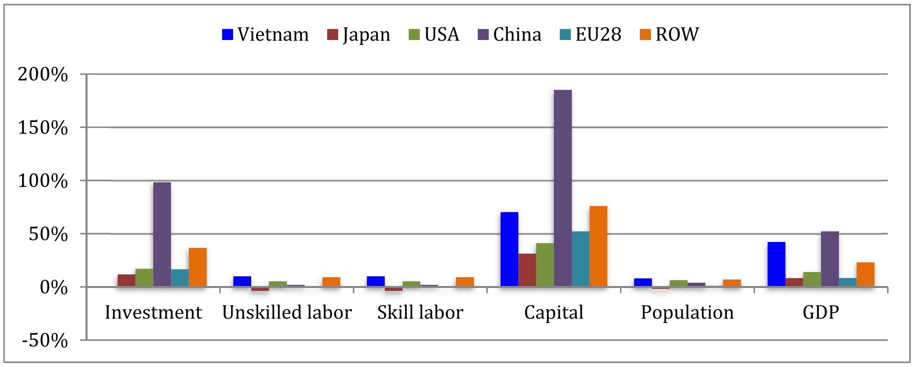

Fig. 3. Projections of selected variables in 2011–2018 (percentage change).
Source: Diffenbaugh et al. (2012) and the International Monetary Fund (2018).

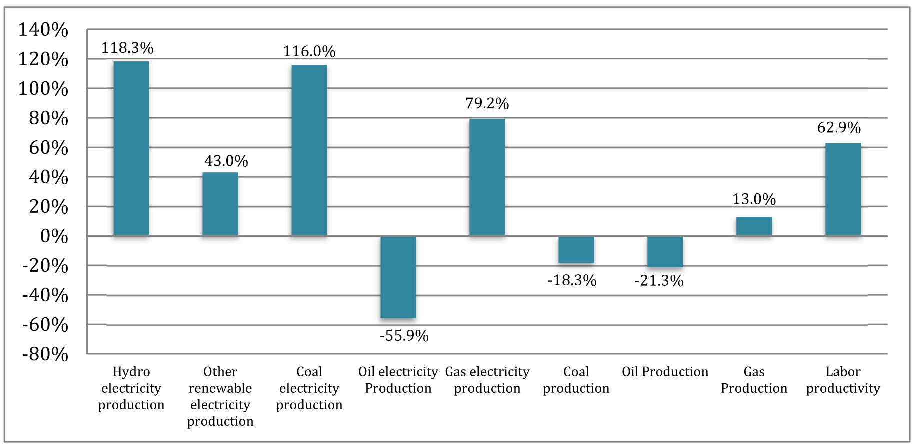

Fig. 4. Energy projections for Vietnam in 2011–2018 (percentage change).
Source: The CEIC (2018).

Table 2
Impact of the Power Development Plan on energy outputs in Vietnam.

Sector	Scenario 1		Scenario 2		Scenario 3	
	% change	Value change ($ million)	% change	Value change ($ million)	% change	Value change ($ million)
Coal mining	−2.99	−131.3	−3.39	−148.9	−5.11	−224.4
Oil extraction	−3.05	−297.7	−3.15	−307.4	−2.37	−231.3
Gas extraction	−2.65	−65.1	−3.39	−83.3	−4.96	−121.8
Petroleum products	−1.64	−138.7	−4.82	−407.6	−5.49	−464.3
Electricity service	162.05	10572.2	313.47	20450.8	539.77	35214.7
BL Coal-fired electricity	75.73	3621.6	215.95	10327.2	255.05	12197.1
BL Gas-fired electricity	11.39	531.6	56.78	2649.9	111.4	5198.9
BL Wind electricity	747.52	184.9	901.7	223.1	1014.94	251.1
BL Hydro electricity	5.42	592.1	12.31	1344.9	50.95	5566.3
BL Other renewable electricity	444.69	83.9	481.82	90.9	517.48	97.7
PL Gas-fired electricity	18.64	505.6	61.5	1668.1	112.47	3050.6
PL Oil-fired electricity	18.53	73.1	60.94	240.4	111.25	438.9
Energy-intensive industries	6.6	4110.0	20.34	12666.3	21.99	13693.8

Note: Scenarios 1, 2, and 3 provide the impact of the Power Development Plan in 2020, 2025, and 2030, respectively.

14.69% to 40.11% over the three scenarios, which are relatively small compared to the decrease in prices of electricity generated from coal-fired, wind and other renewable resources. This is because hydroelectricity is only targeted to boost generation at smaller rates under the Power Development Plan. The prices of gas- and oil-fired electricity will decrease at relatively high rates in Scenario 2 (by around 41%) and Scenario 3 (by 52%) due to substantial decreases in the supplies, while the price only decreases by 3.4% in Scenario 1 because of a low projection target in 2020. The price of electricity services also declines considerably due to highly increased supply of this commodity in the market. For instance, its price decreases by 28.41% in Scenario 1, by 36.49% in Scenario 2, and by 61.51% in Scenario 3.

Major reductions in the prices of electricity commodities are particularly benefical to the Vietnamese economy which consequently boost development because the current price of electricity is relatively high.[3] Electricity is also consumed largely by industrial sectors and households, accounting for 5% of their consumption budgets (Aguiar

[3] https://en.evn.com.vn/c3/gioi-thieu-l/Electricity-Price-9-28.aspx.

Table 3
Impact of the Power Development Plan on energy prices in Vietnam (% change).

Commodities	Scenario 1	Scenario 2	Scenario 3
Coal	2.05	3.38	7.87
Oil	1.5	2.67	4.6
Natural gas	1.01	3.01	7.02
Petroleum products	0.92	2.7	5.2
Electricity service	−28.41	−36.49	−61.51
BL coal-fired electricity	−39.68	−62.91	−65.55
BL gas-fired electricity	−3.37	−41.98	−52.95
BL wind electricity	−74.17	−77.15	−78.13
BL hydro electricity	−14.69	−18.56	−40.11
BL other renewable electricity	−64.34	−66.97	−67.77
PL gas-fired electricity	−3.41	−41.35	−52.11
PL oil-fired electricity	−3.36	−41.27	−51.93
Commodities of energy-intensive industries	−0.76	−2.33	−4.46

et al., 2016). As a result, industrial and private sectors are particularly benefited by such price reductions. The contraction of coal-mining, oil and gas extraction and petroleum products manufacturing sectors slightly boosts the prices of these commodities. However, the impacts on the production levels are relatively small (Table 2), leading to small effects on the prices of their outputs. For example, prices of these commodities only increase by 0.92%–7.87% over the three scenarios. The impacts of such increases on consumers are relatively small because industrial, private and public sectors are highly benefitted from lower prices of electricity, which substitutes for fossil fuels. The country also experiences lower prices for commodities produced by the energy-intensive industries because this sector faces lower input costs due to lower prices of electricity commodities, which eventually boosts their production level. However, the effects on the prices of these commodities are relatively small though the production level increases considerably due to price inelasticity. For instance, the prices of commodities produced by the energy-intensive industries decline by 0.76%–4.46% over the three scenarios.

Major reductions in the prices of electricity commodities have significant implications for the economy, particularly the private sector. Table 4 shows that the private demands for different electricity commodities will increase intensively over the three scenarios, with magnitudes depending on the price changes shown in Table 3. For example, Table 4 shows that the private demand for electricity services strongly increases by 20% in Scenario 1, by 51% in Scenario 2, and by 100% in Scenario 3, which are correlated with the decreasing rates of price of this commodity provided in Table 3. The private demand for coal-fired electricity also rises strongly by 74%–220% over the three scenarios because of intensive expansion in production of this sector, leading to lower prices of this electricity commodity. The private demand for electricity generated from other sources will also rise substantially over the three scenarios. In addition, this is a good signal for the country as the private demand for electricity generated from wind and other renewable sources will increase at relatively higher rates than the demand increases for electricity generated from other sources. For example, the private demand for wind electricity increases by 456%–498% in these three scenarios, while the demand for other renewable electricity enhances by 232%–260%. This is a really good basement for a strong development of renewable energy in Vietnam, which would move the country towards a low carbon and sustainable economy, following the pathways of developed countries.

Table 4
Private demands for energy commodities in Vietnam (% change).

	Scenario 1	Scenario 2	Scenario 3
Coal	−1.65	−8.63	−9.2
Oil	−1.12	−7.99	−6.36
Natural gas	−0.63	−8.3	−8.49
Petroleum products	−0.84	−8.57	−8.71
Electricity service	19.54	50.99	100.13
BL Coal-fired electricity	74.16	184.26	219.61
BL Gas-fired electricity	9.96	51.94	106.59
BL Wind electricity	456.46	463.39	497.78
BL Hydro electricity	5.47	7.2	47.35
BL other renewable electricity	232.64	248.35	260.27
PL Gas-fired electricity	19.6	52	101.9
PL Oil-fired electricity	19.57	51.89	101.53
Commodities of energy-intensive industries	5.65	8.86	19.72

Since the electricity prices decrease materially, the private sector uses it as a substitute for fossil fuels. As a result, the private demand for coal, oil, natural gas, and petroleum products will decrease sharply, particularly in Scenario 2 and Scenario 3 because the private demand for electricity increases at relatively high rates in these two scenarios. It is worth noting that not all equipment or machines are flexible and there may be some conversion costs. These features are not explicitly accounted for in the model. They are only reflected through the assumed elasticities of substitution between energy commodities. In the database, the private sector in Vietnam already uses coal, oil, gas, petroleum products, and electricity at different levels. Hence, depending on the magnitude of the elasticities of substitution and price changes of commodities, the private sector will switch to use other energy commodities at appropriate levels. In other words, the conversion costs and/or inflexibility of equipment or machine to use substitutable energy commodities are accounted for in the constrained elasticities of substitution assumed in the model. The impact on the private demands for fossil fuels is also influenced by the increased prices of these commodities. For example, the prices of these fossil fuels will increase at relatively low rates; hence, the impact on the private demand for these commodities is small. In Scenario 1, the private demand for these fossil fuels will decline only by 0.63%–1.65%, while these reduction rates are between 6.36% and 9.2% in Scenarios 2 and 3 respectively. It is also evident from the results that the private demand for commodities produced by the energy-intensive sectors are highly elastic. For instance, although the prices of these commodities decline by below 4.5% (Table 3), the private sector enhances its demand for these commodities by 5.65%–19.72%.

The results related to the energy sectors and commodities indicate that higher targets boost the development of electricity generation sectors, resulting in higher favorable impacts on the economy. For example, higher electricity development targets result in lower prices for electricity, which substantially foster increasing demand for electricity to substitute for fossil fuels. The private sector also intensively increases its demand for renewable electricity.

3.2. Impact on the overall economy

The impact of the Power Development Plan on industrial, private and public sectors is also reflected in the impact on the overall economy of Vietnam. In this context, vastly reduced prices of electricity lower prices for other commodities (e.g., commodities produced by the energy-intensive industries shown in Table 3), consequently leading to lower overall price levels in the domestic market. This leads to lower export prices. As a result, the terms of trade[4] decline. It is noted that the export prices in this instance are considered from the side of Vietnam. That is, the export prices from the Vietnamese market to the world economy through bilateral trade mechanisms. Lower overall prices in the domestic market in Vietnam make their commodities to become cheaper; hence, it would improve the competitiveness of Vietnamese commodities in the international market. Such export prices considering from the Vietnam's side are endogenously determined. The import prices that

[4] The terms of trade is measured by the ratio of the export price to the import price. The import price is fixed because Vietnam is a price taker in the international economy.

Vietnam faces for its imported commodities from other countries are also not exogenous in this global model, but these import price indexes considering from the Vietnam's perspective would not change due to the policy implemented in Vietnam. It is because Vietnam is a very small economy to affect the international prices.

Fig. 5 shows that the terms of trade decrease by 0.81% in Scenario 1, by 1.91% in Scenario 2, and by 6.12% in Scenario 3. There are decreasing rates in the terms of trade from Scenario 1 to Scenario 3 because the price levels of commodities decrease at relatively higher rates in Scenario 3 compared to the deceases in Scenarios 1 and 2. The decreases in the terms of trade have significant implications on the country's exports and imports. For example, lower price levels in the country encourage exports, while reducing imports, which eventually improves the trade balance.

Table 5 provides results related to the impact on real GDP, its components and the emission level. As the terms of trade decrease, real exports of Vietnam improve substantially because commodities from the Vietnamese markets become relatively cheaper in the international market. For example, real exports increase by 3.75% in Scenario 1, by 9.61% in Scenario 2, and by 20.54% in Scenario 3. Those high increases are governed by the Armington elasticity of substitution assumed in the model. Meanwhile, real imports also rise but at smaller rates of 2.55%–11.53% over the three scenarios. The increased rates of imports are smaller than those for exports for the following reason. Lower terms of trade discourage imports; however, massive expansion of domestic production increases demand for inputs, including those from the international market. As a result, real imports increase but at smaller rates than exports, leading to an improvement in the trade balance.

Lower prices of commodities also enhance real consumption in the private and public sectors. For example, real private consumption raises by 5.48%–19% over the three scenarios, while real public consumption improves by 5.44%–16.88%. Such lower increasing rates of real public consumption are due to the nature of consumption baskets of the sector. Electricity commodities, which experience high decreasing rates of prices, are consumed mostly by the private sector, while the public sector mainly uses service commodities, which experience lower reductions in their prices. High targets to develop electricity power under the Power Development Plan will also reduce the price of investment, which eventually fosters overall investment. Of these, the real investment increases by 0.18% in Scenario 1, by 7.19% in Scenario 2, and by 13.42% in Scenario 3. The impacts on real consumption, investment and

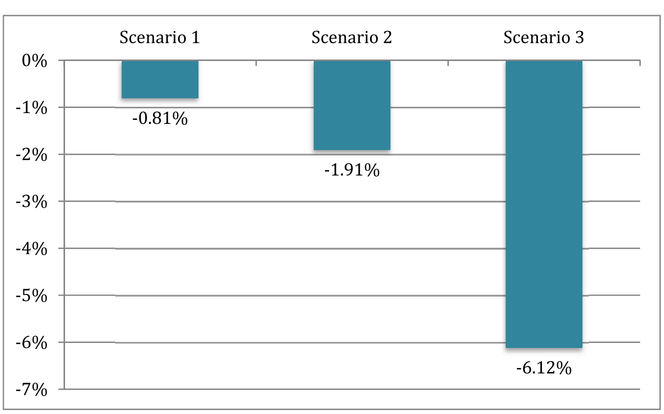

Fig. 5. Percentage change in the terms of trade in Vietnam.

trade consequently result in changes in real GDP. For example, real GDP raises by 5.44% in Scenario 1, by 10.51% in Scenario 2, and by 24.83% in Scenario 3. In particular, the impact on the real GDP is determined by following equation (5).

Table 5
Impact of the Power Development Plan on the Vietnamese real GDP, its components and the emission levels (% change).

	Scenario 1	Scenario 2	Scenario 3
Real exports	3.75	9.61	20.54
Real imports	2.55	6.59	11.53
Real private consumption	5.48	8.44	19
Real public consumption	5.44	7.82	16.88
Real investment	0.18	7.19	13.42
Real GDP	5.44	10.51	24.83
Total emission levels	0.52	1.67	4.3

$$GDP^{*}gdp = PRI^{*}pri + GOV^{*}gov + INV^{*}inv + EXP^{*}exp - IMP^{*}imp \quad (5)$$

where upper-case letters indicate coefficients and lower-case letters show the percentage change of variables. GDP, PRI, GOV, INV, EXP, and IMP refer to real GDP, private consumption, public consumption, investment, export, and import, respectively. Of these, GDP = $219,916.2 million; PRI = $143,384.3 million; GOV = $42,087 million; INV = $47,152.6 million; EXP = $170,979.5 million; and IMP = $183,687.2 million.

Such results indicate that the Power Development Plan significantly boosts the overall development of the Vietnamese economy that makes the country wealthier, by ensuring the energy supply for Vietnam's future development. However, the emission level will slightly increase because of the expansions of the fossil-fired electricity generation sectors. Output of technical progress will help to boost their production levels, but these sectors also require additional inputs, including primary fossil fuels, for their production processes. As a result, Vietnam is likely to increase their emission levels, for example, by 0.52%, 1.67% and 4.3% in the three scenarios, respectively.

Fig. 6 shows that per capita utility in Vietnam will significantly be improved under the Plan. This is because households experience lower price levels, particularly electricity prices, which will improve the consumer purchasing power. Such per capita utility critically relates to changes in real private consumption since population growth is exogenous in the simulations.

Welfare in Vietnam will also improve significantly due to lower prices (Fig. 7). Results show that welfare increases by $8269 million to $28334 million over the three scenarios. In terms of percentage change, welfare rises by 5.5%–18.9% compared with the income level. Such results again confirm that the Power Development Plan in Vietnam really benefits the country and households. The entire economy will experience a surplus in energy supply, lower prices for commodities and higher levels of economic growth. The Plan also encourages significant development of renewable energy, as well as demand for renewable energy. This signals a sustainable development of the country towards cleaner production, as well as a low carbon energy structure.

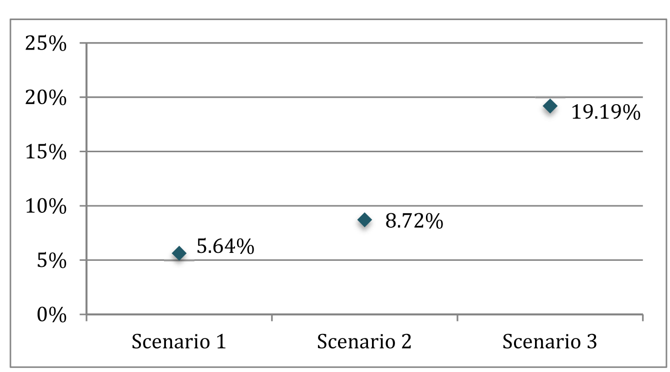

Fig. 6. Impact on per capita utility in Vietnam (% change).

3.3. Comparison with other studies

The results of this study are consistent with another study conducted by Dai et al. (2016), which studied the renewable energy development policy in China. They also found that massive renewable power would be generated in the Chinese market under the proposed policy, which would eventually intensively change the Chinese energy market, as well as the whole economy. The coal mining, oil and gas extraction sectors would also contract. In addition, the price of electricity would decline. However, the impacts on the Chinese economy and different sectors are relatively small compared to the impacts of the policy in Vietnam because the targets for energy development in Vietnam are much higher. In addition, the policy in China was targeted to develop renewable energy power, as well as to decrease coal-fired electricity generation. The Vietnamese Government however fosters all fossil-based and renewable-based energy in the coming years until 2030, consequently there are negative impacts on the Chinese economy found by Dai et al. (2016), while there is significant improvement in the overall Vietnamese economy.

De Arce et al. (2012) also found that there are favorable impacts on the economy of Morocco when studying a renewable energy development policy. However, the favorable impacts of the policy in Vietnam are also much higher, as there are significantly higher installed capacities in Power Plan of Vietnam. In addition, only renewable energy was promoted for development in Morocco, while both fossil-based and renewable-based electricity are fostered under the policy in Vietnam.

4. Conclusion and policy implications

Following the international pathways to tackle climate change outcomes, Vietnam has issued a Power Development Plan, which fosters electricity generation from renewable resources. However, such a technology is relatively costly in short and medium terms for a small developing country like Vietnam in order to have renewable power as a main energy source in the country. As a result, the Plan also fosters fossil-based power, especially coal-fired power, until 2030. While renewable energy development is well studied in major or developed countries, such a study in a small developing country is still quite limited. In addition, existing studies tend to only consider renewable energy development, while Vietnam targets to develop all fossil-based and renewable-based power due to financial and technology constraints. Furthermore, the modeling approach for studying such a policy still remains incomplete, as the models employed have not considered advance technology that enable producers to supply electricity to variable demands at different times and seasons that employ peak and normal demand. This study applies and extends the GTAP-E-Power model to fill this modeling gap to study the Power Development Plan in Vietnam. Since this policy includes development of both fossil-based and renewable-based power, it is worth seeking the potential impacts by comparison with the case of only renewable energy development in other countries. Hence, new empirical findings can be leveraged, which are also important for such countries due to limited studies related to energy/electricity market and policies.

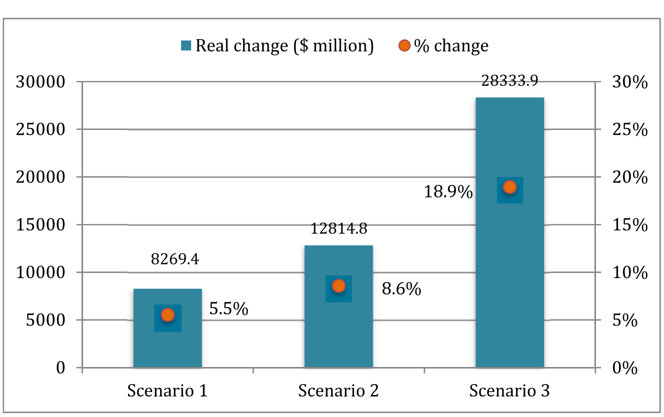

Fig. 7. Impact on the Vietnamese welfare.

There are some key findings with relevant implications. First, a massive electricity supply is likely to considerably decrease the electricity prices in the country (e.g., by 40%–78% under the 2030 target scenario), leading to lower production costs in production sectors, which will consequently reduce their supply prices. Such spillover effects eventually benefit the entire economy because customers experience much lower prices for most commodities.

Second, due to lower prices of electricity, sectors use more electricity to substitute for fossil fuels, such as coal, oil, natural gas, and petroleum products. This substitution will lead to contraction in the production levels of these sectors (e.g., by 2.4%–5.5% under the 2030 target scenario), resulting in less fossil fuel extraction rates. In addition, since fossil fuels are substituted by electricity, including renewable-based electricity, this would help Vietnam gradually lower its dependence on fossil fuels, while increasing the use of renewable energy.

Third, households will be highly benefitted because of lower price levels, particularly the decreases of electricity prices. For instance, per capita utility will increase by 5.64%–19.19%, while welfare, relative to the income level, also increases at similar rates. In addition, households tend to increase their demand for renewable-based electricity (e.g., by 260%–498% for wind and other renewable-based electricity) rather than the increased demand for fossil-based power (e.g., by 107%–220% for gas- and coal-fired electricity), giving a strong attraction for the development of the renewable energy sectors in Vietnam. This result also signals that Vietnam is able to move to a cleaner production and sustainable economy in the future if it follows renewable energy policy development consistently.

Fourth, expansion of the electricity sectors, as well as lower prices of this commodity, particularly benefits the overall country's economy. For example, real GDP increases by 5.44% under the 2020 target scenario, by 10.51% under the 2025 target, and by 24.83% under the 2030 target scenario. Welfare also significantly rises by $8,269–$28,334 million over the three scenarios.

Although the overall impacts on the country's economy are considerable, there are still adverse impacts on some sectors, such as the coal-mining, oil and gas extraction, and petroleum product manufacturing sectors. Since their production levels contract, they will decline in their demand for primary factors, such as labor and capital. People employed in these sectors include numerous un-skilled labor; hence, it would be challenging for these workers to move to other industries. In addition, if such a labor workforce is the main income for their families, it will cause unexpected and unpredictable social outcomes. Hence, the Vietnamese Government should consider transition policies for those workers while implementing the Power Development Plan policy. The Government, for example, could organize training courses for labor in these adversely impacted sectors so that displaced workers can move to other industries. In addition, the Government can open supporting agencies to help unemployed people find new jobs. The Government might have in-kind or cash transfers to support their families in the transitional stages, as such workers are seeking new jobs especially if unemployed people are the main bread winners in their families.

Although the present study has its merits, it can still be extended. Future studies can additionally consider other environmental and social impacts. For example, how labor would move between industrial sectors and regions. Expansion of electricity power plants also requires land for construction; hence, how new constructions will affect the nearby environment, as well as land use change. There would be deforestation due to expansion of hydropower plants, as well as land conversion from agricultural land. These activities would eventually affect water irrigation, agricultural production, and food supply. Hence, studying these issues would be highly desirable as future works proceed. In addition, the Government may revise the policy due to numerous issues as has happened several times in the past.[5] Such revisions for example, may take place because the installed power capacity targets are not highly feasible due to financial constraints or changes of economic conditions or environmental constraints in constructing hydropower plants. In addition, the climate change international commitment would also influence the Vietnamese Government in pursuing the Plan to foster the development of coal-fired power. These issues if occurring would alter the findings in this study, which are also valuable to study in future work. It is also noted that the life cycle costs of plants are not accounted in this modeling approach, if components of the costs were included in the model, there would have been some distortions in the results. However, since we assume the installation capacity is maintained during the study period, it would not significantly affect the results.

Declaration of competing interest

None

CRediT authorship contribution statement

Duy Nong: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing - original draft, Writing - review & editing. **Duong Binh Nguyen:** Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing. **Trung H. Nguyen:** Conceptualization, Writing - original draft, Writing - review & editing. **Can Wang:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Mahinda Siriwardana:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing.

References

Adams, P.D., 2005. Interpretation of results from CGE models such as GTAP. J. Pol. Model. 27 (8), 941–959.
Adams, P.D., 2007. Insurance against catastrophic climate change: how much will an emissions trading scheme cost Australia? Aust. Econ. Rev. 40 (4), 432–460.
Adams, P.D., Parmenter, B.R., 2013. Computable general equilibrium modeling of environmental issues in Australia. In: Dixon, P., Jorgenson, D. (Eds.), Handbook of Computable General Equilibrium Modeling, 1A. North-Holland, pp. 553–657.
Aguiar, A., Narayanan, B., McDougall, R., 2016. An overview of the GTAP 9 data base. J. Globl. Econ. Anal. 1 (1), 181–208.
Alexander, D.C., 2017. Natural Disasters. Routledge.
Amini, M.H., Nabi, B., Haghifam, M.-R., 2013. Load management using multi-agent systems in smart distribution network. In: Paper Presented at the 2013 IEEE Power & Energy Society General Meeting.
Beckman, J., Hertel, T., Tyner, W., 2011. Validating energy-oriented CGE models. Energy Econ. 33 (5), 799–806.
Behrangrad, M., 2015. A review of demand side management business models in the electricity market. Renew. Sustain. Energy Rev. 47, 270–283.
Bekkers, E., Francois, J.F., Rojas-Romagosa, H., 2016. Melting ice caps and the economic impact of opening the northern sea route. Econ. J. 128 (610), 1095–1127.
Cai, Y., Arora, V., 2015. Disaggregating electricity generation technologies in CGE models: a revised technology bundle approach with an application to the US Clean Power Plan. Appl. Energy 154, 543–555.
CEIC, 2018. Vietnam. Retrieved from. https://www.ceicdata.com/en.
Contreras, J., Espinola, R., Nogales, F.J., Conejo, A.J., 2003. ARIMA models to predict next-day electricity prices. IEEE Trans. Power Syst. 18 (3), 1014–1020.
Coxhead, I., Wattanakuljarus, A., Nguyen, C.V., 2013. Are carbon taxes good for the poor? A general equilibrium analysis for Vietnam. World Dev. 51, 119–131.
da Silva Freitas, L.F., de Santana Ribeiro, L.C., de Souza, K.B., Hewings, G.J.D., 2016. The distributional effects of emissions taxation in Brazil and their implications for climate policy. Energy Econ. 59, 37–44.
Dai, H., Xie, X., Xie, Y., Liu, J., Masui, T., 2016. Green growth: the economic impacts of large-scale renewable energy development in China. Appl. Energy 162, 435–449.
Danish Energy Agency, 2017. Vietnam energy outlook report 2017. Retrieved from. https://ens.dk/sites/ens.dk/files/Globalcooperation/Official_docs/Vietnam/vietnam-energy-outlook-report-2017-eng.pdf.
De Arce, R., Mahía, R., Medina, E., Escribano, G., 2012. A simulation of the economic impact of renewable energy development in Morocco. Energy Pol. 46, 335–345.
Diffenbaugh, N.S., Hertel, T.W., Scherer, M., Verma, M., 2012. Response of corn markets to climate volatility under alternative energy futures. Nat. Clim. Change 2 (7), 514.
Dixon, P.B., Jorgenson, D., 2013. Handbook of Computable General Equilibrium Modeling SET, 1A and 1B. Newnes.
Dixon, P., Rimmer, M., 2001. Dynamic General Equilibrium Modelling for Forecasting and Policy. A Practical Guide and Documentation of MONASH. Elsevier.
El Obeid, A., van der Mensbrugghe, D., Dessus, S., 2002. Outward orientation, growth, and the environment. In: Vietnam *Trade And the Environment In General Equilibrium: Evidence From Developing Economies*. Springer, pp. 209–231.
Garnaut, R., 2008. The Garnaut Climate Change Review (Cambridge, Cambridge).
Hong, D.D., Mai, D.T.N., Ha, N.C., Lam, B.D., Tam, L.T., Anh, H.T.L., Thu, N.T.H., 2013. Biodiesel production from Vietnam heterotrophic marine microalga Schizochytrium mangrovei PQ6. J. Biosci. Bioeng. 116 (2), 180–185.
Hoseinzadeh, B., Amini, M.H., Boroojeni, K.G., Bak, C.L., 2018. RTDS demonstration of harmonic amplification in under sea/ground cables of offshore wind farms. In: Paper Presented at the 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe).
International Monetary Fund, 2018. Real GDP growth - annual percent change. Retrieved from. https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/JPN.
Irfanoglu, Z.B., van der Mensbrugghe, D., 2015. Development of the Version 9 non-CO2 GHG Emissions Database. GTAP Data Documentation. Purdue University.
Kusumo, F., Silitonga, A., Masjuki, H., Ong, H.C., Siswantoro, J., Mahlia, T., 2017. Optimization of transesterification process for Ceiba pentandra oil: a comparative study between kernel-based extreme learning machine and artificial neural networks. Energy 134, 24–34.
Machado, G., Schaeffer, R., Worrell, E., 2001. Energy and carbon embodied in the international trade of Brazil: an input–output approach. Ecol. Econ. 39 (3), 409–424.
Mahlia, T.M.I., Syazmi, Z.A.H.S., Mofijur, M., Abas, A.P., Bilad, M.R., Ong, H.C., Silitonga, A.S., 2020. Patent landscape review on biodiesel production: technology updates. Renew. Sustain. Energy Rev. 118, 109526.
Martínez, S.H., van Eijck, J., da Cunha, M.P., Guilhoto, J.J., Walter, A., Faaij, A., 2013. Analysis of socio-economic impacts of sustainable sugarcane–ethanol production by means of inter-regional Input–Output analysis: demonstrated for Northeast Brazil. Renew. Sustain. Energy Rev. 28, 290–316.
McDougall, R., Golub, A., 2007. GTAP-E: A Revised Energy-Environmental Version of the GTAP Model. GTAP Resource, p. 2959.
Meng, S., Siriwardana, M., 2016. Assessing the Economic Impact of Tourism: A Computable General Equilibrium Modelling Approach. Springer.
Meng, S., Siriwardana, M., McNeill, J., 2013. The environmental and economic impact of the carbon tax in Australia. Environ. Resour. Econ. 54 (3), 313–332.
Meng, S., Siriwardana, M., McNeill, J., Nelson, T., 2018. The impact of an ETS on the Australian energy sector: an integrated CGE and electricity modelling approach. Energy Econ. 69, 213–224.
Nelson, J., Simshauser, P., 2013. Is the merchant power producer a broken model? Energy Pol. 53, 298–310.
Nelson, T., Kelley, S., Orton, F., 2012. A literature review of economic studies on carbon pricing and Australian wholesale electricity markets. Energy Pol. 49, 217–224.
Nelson, T., McCracken-Hewson, E., Whish-Wilson, P., Bashir, S., 2018. Price dispersion in Australian retail electricity markets. Energy Econ. 70, 158–169.
Nelson, T., Pascoe, O., Calais, P., Mitchell, L., McNeill, J., 2019. Efficient integration of climate and energy policy in Australia's National Electricity Market. Econ. Anal. Pol. 64, 178–193.
Nguyen, K.Q., 2007. Wind energy in Vietnam: resource assessment, development status and future implications. Energy Pol. 35 (2), 1405–1413.
Nguyen, K.Q., 2008. Impacts of a rise in electricity tariff on prices of other products in Vietnam. Energy Pol. 36 (8), 3145–3149.
Nguyen-Tien, V., Elliott, R.J., Strobl, E.A., 2018. Hydropower generation, flood control and dam cascades: a national assessment for Vietnam. J. Hydrol. 560, 109–126.
Nong, D., 2018. General equilibrium economy-wide impacts of the increased energy taxes in Vietnam. Energy Pol. 123, 471–481.
Nong, D., 2019. A general equilibrium impact study of the Emissions Reduction Fund in Australia by using a national environmental and economic model. J. Clean. Prod. 216, 422–434.
Nong, D., 2020. Development of the electricity-environmental policy CGE model (GTAP-E-PowerS): a case of the carbon tax in South Africa. Energy Pol. 140, 111375.
Nong, D., Countryman, A.M., Warziniack, T., 2018. Potential impacts of expanded Arctic Alaska energy resource extraction on US energy sectors. Energy Pol. 119, 574–584.
Nong, D., Meng, S., Siriwardana, M., 2017. An assessment of a proposed ETS in Australia by using the MONASH-Green model. Energy Pol. 108, 281–291.
Nong, D., Nguyen, T.H., Wang, C., Van Khuc, Q., 2020. The environmental and economic impact of the emissions trading scheme (ETS) in Vietnam. Energy Pol. 140, 111362.
Nong, D., Siriwardana, M., 2018. Potential impacts of the emissions reduction Fund on the Australian economy. Energy Econ. 74, 387–398.
Nong, D., Siriwardana, M., Perera, S., Nguyen, D.B., 2019. Growth of low emission-intensive energy production and energy impacts in Vietnam under the new regulation. J. Clean. Prod. 225, 90–103.
Ong, H.C., Milano, J., Silitonga, A.S., Hassan, M.H., Shamsuddin, A.H., Wang, C.T., et al., 2019. Biodiesel production from Calophyllum inophyllum-Ceiba pentandra oil mixture: optimization and characterization. J. Clean. Prod. 219, 183–198.
Peters, J.C., 2016a. GTAP-E-Power: an electricity-detailed economy-wide model. J. Globl. Econ. Anal. 1 (2), 156–187.
Peters, J.C., 2016b. The GTAP-power data base: disaggregating the electricity sector in the GTAP data base. J. Globl. Econ. Anal. 1 (1), 209–250.
Polo, J., Bernardos, A., Navarro, A., Fernandez-Peruchena, C., Ramírez, L., Guisado, M. V., Martínez, S., 2015. Solar resources and power potential mapping in Vietnam using satellite-derived and GIS-based information. Energy Convers. Manag. 98, 348–358.

[5] http://gizenergy.org.vn/media/app/media/legal%20documents/GIZ_PDP%207%20rev_Mar%202016_Highlights_IS.pdf.

Silitonga, A.S., Masjuki, H.H., Mahlia, T.M.I., Ong, H.C., Chong, W.T., Boosroh, M.H., 2013. Overview properties of biodiesel diesel blends from edible and non-edible feedstock. Renew. Sustain. Energy Rev. 22, 346–360.

Silitonga, A.S., Masjuki, H.H., Ong, H.C., Sebayang, A.H., Dharma, S., Kusumo, F., Mahlia, T.M.I., 2018. Evaluation of the engine performance and exhaust emissions of biodiesel-bioethanol-diesel blends using kernel-based extreme learning machine. Energy 159, 1075–1087.

Silitonga, A.S., Shamsuddin, A.H., Mahlia, T.M.I., Milano, J., Kusumo, F., Siswantoro, J., et al., 2020. Biodiesel synthesis from Ceiba pentandra oil by microwave irradiation-assisted transesterification: ELM modeling and optimization. Renew. Energy 146, 1278–1291.

Simshauser, P., 2018. On intermittent renewable generation & the stability of Australia's National Electricity Market. Energy Econ. 72, 1–19.

Simshauser, P., Tiernan, A., 2018. Climate change policy discontinuity and its effects on Australia's national electricity market. Aust. J. Publ. Adm. 1–20. https://doi.org/10.1111/1467-8500.12328.

Siriwardana, M., Meng, S., McNeill, J., 2013. A CGE assessment of the Australian carbon tax policy. Int. J. Global Energy Issues 36 (2–4), 242–261.

Siriwardana, M., Nong, D., 2018. Economic implications for Australia and other major emitters of trading greenhouse gas emissions internationally. Int. J. Glob. Warming 16 (3), 261–280.

Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Edmonson, N., 2006. Stern Review: the Economics of Climate Change, 30. HM treasury London.

Toan, P.K., Bao, N.M., Dieu, N.H., 2011. Energy supply, demand, and policy in Viet Nam, with future projections. Energy Pol. 39 (11), 6814–6826.

Tran, T.M., Siriwardana, M., Meng, S., Nong, D., 2019. Impact of an emissions trading scheme on Australian households: a computable general equilibrium analysis. J. Clean. Prod. 221, 439–456.

Tran, V.-T., Chen, T.-H., 2013. Assessing the wind energy for rural areas of Vietnam. Int. J. Renew. Energy Resour. 3 (3), 523–528.

Truong, A.H., Patrizio, P., Leduc, S., Kraxner, F., Ha-Duong, M., 2019. Reducing emissions of the fast growing Vietnamese coal sector: the chances offered by biomass co-firing. J. Clean. Prod. 215, 1301–1311.

Vietnamese Ministry of Industry and Trade, 2017. Viet Nam's Power Development Plan.

Vithayasrichareon, P., MacGill, I.F., 2012. A Monte Carlo based decision-support tool for assessing generation portfolios in future carbon constrained electricity industries. Energy Pol. 41, 374–392.

Wang, C., Siriwardana, M., Meng, S., 2019. Effects of the Chinese arable land fallow system and land-use change on agricultural production and on the economy. Econ. Modell. 79, 186–197.

Wang, X.C., Klemeš, J.J., Wang, Y., Dong, X., Wei, H., Xu, Z., Varbanov, P.S., 2020. Water-Energy-Carbon Emissions nexus analysis of China: an environmental input-output model-based approach. Appl. Energy 261, 114431.