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Energy mix and its implications on the Vietnamese economy by 2030: A CGE analysis using GTAP-E-Power

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Abstract

This study uses the GTAP-E-Power model to examine the economic and environmental implications of transitioning to different energy generation mixes in Vietnam by 2030. Three scenarios were considered for that year: (1) low-coal and high-gas, (2) low-coal and high-renewables, and (3) high-coal. Scenario 2 emerges as the most balanced approach, resulting in a 1.02% GDP decline and a 0.78% increase in CO_2 emissions. In this scenario, the electronics sector grows slightly (+0.3%), while metals (–3.1%) and chemical products (–1.0%) experience moderate declines. In terms of exports, Scenario 2 gives rise to an increase in the trade balance (151 million USD) and a modest gain in exports to China (+0.46%), Japan (+0.37%), Korea (+0.33%), and Western Europe (+0.35%). Across all three scenarios, the output of the electronics industry shows sensitivity to energy mix changes, while the coal mining sector seems to be resilient to changing the energy mix.

Keywords

- GTAP-E-Power
- CGE
- Vietnam
- energy mix
- renewable energy

JEL codes: C68, O13, Q43.

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Introduction

The composition of electricity generation, also termed the energy mix, plays an important role in determining a country's economic and environmental outcomes (Adebayo et al., 2024). A fossil-heavy mix provides a cheap and stable energy supply but increases dependence on fossil fuel prices, while a renewable-focused mix enhances energy security but requires high capital investment (Marques et al., 2019). Additionally, an energy mix dependent on imports can affect growth through trade imbalances and price volatility (Murshed, 2021). In terms of environmental impact, fossil-heavy electricity generation is the largest contributor to global emissions (IEA, 2019). Therefore, a transition to low-carbon energy is essential to meet climate targets and align with the Paris Agreement (UNFCCC, 2015). This has been supported by a great deal of research highlighting the negative relationship between the share of renewable energy resulting from phasing out coal power and emissions from the electricity sector (Raza et al., 2025).

As a developing country, Vietnam presents an interesting case for studying the economic implications of energy transition. The country has witnessed significant economic growth, with an average annual GDP growth rate of 6.5% between 2000 and 2019 (World Bank, 2021). However, this growth has also led to increased energy consumption and greenhouse gas emissions. In 2019, Vietnam's total greenhouse gas emissions reached 364.5 million metric tons of CO_2 equivalent, with the energy sector contributing 65.8% of the total emissions (Ministry of Natural Resources and Environment, 2020). Recognizing these environmental consequences, Vietnam updated its Nationally Determined Contribution (NDC) under the Paris Agreement in 2022, committing to a 15.8% reduction in greenhouse gas emissions by 2030 compared to the business-as-usual scenario, with the potential to increase this reduction to 43.5% with international support (UNFCCC, 2022). The government also identified shifting the energy mix towards low-carbon energy as a key strategy for Vietnam in fulfilling the NDC commitments (Handayani et al., 2022). This strategy has already been proved to be potentially effective in some empirical studies in the Vietnamese context. For example, using wavelet analysis, Le (2022) analysed the time-varying nature of relationships between non-renewable and renewable energy consumption, economic growth, and CO_2 emissions in Vietnam and found that the relationship between renewable energy and CO_2 emissions is more pronounced in the period from 2003 onwards. The study also pointed out that although consumption of non-renewables is important in promoting early economic development, the magnitude of this relationship is diminishing over time, and its impact on CO_2 emissions tended to grow from 2009 onwards. This finding is further corroborated by V. C. T. Nguyen and Le (2022), who used an Error Correction Model to show a long-term positive but short-term negative relationship between consumption of non-renewables and growth. Another interesting mechanism in the Vietnamese renewable-emission nexus has been proposed by Hung (2023), who offered evidence on the role of remittances in accelerating CO_2 emissions by using wavelet analysis. The study found that remittances significantly contribute to elevated CO_2 emissions in the short- and medium term, mostly via investment in non-renewable energy projects, and that renewable energy and CO_2 emissions actually have bidirectional causality, suggesting that financial moderation of remittances focused on environmentally friendly projects might have impacts on the long-term expansion of renewables. Other approaches that can be considered for Vietnam to promote the energy shift include leveraging international climate funds, joining carbon credit markets, and streamlining foreign direct investment (FDI). Participation in global initiatives can facilitate financial support for developing countries to scale up clean energy projects. In addition, joining international carbon credit markets, following Article 6 of the Paris Agreement, allows Vietnam to sell carbon credits derived from renewable projects, which in turn provides Vietnam with the necessary climate finance and technology support to further expand its renewable share. Streamlining FDI investments towards green projects can contribute to technology transfer, infrastructure development, and project financing, ensuring a more sustainable and cost-effective energy transition. These approaches have been proved to be effective ways to promote green energy transition (Buchner et al., 2023; Huang et al., 2023; Oladapo et al., 2024).

However, the transition to a low-carbon power system also carries economic implications and difficulties, including asset risk for coal power plants, the need for transmission and renewable generation investments, and the potential impacts on the fossil fuel industry (IRENA, 2017, 2018; Spencer et al., 2018). To be specific, high initial investment in renewable infrastructure, grid integration and technology can pose a significant challenge for developing countries like Vietnam, where access to affordable financing and long-term capital remains limited. In addition, numerous factors, such as policy uncertainty, concerns over power purchase agreements, grid infrastructure reliability and market volatility, can also discourage investment in renewable power. Vietnam, in particular, has made some efforts to mitigate these financial risks by introducing feed-in tariffs (FITs) for wind and solar projects and has already achieved some success in expanding these energy types. Other measures taken by developed nations to mitigate such risks and ensure a stable investment environment for renewable energy development include auction-based pricing mechanisms, green bonds, and financial guarantees to attract both domestic and foreign capital.

In this study, we evaluate the economic implications of transitioning to different energy mixes in Vietnam. To achieve this objective, we first analysed the

Vietnamese government's master plans for energy development to determine optimistic and pessimistic energy generation mixes by 2030. We then simulated these scenarios in a computable general equilibrium (CGE) framework to reveal important economic indicators and welfare relative to the baseline scenario in 2030, where no power transition policies are implemented. The results of this analysis are expected to provide valuable insights and recommendations for policymakers, stakeholders, and researchers in Vietnam, justifying the transition to a renewable energy mix as a feasible solution for fulfilling NDC commitments.

1. Methodology

1.1. The GTAP-E-Power model

To examine the implications of different energy mixes on the Vietnamese economy, we used the GTAP-E-Power model. GTAP-E-Power is a type of applied CGE model commonly used in ex-ante policy analysis, especially when it comes to environmental and energy issues. Being a CGE model, the GTAP-E-Power model consists of a system of simultaneous equations grounded in economic theory that describes the behaviors of economic agents in the economy and is solved following general equilibrium theory (supply equals demand in all goods and factor markets). The model consists of multiple regions, all linked via export and import equations. In each region, a hypothetical regional household collects all income from one private household, one government, and many representative firms, each representing one industry. The collected income is then redistributed among the private household, the government, and investment so that the utility (in Cobb-Douglas form) of these three entities is maximised. The representative firm operates under a cost-minimising condition and utilises numerous inputs following a constant elasticity of substitution (CES) production structure with many levels, also called nests, to produce an output, as illustrated in Figure 1. In the conventional CES production function with one level, all inputs are assumed to share one elasticity of substitution (σ). In the nested CES production function, some inputs can have an elasticity of substitution that is different from that of some other inputs, allowing for a better representation of the functional role of inputs in production.

The GTAP-E-Power model is a combination of GTAP-E, the environment-energy extension of the standard Global Trade Analysis Project (GTAP) model, and GTAP-Power, the electricity-detailed extension of the standard GTAP

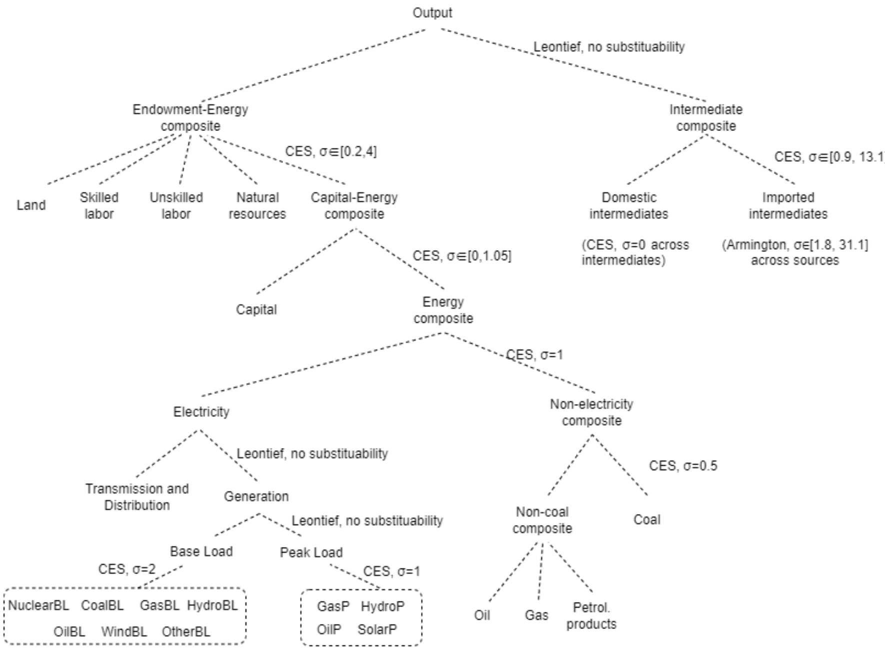

Figure 1. Production structure in GTAP-E-Power model

Source: adapted from the GTAP-E-Power model and (Peters, 2016).

model. In the GTAP-E model, the production structure adds energy as a new production factor (in addition to capital, labour, and intermediates), and integrates it with capital to form a capital-energy composite factor. The energy commodity nest is further broken down into smaller nests formed by electricity, coal, crude oil, gas, and petroleum products. This nested structure of the GTAP-E-Power model allows sectors to substitute between intermediate inputs, fossil fuels, energy types, and endowments. In addition, separating energy into different sub-commodities allows for the calculation of emission intensity and total emission resulting from the usage of coal, crude oil, gas, and petroleum products, the four primary carbon-emitting commodities. In the GTAP-Power model, Peters (2015) further broke down the electricity commodity into the transmission and distribution commodity and the generation commodity. The generation commodity is formed by a base-load nest and a peak-load generation nest. Baseload electricity covers generation technologies characterized by high efficiency but substantial investment costs, and which cannot adjust quickly to fluctuations in demand. On the contrary, peak load technologies involve less investment outlay but with lower efficiency, and designed to respond quickly to demand fluctuations. The distinction between base- and peak-load generation reflects the unique properties of the electricity

Table 1. Region and sectoral aggregation of the GTAP-E-Power model

Regions		Sectors	
1	Vietnam	1	Agriculture
2	China	2	Coal mining
3	Korea	3	Crude oil
4	Japan	4	Gas extraction & distribution
5	India	5	Extraction of other minerals
6	The US	6	Processed food
7	Western Europe	7	Refined oil products
8	Rest of the world	8	Textiles & wearing apparel
		9	Chemical products
		10	Non-metallic minerals
		11	Metals
		12	Electronics & electrical equipment
		13	Machinery & other equipment
		14	Vehicles and parts & other transport equipment
		15	Other industries
		16	Transmission & distribution of electricity
		17	Nuclear baseload
		18	Coal baseload
		19	Gas baseload
		20	Wind baseload
		21	Hydro baseload
		22	Oil baseload
		23	Other baseload
		24	Gas peakload
		25	Hydro peakload
		26	Oil peakload
		27	Solar peakload
		28	Services

Source: adapted from (Aguiar et al., 2022).

market, where power demand can fluctuate, and different generation technologies serve complementary roles to satisfy the electricity demand. Later, Peters (2016) unified the features in the production nest of both extensions into a single model of GTAP-E-Power. Table 1 presents sectors and regions included in the GTAP-E-Power model used in this study.

The data for the GTAP-E-Power model were aggregated from the GTAP database version 11, with the base year of 2017, which covers 160 regions and 65 sectors. 2017 is the most recent year in which GTAP-E-Power database updates were available at the time of conducting this study. It also represents a pre-pandemic state, where all economic structures and transactions are normal and not affected by COVID-19 pandemic restrictions. We also supplemented the model with capital-energy substitution elasticities that were econometrically estimated in our previous study (D. C. Nguyen & Ko, 2024).

1.2. Scenarios

The scenarios employed in our study were designed as follows. We first projected the aggregated GTAP-E-Power database to the year 2030 by shocking capital stock, labour force, population, and GDP of all regions to the year 2030 under a modified closure, where GDP is set as exogenous and endowment productivity as endogenous. The 2017–2030 growth rates are calculated using data from World Bank Indicators (for the 2017–2023 period) and the forecast from the SSP2 scenario of Fontagné et al. (2022) (for the 2023–2030 period). The use of projection based on real data for the 2017–2023 period allows the model to capture pandemic-induced abnormalities in growth. After conducting the 2017–2030 projection, the closure was reverted to the standard closure, and productivity changes were used in place of GDP projections to form the baseline scenario.

Using this baseline, we developed three policy scenarios with different electricity output compositions coming from generation technologies in Vietnam, as summarised in Table 2. The generation mix was specified by adjusting the output of electricity sectors under a modified closure, where the output of the shocked sector was set as exogenous and swapped with its technical productivity. In the first scenario—termed low coal, high gas—in addition to the baseline projection shocks, we applied appropriate shocks to outputs of gas-fired, coal-fired, and hydroelectricity sectors in the Vietnam region so that the simulated energy mix approximates the 2030 target mix described in Vietnam's newest energy plan: Decision 500 (Prime Minister of Vietnam, 2023). Signed by the Prime Minister of Vietnam in May 2023, Decision 500 describes Vietnam's national electricity development plan for the period 2021–

Table 2. Simulated energy mixes for Vietnam in the GTAP-E-Power model

Scenario	Simulated energy mixes				Reference energy mixes	
	Baseline (%)	Scenario 1 low-coal high-gas (%)	Scenario 2 low-coal high-re-newables (%)	Scenario 3 high-coal (%)	Decision 500–2030 target mix (%)	Decision 428–2030 target mix (%)
Renewables	57.7	55.6	60.4	42.2	49.8	40.9
Coal-fired	29.5	24.9	26.8	41.9	25.7	42.6
Gas-fired	12.3	19.1	12.2	14.4	20.7	14.7
Oil-fired	0.5	0.2	0.5	0.0	0.0	0.0
Others	0.1	0.2	0.1	1.5	3.8	1.8

Source: calculated from GTAP-E-Power model results and policy documents.

2030 with a vision to 2050 and serves as one of the key policy measures to help accomplish the ambitious NDC submitted in 2022. The decision sets out targets for the shares of different generation sources in the country's electricity mix by 2030, with a focus on more renewables and gas.

The second scenario—termed low-coal, high-renewables—is similar to the first scenario except that we only applied a shock to the output of the coal-fired electricity sector to resemble Decision 500's decommission pathway for coal-fired power plants in Vietnam to 2030 and allowed outputs of non-coal electricity sectors to be endogenously determined. This resulted in a scenario where renewable energy, mainly comprising hydroelectricity, predominates over other generation sources. The rationale behind this second scenario is to assess how the Vietnamese economy responds to the aggressive phasing-out of coal power, while allowing market forces to determine the mix of replacement generation.

In the third scenario—termed high-coal—baseline shocks were applied to the model and a large shock to the output of the Vietnamese coal-fired power sector in order that the final energy mix resembles that described in Decision 428 (Prime Minister of Vietnam, 2016). Decision 428, issued in March 2016, approved the Revised National Power Development Master Plan for the 2011–2020 Period with a Vision to 2030, focusing on expansion of coal-fired power generation by 2030. Its target is for coal power capacity to reach over 55 GW by 2030, accounting for 42.6% of the total installed capacity. However, in 2023 it was superseded by Decision 500.

2. Results and discussion

2.1. Simulated changes in Vietnamese sectoral outputs

Shifting the energy mix toward a less carbon-intensive composition is expected to reduce the demand for fuel commodities and possibly lower output in sectors whose input composition is heavily dependent on fossil-based energy, and vice versa (Sikder et al., 2019). Table 3 presents the impact of different energy mixes on the sectoral outputs of Vietnam in 2030. In Scenario 1, we restricted the output growth of Vietnam's renewable, coal, and oil energy sectors to achieve the target composition. As a result, the output of gas and other energy sources was raised to compensate for the loss in electricity output. The gas power sector's output increased by 66.9% compared to the baseline. This increase is primarily attributable to the baseload gas power sector, where a change of approximately 293% was registered. Strikingly, although the output of the coal power sector was forced to remain almost unchanged compared to the 2017 baseline, we found that the coal power sector actually consumed around 101% more input (e.g., coal, electricity, or capital). Under a production function with constant return to scale and endogenous technical change, this can only mean that output-augmenting technical change was significantly lowered (–69% compared to the baseline). Our findings on the increased input consumption in the coal power sector, despite unchanged output, align with the observations of Cui et al. (2019), who noted that policy constraints on coal power plants can lead to operational inefficiencies. In our model, the reduced productivity of the coal power sector could be attributed to rising coal prices (4.17% compared to the baseline). Typically, the increase in coal prices would have led to higher input costs for the coal power industry, and the sector, facing rising costs, would have attempted to adjust input usage or production levels to minimise costs. However, because a fixed output constraint was imposed on coal power and because the electricity generation sectors are not allowed to substitute inputs in the GTAP-E-Power model, the coal power sector is unable to reduce its coal consumption. As a result, it must compensate by using additional input—including electricity and capital—to maintain the same level of output, leading to production inefficiency. The increased use of coal, despite its higher price, is part of this overall efficiency reduction, where more input is required to produce the same output.

As the largest consumer of coal in Vietnam, the coal power sector's increased coal consumption has also led to higher output in the domestic coal mining sector. Specifically, the energy mix policy effected a 30.2% rise in coal mining output in Scenario 1 relative to the baseline. This is due to the aforementioned coal price rise, which incentivises the sector to produce more coal,

Table 3. Impact of changes in energy mix on the sectoral output of Vietnam relative to the 2030 baseline (US$ million)

	Scenario 1	Scenario 2	Scenario 3
Agriculture	–749 (–0.8%)	–27 (0.0%)	–248 (–0.3%)
Coal mining	818 (30.2%)	24 (0.9%)	1,099 (40.6%)
Crude oil	–133 (–3.2%)	6 (0.1%)	–147 (–3.5%)
Gas extraction & distribution	–186 (–9.6%)	–2 (–0.1%)	79 (4.1%)
Extraction of other minerals	75 (2.2%)	–49 (–1.4%)	268 (7.9%)
Processed food	–532 (–1.1%)	–142 (–0.3%)	337 (0.7%)
Refined oil products	–686 (–1.8%)	104 (–0.1%)	–1,194 (0.4%)
Textiles & wearing apparel	–981 (–14.2%)	–60 (2.1%)	198 (–24.7%)
Chemical products	–923 (–2.2%)	–412 (–1.0%)	–724 (–1.7%)
Non-metallic minerals	–98 (–0.6%)	–351 (–2.2%)	1,453 (9.0%)
Metals	–4,640 (–12.4%)	–1,142 (–3.1%)	1,984 (5.3%)
Electronics & electrical equipment	–36,700 (–24.2%)	470 (0.3%)	–16,038 (–10.6%)
Machinery & other equipment	–497 (–6.4%)	–85 (–1.1%)	20 (0.3%)
Vehicles, parts & other transport equipment	1,083 (6.6%)	–246 (–1.5%)	2,087 (12.8%)
Other industries	47 (0.1%)	–632 (–0.8%)	1,643 (2.0%)
Transmission & distribution of electricity	894 (12.3%)	–349 (–4.8%)	1,539 (21.1%)
Renewable power	–294 (–2.7%)	365 (3.3%)	–2,503 (–22.8%)
Coal-fired power	–961 (–17.1%)	–736 (–13.1%)	3,771 (66.9%)

table 3 continued

	Scenario 1	Scenario 2	Scenario 3
Gas-fired power	1,594 (66.9%)	–61 (–2.6%)	826 (34.7%)
Oil-fired power	–75 (–80.7%)	–1 (–1.1%)	–104 (–112.4%)
Other power	29 (236.7%)	0 (0.5%)	360 (2983.2%)
Services	–5,339 (–2.8%)	–1,048 (–0.5%)	–3,868 (–2.0%)

Source: calculated from the GTAP-E-Power model result.

hence higher output. Similar patterns have been observed in other contexts, such as China and India, where energy mix policies emphasising coal-fired power generation have led to significant increases in coal output (IEA, 2020; Ministry of Coal, 2021). The new energy mix reduced output in the electronics and electrical equipment sector by 24.2%, with demand for energy in this sector increasing by approximately 20%. However, this was overshadowed by a decline in capital use (–46%) and intermediate input (–21.5%). On the other hand, we found that the shift in the energy mix led to the reallocation of capital towards sectors more directly involved in the new energy infrastructure. Indeed, we established that significant capital endowments were allocated to major sectors of the Vietnam economy to accommodate the forced energy shift, including the coal mining sector (204%), coal power (102%), baseload hydropower (117%), and baseload gas power (282%). Similar situations were also observed in textiles and apparel, metals and machinery, and other equipment sectors. This observation is consistent with Khalil and Strobel (2023), who found that climate policy can induce a capital shift from carbon-intensive sectors to sectors with lower emission intensity.

In Scenario 2, where only the output of the coal-fired power sector was restricted, the impacts appear to be milder across most sectors of the Vietnamese economy compared to Scenario 1, thus suggesting that a shift toward a more renewable-focused energy mix might lead to less economic disruption than a more gas-heavy composition. In the power generation sector, constraining the growth of coal-fired power shifted the composition towards renewables, with renewable power registering growth of 3.3%. Gas-fired and oil-fired power show smaller decreases of 2.6% and 1.1%, respectively. Interestingly, despite the decrease in coal-fired power, the coal mining sector registered a slight increase of 0.9% in output. Although the coal power sector does not consume significantly more coal compared to the baseline, other sectors, such as the coal mining sector itself, the agriculture sector, and the electronics and electrical equipment, increased their coal usage (4%, 2%, and 2%, respectively) to substitute for smaller increases in capital endowments. These findings carry two main implications. First, simply decommissioning the coal power sector without imposing restrictions on other power sources is unlikely to bring about significant changes in the outputs of upstream extractive sectors. Second, these sectors may demonstrate some resilience or adaptability in response to changing energy policies in the form of the ability to shift production towards export markets or to change their input composition flexibly. With specific regard to Vietnam's coal mining sector, the substitution elasticity between production factors is approximately 4, which is much higher than those of other sectors, such as oil extraction (0.4), gas extraction (0.04), and manufacturing industries (1.26). This allows the coal mining sector to maintain or even slightly increase its output, despite reduced demand from the coal-fired power sector.

The electronics and electrical equipment sector in Scenario 2 registered an increase in output of 0.3% relative to the baseline. Examining the change in demand in this sector reveals that demand for energy in the sector dropped by –4.9%, with demand for capital increasing by 1.2% as a result of the coal power reduction policy. This contrasts with Scenario 1, where significant capital was reallocated from non-energy to energy sectors. For vehicles, parts, and other transport equipment, we note the opposite shift from positive (6.6%) to negative outcomes (–1.5%) when moving from Scenarios 1 to 2. This differing impact can be attributed to the fact that Vietnam's vehicles sector has far lower export levels compared to its electronics and electrical equipment sector, making it more reliant on and thus sensitive to domestic demand. This could be easily altered by domestic energy shifts. Indeed, comparing demand for vehicles and vehicle parts in the two scenarios reveals that the aggressive energy shift in Scenario 1 led to significant changes in demand for vehicle commodities in energy generation sectors, including coal baseload (101%), gas baseload (282%) and hydro baseload (117%). Meanwhile, in Scenario 2, the coal baseload, gas baseload, and hydro baseload sectors only required 0.94%, 7.18%, and 2.96% more vehicle commodities relative to the baseline, respectively.

In Scenario 3, where coal-fired power predominates over other generation technologies, in addition to obvious changes in the power sectors, we noted a significant, positive impact of coal power-promoting policy on the output of the coal mining (40.6%), mineral extraction (7.9%), non-metallic minerals (9%), metals (5.3%), vehicles (12.8%) and electricity transmission (21%) sectors. It is easy to justify the coal mining sector's sharply elevated output in response to the policy shock because Scenario 3 mainly focused on expanding the share of coal power in the energy mix. As a result, this mining sector has to raise its production to provide coal for power generation. For the non-metallic minerals sector, the sector with the second highest coal consumption, the policy caused the demand for energy commodities in this sector to rise by 21.89%. However, this was compensated by a reduction in capital demand by –13.37%, which was reallocated to facilitate the expansion of coal energy. The phenomenon of capital divestment is not unique to the non-metallic minerals sector. In fact, we found that crude oil extraction, mineral extraction, food processing, oil refinery, chemical, electronics, machinery, and equipment sectors all suffered from a reduction in capital, ranging from –7.6% to –26.5%. Such significant capital reallocation observed in this scenario raises concerns about long-term economic sustainability and diversification. While the expansion of coal-fired power drives growth in related heavy industries, the capital divestment from crucial industries like electronics, machinery, and chemicals could potentially hinder Vietnam's ability to move up the global value chain and diminish its ability to innovate and compete internationally (Nguyen et al., 2020). Moreover, the heavy reliance on coal power in this scenario may pose significant challenges to Vietnam's ability to meet its international climate commitments and could expose the country to future economic risks as global markets increasingly prioritise low-carbon goods and services (Ha-Duong et al., 2016).

2.2. Simulated changes in exports, GDP, welfare, and emissions

Table 4 presents the impact of changes in Vietnam's energy mix on the export values of important commodities to major trading partners under Scenarios 1, 2, and 3, compared to the 2030 baseline. Across the three scenarios, the overall trends indicate that aggressive shifts in Vietnam's energy mix have significant impacts on its export performance. This finding aligns with Antimiani et al. (2016), who also observed substantial effects of energy policy changes on the trade patterns of many countries. Scenario 1 showed considerable declines in total exports to major trading partners, with exports to China dropping by $9,669 million (–28.56%). In addition, the electronics and electrical equipment sectors experienced substantial declines in absolute exports across all trading partners. There are two main reasons for this decline. First, the sector suffers from capital diversion, where significant capital was reallocated to promote the production of gas-fired energy, as previously evidenced by a 46% decline in capital use. Second, increased production costs induced Vietnamese exporters to raise prices, making their products less competitive than those from other countries. Closer inspection of model linkages confirms this speculation by revealing the policy-induced impact of 2.4%, 7.5%, and 0.73% increases on prices of skilled labour, capital, and electronics and

Table 4. Impact of changes in energy mix on export of some main commodities of Vietnam relative to the 2030 baseline (US$ million)

	Scenario 1	Scenario 2	Scenario 3
Export to China	–9,238 (–12.07%)	62 (0.06%)	–3,679 (–4.31%)
Textiles & wearing apparel	–31 (–0.68%)	–2 (–0.05%)	63 (1.38%)
Electronics & electrical equipment	–9,669 (–28.56%)	155 (0.46%)	–4,659 (–13.76%)
Machinery & other equipment	–3 (–0.29%)	–12 (–1.32%)	82 (9.17%)
Other manufacturing products	203 (4.74%)	–37 (–0.87%)	301 (7.05%)
Export to Japan	–1,974 (–7.07%)	–78 (–0.28%)	–835 (–3.56%)
Textiles & wearing apparel	–175 (–4.14%)	–2 (–0.04%)	–89 (–2.10%)
Electronics & electrical equipment	–1,291 (–25.19%)	19 (0.37%)	–706 (–13.72%)
Machinery & other equipment	–182 (–20.60%)	–6 (–0.63%)	–113 (–12.83%)
Other manufacturing products	–193 (–5.04%)	–32 (–0.83%)	22 (0.56%)
Export to Korea	–1,411 (–4.81%)	–28 (–0.14%)	–223 (–1.00%)
Textiles & wearing apparel	–75 (–2.13%)	–2 (–0.05%)	–7 (–0.20%)
Electronics & electrical equipment	–1,308 (–16.88%)	25 (0.33%)	–390 (–5.03%)
Processed food products	–3 (–0.28%)	–1 (–0.07%)	13 (1.47%)
Other manufacturing products	–20 (–1.19%)	–32 (–0.80%)	80 (4.83%)
Export to India	3 (2.95%)	–44 (–0.68%)	69 (8.96%)
Metals	–186 (–20.36%)	–49 (–5.32%)	46 (5.01%)
Electronics & electrical equipment	–108 (–5.47%)	6 (0.28%)	180 (9.13%)

table 4 continued

	Scenario 1	Scenario 2	Scenario 3
Agricultural products	84 (29.93%)	9 (3.17%)	54 (19.15%)
Other services	58 (14.85%)	3 (0.82%)	69 (17.76%)
Export to the US	–3,167 (–5.11%)	–148 (–0.23%)	–625 (–1.16%)
Textiles & wearing apparel	–170 (–1.21%)	–7 (–0.05%)	142 (1.01%)
Electronics & electrical equipment	–2,507 (–23.76%)	37 (0.35%)	–1,263 (–11.98%)
Machinery & other equipment	–151 (–11.19%)	–7 (–0.54%)	–64 (–4.73%)
Other manufacturing products	–418 (–2.98%)	–108 (–0.77%)	388 (2.77%)
Export to Western Europe	–5,203 (–7.56%)	11 (–0.10%)	–152 (–5.03%)
Textiles & wearing apparel	–144 (–3.13%)	–2 (–0.04%)	142 (1.63%)
Electronics & electrical equipment	–4,616 (–26.44%)	61 (0.35%)	–2,634 (–15.09%)
Other services	–270 (–6.47%)	11 (0.34%)	–152 (–4.81%)
Other manufacturing products	–315 (–3.78%)	–58 (–0.69%)	–25 (–0.30%)
Export to rest of the world	–7,191 (–6.84%)	–193 (–0.22%)	–202 (–1.84%)
Electronics & electrical equipment	–6,073 (–21.99%)	105 (0.37%)	–2,587 (–9.37%)
Processed food products	22 (0.42%)	–4 (–0.08%)	120 (2.32%)
Other services	–270 (–4.51%)	24 (0.41%)	–202 (–3.36%)
Other manufacturing products	–200 (–3.23%)	–50 (–0.81%)	175 (2.83%)

Source: calculated from the GTAP-E-Power model result.

electrical equipment, the three most important inputs for the production of electronics and electrical equipment. These findings are consistent with the study by Doan et al. (2019), which highlighted the vulnerability of Vietnam's electronics sector to varying input prices. On the other hand, exports from light manufacturing sectors such as textile and apparel, food processing, other manufacturing, and services were not significantly affected by the policy. This is because these sectors are generally less energy-intensive compared to heavy industries like electronics manufacturing. Consequently, increases in energy costs resulting from the shift towards gas-fired power are not likely to lead to significant cost rises.

Scenario 2 appears to have the least disruptive impact on Vietnam's export economy compared to the other two scenarios, with most changes being within ±1% of the baseline. Notably, exports to China show a slight overall increase of 0.06% ($62 million), primarily driven by growth in the electronics and electrical equipment sector (0.46% or $155 million). Similar modest gains in electronics exports were observed across other major markets, including Japan, Korea, the US, and Western Europe. However, some sectors and destinations do experience minor declines. For instance, machinery and other equipment exports to China decreased by 1.32% ($12 million), and exports of other manufacturing products showed slight decreases across several markets. Interestingly, exports to India are mixed with a slight overall decline of 0.68% ($44 million), despite growth in the electronics and agricultural products sectors. The textiles and wearing apparel sector, crucial to Vietnam's export economy, remains remarkably stable across all destinations, with changes not exceeding –0.05%.

The exports in Scenario 3 remain below baseline levels, and energy-intensive sectors like electronics still face substantial declines. These trends are generally consistent with previous results regarding sectoral outputs. The most notable figure is the stark decline in electronics exports to China of $4,659 million (–13.76%), followed by a decline to Japan by $706 million (–13.72%) and to the USA by $1,263 million (–11.98%). However, electronics exports to India registered a significant increase of 9.13% ($180 million). Analysis of the export decline to China reveals that import demand for electronics increased by 3.92% in China, but the import price to China also decreased by –5.75%. However, this was heavily compensated for by the drop in the price of the imported composite of electronics and electrical equipment in China (–7.28%), suggesting that the policy hampered the international competitiveness of the Vietnamese electronics industry compared to other regions exporting to China. On the other hand, the textiles and wearing apparel sector registered export growth to some destinations, with increases of $63 million (1.38%) to China, $142 million (1.01%) to the USA, and $142 million (1.63%) to Western Europe. This can be explained by increased coal usage leading to lower energy costs and production expenses, which in turn improves the competitiveness of Vietnamese light manufacturing commodities in these markets. Exports of machinery and other equipment show mixed results, with an increase in China (9.17%) but a decrease in Japan (–12.83%) and the US (–4.73%). This is due to China's demand for machinery related to the industrial and energy sectors. Processed food products register increases across several markets, particularly in the rest of the world (2.32%).

Table 5 presents the macroeconomic and environmental impacts on Vietnam's economy of three different energy mix scenarios relative to the 2030 baseline. The most severe impacts can be observed in Scenario 1, where GDP decreased by 8.02%, and welfare by $14,254 million, which is primarily due to a significant negative technical change effect of $20,925 million. The trade balance worsens by $7,001.81 million, indicating increased imports or decreased exports, possibly due to higher energy costs and reduced competitiveness in key sectors like electronics. CO_2 emissions rose by 18.04%, primarily driven by a 39.46% increase in coal emissions, despite the reduction in coal-fired power, suggesting inefficiencies or increased coal use in other sectors.

Table 5. Impact of changes in energy mix on GDP, trade balance, emissions and welfare of Vietnam relative to the 2030 baseline

	Scenario 1	Scenario 2	Scenario 3
GDP (%)	–8.02	–1.02	–3.31
Trade balance (US$ million)	–7,001.81	151.34	–1,493.26
Welfare (US$ million)	–14,254.00	–1,888.68	–8,600.05
Welfare—Allocative efficiency (US$ million)	–1,151.96	–461.56	–813.55
Welfare—Endowment effect (US$ million)	4,467.02	–132.82	3,853.50
Welfare—Technical change effect (US$ million)	–20,925.00	–1,313.11	–12,601.20
Welfare—Terms of trade effect (US$ million)	3,930.47	83.69	1,454.91
CO_2 emission (%)	18.04	0.78	28.89
CO_2 emission—coal (%)	39.46	0.82	51.50
CO_2 emission—oil (%)	–6.69	0.36	0.57
CO_2 emission—gas (%)	–18.24	–1.27	15.96
CO_2 emission—oil products (%)	–6.94	1.43	–8.95

Source: calculated from the GTAP-E-Power model result.

In contrast, Scenario 2, featuring a reduction in coal-fired power and a slight increase in renewables, demonstrated the least disruptive impact on the economy and environment. GDP declined marginally by 1.02%, and welfare by $1,888.68 million, with minimal negative effects on allocative efficiency and endowments. The trade balance slightly improved by $151.34 million, reflecting stable export performance and reduced import dependency. CO_2 emissions increased negligibly by 0.78%, highlighting the environmental benefits of reducing coal reliance and promoting renewables. While this result may be at odds with prior expectations regarding the energy shift, it can be attributed to industries' ability to substitute electricity input with coal and other fuels in response to lower electricity input so that the equilibrium production quantity can be achieved. This is consistent with a previous meta-analysis by Stern (2012), which suggested that there is generally some degree of substitutability between energy inputs of manufacturing industries and is further evidenced by a rise in emissions resulting from the consumption of crude oil and oil products, even though Vietnam's generation sectors consumed very little of this commodity in Scenario 2. Scenario 3, which significantly increases coal-fired power and decreases renewables, resulted in a moderate GDP decline of 3.31% and a welfare loss of $8,600.05 million. However, it led to the highest rise in CO_2 emissions at 28.89%, primarily due to a 51.5% spike in coal emissions. These results suggest that Scenario 2 offers a balanced approach, minimising economic disruptions while achieving environmental benefits, whereas Scenarios 1 and 3 pose significant economic and environmental challenges for Vietnam.

Conclusions and policy implications

We examined the economic and environmental implications of transitioning to different energy generation mixes through three scenarios: a gas-heavy mix, a renewable-focused mix, and a coal-dominant mix. Notably, the renewables-focused scenario (Scenario 2) emerged as the most balanced approach, minimising economic disruptions while achieving environmental benefits. This led to a marginal GDP decline of 1.02% and a slight increase in CO_2 emissions of 0.78%. In contrast, the gas-heavy (Scenario 1) and coal-dominant (Scenario 3) scenarios resulted in more substantial economic costs and environmental impacts. In the gas-heavy scenario, this sector experienced a significant decline in output and exports, suggesting the possibility of capital diversion to power generation sectors. Conversely, the coal-heavy scenario showed adverse impacts on output, export and welfare.

It is worth reiterating that the shift toward renewable energy is indisputably important for achieving better environmental outcomes for Vietnam. However, our findings suggest that imposing a strict limit on the output of gas, coal and renewable power, as in Scenario 1, necessitates reallocating capital from important industries such as electronics and textiles to the gas and renewable energy sectors, which in turn impacts the export of these sectors. Therefore, we recommend setting gradual targets for renewable energy adoption, while providing incentives and support for affected industries to improve their energy efficiency and transition to cleaner technologies. In addition, special treatment for the electronics sector—one of Vietnam's key industries—is needed to mitigate its heavy output decline resulting from the implementation of Scenario 1. First, it is important to ensure that the electronics sector enjoys sufficient access to financing when the capital shift takes place. This could involve providing tax incentives and compensation for the electronics firms affected by capital shortages to upgrade production facilities, and to sustain production and maintain the workforce. Second, maintaining an affordable supply of intermediates and energy for electronics firms can mitigate the adverse impact of capital shift, since the result shows some flexibility in input substitution of the electronics industry. Relevant strategies might involve imposing industrial energy pricing policies that protect electronics firms from excessive volatility in energy price and reduce the import tax of key materials such as semiconductors, precision metals, and specialized components.

Our model also points out that production in the coal power sector will become inefficient if its output is fixed. This is largely due to the inability of this sector to substitute coal input with other fuels. Despite the model's assumption of endogenous productivity, which may not reflect real-world responses to fixed generation output, this phenomenon still highlights a key bottleneck of the coal power sector, namely, its reliance on coal inputs. Therefore, we recommend expediting the adoption of co-fired coal technology to enhance the efficiency and sustainability of coal power generation in Vietnam. Cofiring involves blending coal with alternative fuels such as biomass, natural gas, crude oil or refined oil products in the combustion process. This approach is less capital-intensive than a complete transition to other energy sources and can decrease carbon emissions, improve output productivity, and, most importantly, allow existing coal power plants to substitute coal with other inputs, in order that the industry can reduce its reliance on pure coal inputs. To support the adoption of co-fired coal technology, policymakers should consider providing financial incentives such as subsidies or tax breaks for initial investments in co-firing infrastructure and even for a certain period after the plant has come into full operation.

Given the prediction that substantial capital investment is required to support renewable energy expansion while minimising economic consequences, we recommend employing a combination of different financing instruments, including participation in international climate initiatives and improving domestic investment. First, international funding sources such as the Green

Climate Fund (GCF) and Just Energy Transition Partnerships (JETP) can provide concessional financing to facilitate large-scale renewable energy projects, thus reducing the financial burden on domestic resources. Another approach to secure foreign funding involves selling carbon credits obtained through renewable investments in international markets and reinvesting these funds in green energy infrastructure. Second, domestic investment should be improved through supporting private green investment and relevant industries, including the manufacture of power generation equipment, solar panels, and gas turbines. Specifically, domestic renewable energy manufacturers should be supported by tax credits, low-interest loans, and preferential financing so that their output can be improved, which in turn raises domestic capital accumulation for energy sectors. Support for private investments in green energy projects should also be considered, preferably through streamlined administration, loan guarantees, high feed-in tariffs (FITs), and investment tax credits.

Although Scenario 2 yielded the most optimistic outcomes, our model also predicted that domestic demand for machinery, other equipment, vehicles, parts & other transport equipment will experience a decline as a result of this transition. Therefore, we recommend supplementing the energy transition strategy with plans to improve the quality of labour force in affected sectors, enabling them to substitute the decline in important inputs with more skilled labour. Specific measures might include increasing the admissions quota for vocational schools and providing financial support for workforce retraining to facilitate the transition of workers into affected manufacturing sectors such as vehicles, renewable energy technology, and machinery. Furthermore, we recommend implementing policies for the energy-intensive sectors that cater to the growing renewable energy market. Specific measures might include targeted tax reductions and low-interest loans for domestic manufacturers of important renewable energy components such as turbines, solar panels, and batteries. Similar policies aiming to attract international manufacturers in green technology and sustainable manufacturing could also be considered. By employing these measures, Vietnam can effectively mitigate the negative impacts of the energy transition on key industries, while simultaneously creating export opportunities and attracting investments.

Some limitations need to be acknowledged in this study. First, GTAP-E--Power has limitations that are inherent to other CGE models, particularly regarding the assumed form of the production function. To be specific, the nested CES production function implies that inputs situated at the same level (nest) share the same elasticity of substitution. This assumption may not hold in certain contexts, for instance, in heavy manufacturing and fossil fuel-based power generation industries, where powered machinery (i.e. capital-energy composite) can be easily adjusted for higher working capacity if operators become scarce, but these trained operators cannot be easily replaced with unskilled manpower. This assumption may lead to transition costs being underestimated in industries where specialised labour and capital-intensive technologies are crucial in production processes, because switching from skilled to unskilled labour can be more costly than from skilled labour to powered machinery. This shortcoming can be addressed by adopting firm heterogeneity in model design, where some industries can take a different production structure to reflect these complexities. Second, the current GTAP-E-Power model lacks empirically estimated elasticities in production nests deep down the production structure, e.g., between electricity and non-electricity goods or between coal and non-coal goods. This issue can be remedied by better data availability and more sophisticated approaches in estimation strategies, which should be tackled by future econometric studies. Third, the current CGE results only represent a snapshot of the economy at one point at which all policy shocks take place, rather than the trends of policy impacts over time. This shortcoming stems from the static nature of the GTAP-E-Power model but can be addressed by adopting a dynamic CGE model. In the context of energy transition policies, an examination of whether the capital requirements can be offset by capital accumulation-phased implementation of power output change in a dynamic CGE framework would allow a better understanding of the outcomes of industries in response to capital shifts over time. Another benefit of a dynamic framework is that it could better quantify effects that cannot exist instantaneously, such as reduced energy costs and fossil imports, all of which contribute to improved growth. This could provide a better assessment of the cumulative benefits of each scenario over time.

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