PATHWAYS TO LOW-CARBON DEVELOPMENT FOR VIET NAM

ASIAN DEVELOPMENT BANK

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Notes:
In this publication, "$" refers to US dollars.
ADB recognizes "China" as the People's Republic of China, "Vietnam" as Viet Nam, and "Hanoi" as Ha Noi.

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FOREWORD

Viet Nam will be strongly affected by the consequences of unmitigated climate change. As one of the first countries to ratify the United Nations Framework Convention on Climate Change, the Government of Viet Nam has also long displayed commitment to doing its part to reduce greenhouse gas (GHG) emissions. Viet Nam was also one of the first countries to ratify the Paris Agreement on Climate Change, building on the Governments repeated support for an international climate agreement that aims to contain global warming to 2 degrees Celsius above preindustrial levels. Viet Nam's Nationally Determined Contribution to the Paris Agreement aims for 8% reduction in GHG emissions by 2030 relying solely on domestic resources, and targets 25% reduction if sufficient international support is provided.

The Government of Viet Nam has implemented an array of national programs to help reduce the carbon intensity of growth. The 2008 National Target Program to respond to Climate Change developed an array of mitigation and adaptation measures. Subsequently, the 2011 National Climate Change Strategy focuses on more use of advanced energy technologies, improved energy efficiency, increased use of public transport and cleaner transport fuels, and afforestation. The 2012 Green Growth Strategy aims to reduce GHG emissions by up to 2% annually over the long term, and identifies 66 actions to do so. The 8th Socio-Economic Development Plan (SEDP) for 2016–2020 also commits the country to increase renewable energy generation.

This study aligns closely with the Governments policy objectives and illustrates how important goals of the Nationally Determined Contribution and Green Growth Strategy can be achieved. This research has been conducted in close coordination among experts from the Ministry of Planning and Investment, the Central Institute for Economic Management (CIEM), the Institute of Energy, the Transport Development and Strategy Institute, the World Bank, the United Nations Development Program, the Asian Development Bank (ADB) and international scholars. During study conduct, experts from Viet Nam benefited from a range of capacity building events on modeling of mitigation policies and potential.

The main message of the study is that Viet Nam may achieve substantial greenhouse gas emissions reduction at low cost if it were to take targeted mitigation actions. Moreover, Viet Nam's economic growth is actually accelerated and made more inclusive over the longer term from taking such measures. Key mitigation actions include replacement of imported coal with renewables in the future power generation mix, increased energy efficiency in building cooling and steel production, efficient vehicle technology and increased use of public transportation.

The Government of Viet Nam is committed to making this mitigation potential a reality. This report can help to inform future revision of power development plans, as well as implementation of the SEDP, so that the country develops toward a low carbon future. To that end, the 2016–2020 Country Partnership Strategy with ADB identifies “improving environmental sustainability and climate change response” as one its three pillars, under which “climate change mitigation” is a focus of continued investment. Under this focus, the Government of Viet Nam looks forward to continued collaboration with ADB to increase use of renewable energy, promote energy efficiency, and reduce the carbon intensity of transport, as this report suggests.

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FOREWORD

Viet Nam's economic development has been rapid, with an average of 7% growth in gross domestic product over the last 2 decades. However, that growth has been energy intensive, and the carbon footprint of energy has been rising. Without dedicated policies and actions, these trends are likely to continue. This implies that future greenhouse gas (GHG) emissions may be much higher than current levels, which still remain below the global average on a per capita basis. Moving to a low-carbon development pathway can not only benefit the global climate, but also help to make the economy more efficient and competitive, increase energy security, and generate an array of co-benefits to human health and well-being.

The Government of Viet Nam has undertaken many policy measures to promote low-carbon growth. In 2012, it adopted the Viet Nam Green Growth Strategy (VGGS), which promotes low-carbon economic development and energy efficiency, and offers the first official establishment of GHG emissions intensity reduction goals. In 2015, the country pledged to reduce GHG emissions by 8% by 2030, as compared with business as usual, with a possible reduction of 25% under international support. To help reach this goal, a Renewable Energy Development Strategy was issued in 2015 to cover the period through 2030, with a vision to 2050.

This study assesses how Viet Nam's green growth objectives can be achieved through a detailed modeling approach that draws on extensive national stakeholder input to ensure alignment with sector plans and strategies. It assesses 63 specific measures in the four key sectors in Viet Nam that dominate GHG emissions: power generation, household electricity consumption, industry, and transportation. In line with the vision of Viet Nam's strategies, the study focuses on the period through 2050, as many low-carbon development investments will take considerable time before their full mitigation potential is realized. The approach couples bottom–up engineering-type modeling with top–down economy-wide modeling to understand broader economic and poverty impacts.

The study affirms the tremendous GHG mitigation potential in Viet Nam at low or even negative costs. Assessed measures are found to have the potential to mitigate over 4,600 million tons of carbon dioxide equivalent ($MtCO_2e$), with nearly zero net cost per ton of carbon dioxide equivalent (tCO_2e) for the period through 2050. The vast majority of abatement is generated by the power sector, where imported coal is replaced by biomass, solar, and wind power. Transport follows next, where improvements in vehicle technology and modal shifts to public transport dominate mitigation outcomes. Industry and household sectors illustrate the potential to replace inefficient equipment, particularly for the steel industry and for building cooling, to help reduce energy needs and emissions.

Moreover, the study has found benefits to investing in a low-carbon future. Although there are some front-loaded investment costs, economy-wide modeling reveals that economic growth is accelerated for most of the analytical period under the low-carbon scenario. That acceleration is also found to benefit lower income populations more, so that growth is more inclusive.

We would like to thank the Government of Viet Nam for its support and suggestions throughout the implementation of this study. ADB looks forward to working with Viet Nam to further mainstream low carbon growth in a range of sectors through continued dialogue and engagement.

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This report was prepared by a team including members from ADB, CIEM, and an independent expert. ADB team members include David Raitzer and Jindra Samson. CIEM members include Nguyen Manh Hai and Dang Thi Thu Hoai. John Rogers served as a team member and prepared a key background paper on the bottom-up modeling for this study. Cung Nguyen Duc prepared the Vietnamese translation of this report. Copyediting was performed by Tuesday Soriano and Joe Mark Ganaban prepared the graphic design.

Edimon Ginting, Director of the Economic Analysis and Operations Support Division of the Economic Research and Regional Cooperation Department of ADB provided guidance for the study; Suphachol Suphachalasai (formerly ADB, now with the World Bank) did the initial conceptualization; and Jindra Samson, Maria Melissa Gregorio-Dela Paz, Gee Ann Burac, Do Thuy Huong, and Roslyn Perez of ADB supported the implementation. Marife Bacate (ADB consultant) assisted with research. Rehan Kausar of the Southeast Asia Department offered valuable advice and suggestions, and Lauren Sorkin (formerly of ADB's Viet Nam Resident Mission) helped to facilitate initial implementation, as well as collaboration with the World Bank. Previous guidance was provided by Cyn-Young Park, and Juzhong Zhang former Directors of the Economic Analysis and Operations Support Division.

The analysis was made possible with considerable assistance from research teams in Viet Nam, particularly Nguyen Duc Song (IEVN), and Nguyen Phuong Hien and Hang Thi Diem Nguyen of the Transport Development Strategy Institute (TDSI). Nguyen Thi Thanh Nga and Vo Bang Nga of the Agenda 21 Office of MPI coordinated the study's final workshop in Ha Noi.

The report builds on the underlying reports and analysis to 2030 prepared by a World Bank team led by Pierre Audinet and consisting of Bipul Singh, Duane Kexel, Suphachol Suphachalasi, Pedzi Makube, and Kristy Mayer. It also builds on parallel work performed under ADB's policy and advisory technical assistance on Support for the National Target Program with a Focus on Energy and Transport, the United Nations Development Programme (UNDP) technical assistance to support the Green Growth Strategy, and UNDP technical assistance on fossil fuel subsidy reform. This earlier work contained considerable analysis and input from Ernst and Young, CIEM, IEVN, and TDSI. The Ernst and Young team was led by Shuvendu Bose. The CIEM team led by Nguyen Manh Hai consisted of Dang Thu Hoai and Ho Cong Hoa. The IEVN team was co-led by Nguyen Anh Tuan and Tran Manh Hung and was made up of Nguyen Duc Song, Nguyen Khoa Dieu Ha, Le Nguyet Hang, and Nguyen Hoang Anh. The TDSI team was led by Nguyen Thi Phuong Hien and comprised Trinh Thi Bich Thuy, Cao Thi Thu Huong, Nguyen Manh Cuong, Tran Thi Kim Thanh, Nguyen Huy Hoang, Nguyen T Diem Hang, Nguyen Hung Cuong, and La Tra Linh.

ABBREVIATIONS

AC	air conditioning
ADB	Asian Development Bank
BAU	business as usual
CGE	computable general equilibrium
CIEM	Central Institute for Economic Management
CO_2	carbon dioxide
EFFECT	Energy Forecasting Framework and Emissions Consensus Tool
ESCO	energy service company
EU	European Union
FTKT	freight-ton-kilometer traveled
GDP	gross domestic product
GHG	greenhouse gas
GJ	gigajoule
GJ/t	gigajoule per ton
GW	gigawatt
ISP	integrated steel plant
kg	kilogram
IEVN	Institute of Energy
IFC	International Finance Corporation
km	kilometer
kWh	kilowatt-hour
LCS	low-carbon scenario
LCV	light commercial vehicle
LNG	liquefied natural gas
m^2	square meter
MAC	marginal abatement cost
MACC	marginal abatement cost curve
MEPS	minimum energy performance standards
MOIT	Ministry of Industry and Trade
MONRE	Ministry of Natural Resource and Environment
MPI	Ministry of Planning and Investment
$MtCO_2e$	million tons of carbon dioxide equivalent
MW	megawatt
NDC	Nationally Determined Contribution
NO_x	nitrogen oxide
OPC	ordinary portland cement

PDP-VII	Power Development Master Plan for 2011–2020 with outlook to 2030
PKT	passenger-kilometer traveled
PM	particulate matter
PPC	pozzolanic portland cement
PPP	purchasing power parity
PV	photovoltaic
SMEs	small and medium-sized enterprises
SSP	small-scale producer
TDSI	Transport Development and Strategy Institute
TWh	terawatt-hour
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
VGGS	Viet Nam Green Growth Strategy
VHLSS	Viet Nam Household Living Standards Survey
VOC	volatile organic compounds
VREDS	Viet Nam Renewable Energy Development Strategy

EXECUTIVE SUMMARY

Viet Nam's economy is becoming more carbon intensive

Viet Nam has developed rapidly over the past decades. However, the development of Viet Nam's renewable energy supply (mainly hydro and biomass) has not kept pace with the needs of its economy, which has grown to rely on higher carbon energy. In 1990, over 60% of electricity was produced from hydropower and more than 70% of total energy consumption was low-carbon. By 2010, this situation had reversed with only 30% of electricity produced from hydroelectric power and over 70% of total energy consumption from fossil fuels.

Greenhouse gas emissions growth will continue to be rapid without a change of course

Under a growing economy, emissions are poised to increase rapidly. As shown in this study, Viet Nam's economy could expand by almost 14 times in real terms over the 4 decades between 2010 and 2050 under the 7% annual economic growth targeted by the Government of Viet Nam. Viet Nam's population may grow from 85 million to over 105 million, and lifestyles will change from mainly rural to predominantly urban. Gross domestic product (GDP) per capita over this period could increase over 10 times, with the greatest growth in urban areas. As a result of this growth and an increasingly carbon-intensive energy mix, energy-associated emissions may also have a 10-fold increase between 2010 and 2050.

The Government of Viet Nam recognizes the need for low emissions growth

To achieve rapid economic growth that is sustainable, a change of course in the energy sector is needed. The Government is aware of these challenges. The approvals of Viet Nam's National Climate Change Strategy in 2011 and the Viet Nam Green Growth Strategy (VGGS) in 2012, and the submission of a Nationally Determined Contribution (NDC) to the Paris Agreement underscore the Government's commitment to low-carbon development.

A low-carbon development pathway is feasible

This study uses the current sectoral master plans, particularly the National Master Plan on Power Development, as its reference. It applies a detailed bottom–up analysis of household electricity demand; emissions from five energy-intensive industries; on-road, rail, inland waterway, and coastal transport; and the power sector—electricity generation—to identify a possible alternative low-carbon development scenario.

This study covers most of the energy sector and all the areas from which a marked increase in greenhouse gas (GHG) emissions can be expected over the time frame to 2050. It evaluates 63 measures to reduce GHG emissions from the energy sector and process emissions from five industries. The greatest mitigation contribution of nearly 500 million tons of carbon dioxide equivalent ($MtCO_2e$) in 2050 comes from the power sector, based on efficiency measures that reduce the demand for electricity and a strong move toward low-carbon generation options on the supply side.

Viet Nam can meet or exceed its mitigation targets

The modeled low-carbon pathway exhibits a mitigation of 7% in 2020, compared with a VGGS target of 10%. In 2030, the modeled pathway exhibits a mitigation of 18% compared with a VGGS target of 20% and, in 2050, a mitigation of 54% compared with a VGGS target of 50%. Compared with the NDC, it has nearly the same relative reduction as the contribution under international support (25% reduction), and represents a lower level of 2030 emissions, due to a lower reference emission level. This suggests that national mitigation targets are achievable.

Ambitious mitigation can save costs

Application of the 63 measures reduces CO_2e emissions from 2010 to 2050 by over 4,600 million tons with an average mitigation cost of –$1 per ton of CO_2e and a leveling off of annual GHG emissions at around 500 million tons per year from 2035 onward. Over 75% of the total mitigation can be achieved with a negative or zero mitigation cost.

The study demonstrates that a low-carbon development pathway can be economically attractive, requiring lower investment, fuel, and operating expenses in the sectors that were evaluated than in a business-as-usual "reference scenario" based on sector development plans. In the low-carbon scenario, cash flow expenditures ultimately fall because of reduced expenditure on fuel, particularly imported coal. By 2050, fossil fuel consumption in the low-carbon scenario (in million tons of oil equivalent) is approximately half that of the reference scenario.

Low-carbon development can accelerate economic growth

To assess broader economic impacts, the study applies the low-carbon scenario in a computable general equilibrium model of Viet Nam's economy. This finds some initial costs from investment requirements, which are more than offset by faster economic growth and a larger economy after 2030. The effect of growth is inclusive, as poorer populations have larger relative gains in consumption than those with higher income.

A less carbon-intensive power sector is critical to reducing emissions

Power generation changes contribute more than 70% of the total mitigation potential over 2010–2050. This sector has lower GHG emissions in the low-carbon scenario than in the reference scenario because of supply-side measures and reduced demand resulting from energy-efficiency measures. End-user energy-efficiency measures contribute 15% of this reduction, while the remainder is brought about by changes in electricity generation. This study evaluates 12 supply-side measures to reduce GHG emissions, increasing generation from biomass, solar, onshore wind, and microhydro. Together, these generate a total mitigation of nearly 3,000 MtCO_2e at a negative weighted average marginal abatement cost. Under the low-carbon scenario, the direct cost of electricity generation is reduced in the future, while energy security is enhanced.

Saving household energy is a low cost mitigation strategy

Electricity demand-side measures including increased household appliance efficiency coupled with building improvements add 400 MtCO_2e of mitigation potential over 2010–2050. Over the 40-year analytical time frame, the greatest increase in electricity demand from households is expected to result from widespread adoption of air conditioning. To stem the demands of increasing air conditioning use on the grid, particularly from 2035 onward, simple building retrofit measures—such as low-e window glazing, window shades, and ceiling fans, plus hybrid solar/electric water heating—become cost-efficient mitigation techniques that should be considered together with comparable building standards for new construction.

Improving appliance energy efficiency through mandatory standards costs less than increasing generation capacity. Linking such standards directly to those of a larger market can simplify implementation for both the national agency and for manufacturers involved.

There is substantial potential to enhance industrial energy efficiency

A strong industrial energy-efficiency program could help Viet Nam realize the mitigation opportunities and follow through with supportive regulations, institutional frameworks, and financing until these are achieved. The energy-efficiency measures studied in five high-energy-consuming industries (iron and steel, cement, fertilizer, refining, and pulp and paper) contributed a total mitigation of over 600 $MtCO_2e$ in 2010–2050 at an overall average mitigation cost of $2/$tCO_2e$. Of this, almost 80% of emissions savings through energy-efficiency measures come from power generation from waste heat recovered in large integrated iron and steel and cement plants. Fiscal measures, support to Energy Service Company markets, improved analysis of energy-efficiency performance, and better information dissemination can help to achieve these improvements.

Transport mitigation is important both to climate change and to quality of life

Private car ownership may grow thirty-five-fold from 2010 to 2050, with attendant potential greenhouse gas and pollution emissions increases. Transport sector measures account for nearly 15% of the total 2010–2050 mitigation (contributing a reduction of 650 $MtCO_2e$ over this period). Of the 10 packages of measures considered, improving vehicle technology, biofuel use, and modal shifts from private motorized vehicles to public transit provided 540 $MtCO_2e$ of mitigation.

In future years, GHG emissions per passenger-kilometer from electric two-wheelers can effectively compete with those from public transit. However, promoting an aggressive modal shift to mass transit is still critical to health, quality of life, and urban development. Even if one-half of all motorized passenger-kilometers were handled by mass transit, total passenger-car kilometers in 2050 could be similar to that of two-wheelers in recent years, while two-wheeler vehicle kilometers may double, with severe implications for congestion, health, and productivity. Urban planning may actively promote mass transit, discourage car ownership and use within cities, and reduce the need to travel.

A low-carbon transition depends upon establishing the right enabling conditions

Low-carbon development depends upon realigning incentives. Previously, Viet Nam had subsidies for fossil fuels for the power sector. Under the National Master Plan on Power Development, these subsidies are being removed, with a commensurate increase in the price of electricity to cover its cost of generation. More broadly, decarbonization will require sustained political commitment that transcends master plans to lower barriers to energy efficiency, and attract investment in green growth and low-carbon development opportunities.

1. INTRODUCTION

1.1 A Low-Carbon Future Matters for Viet Nam

Viet Nam is among the world's most vulnerable countries to unmitigated climate change. With a long, low-lying coastline in the "typhoon belt" of Southeast Asia, the country has been ranked eighth highest globally in terms of climate vulnerability over the 1996-2015 period (Kreft et al. 2016).

The largest source of recent disaster losses in Viet Nam has been flooding, and climate change will exacerbate this risk (UNISDR 2015). As climate change progresses, precipitation is expected to become more concentrated, variable and extreme. Even as total rainfall increases, the length of the dry season is expected to grow, so that there is increased risk both from flooding and from drought (MONRE 2010).

These effects will be compounded by sea-level rise, which poses a particularly high risk to Viet Nam, due to its combination of large delta regions and an extensive coast. Sea-level rise will not only directly inundate land and assets, but will also increase damage from storm surges and flooding. As early as 2030, $250 billion in assets may already be at risk from flooding expansion under climate change (Rutten et al. 2014).

Agriculture, which accounted for 44% of national employment in 2015, is especially threatened. Increased heat stress from longer periods of peak temperatures will adversely affect crops and livestock, and drought losses will be exacerbated by prolonged dry seasons. Only considering precipitation, radiation and temperature effects, Nelson et al. (2010) found more than 10% yield reduction for irrigated rice, the main staple crop, in 2050 under the "balanced growth" A1B climate change scenario. In addition, over 2,000,000 hectares of agricultural land are threatened by the effects of sea level rise, storm surges and related salinity intrusion (Wassmann et al. 2004), and projections of production losses due to salinity and inundation are approximately twice those of temperature, radiation and rainfall effects alone (Yu et al. 2010). Moreover, the periods over which humidity adjusted temperatures exceed limits for intense human physical activity will grow, limiting labor availability for agricultural operations (Kjellstrom et al. 2009).

Beyond agriculture, temperature increases under the A1B scenario may lead to 13% increased energy demand by 2050, as more cooling is needed (Raitzer et al. 2015). Tourism will suffer, as the climate becomes less ideal for tourist arrivals, which may be reduced by 12% by 2050. Catastrophic risk to infrastructure, assets, ecosystems, and human safety will rise along with increased storm damage. Collectively considering a range of effects, climate change may push over 1,000,000 people in Viet Nam into extreme poverty already by 2030, and many more thereafter (Rozenberg and Hallegatte 2016).

Minimizing these adverse impacts depends on concerted action to address climate change. Although adaptation is important for those effects that cannot be avoided, the first best solution is mitigation to minimize global warming. Viet Nam has important potential to contribute to achieving a low-carbon future for the world, which is very much in its own interest.

1.2 Viet Nam's Energy and Emissions Context

Historically, Viet Nam has not been a major contributor to climate change. However, the country's rapid economic growth, in the context of an increasingly carbon intensive energy system, is changing this situation. Over the last 2 decades, Viet Nam doubled its gross domestic product (GDP) per capita with an average GDP growth rate of about 7%. Between 2010 and 2020, despite the global economic downturn, the Government of Viet Nam is targeting to again double GDP per capita while increasing per capita income at an even faster rate of 10% annually.

Over recent decades, growth has been resource-intensive, with relatively little diversification and added value in exports. In addition, high fossil fuel subsidies and low energy prices have undermined investment in the energy sector and discouraged efficient use of energy. The economy has also exhibited macroeconomic turbulence with double-digit inflation and loss of international reserves.

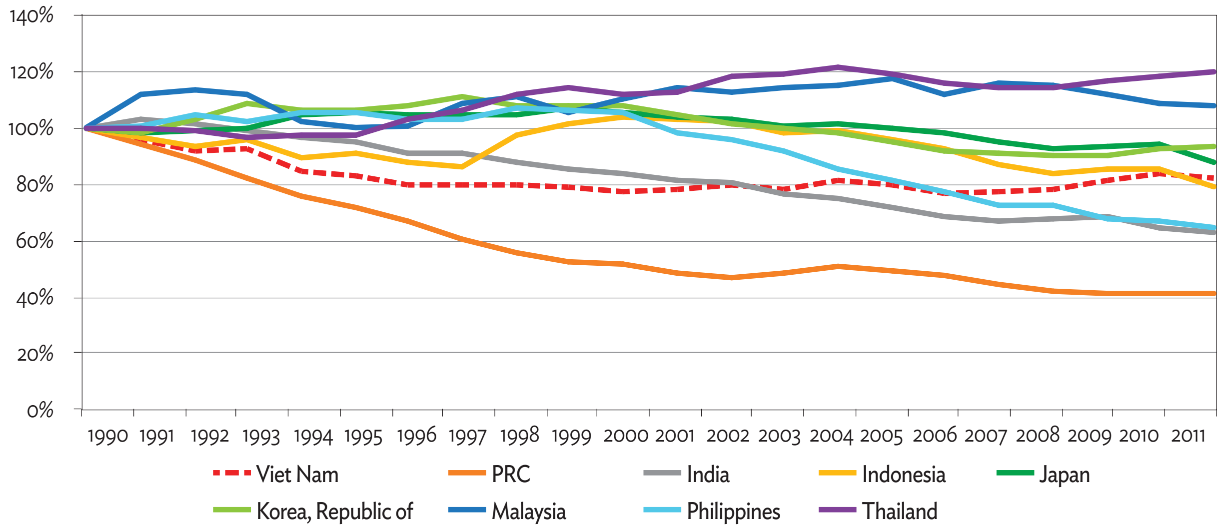
One threat to market competitiveness has been that power generation has had problems keeping pace with the growing demand. In 1990, almost three-quarters of primary energy consumption were from nonfossil fuels and over 60% of electricity came from hydroelectric generation. By 2010—the base year for this study—the situation had reversed with over 70% of total energy consumption coming from fossil fuels and less than one-third of electricity from hydro. The national supply of coal is projected to grow at a lower rate than the increase in electricity demand, resulting in a growing dependence on imported fuels that are rapidly increasing in cost. This raises energy security concerns and makes improving the economy's energy efficiency more critical than ever.

In terms of energy intensity improvement, Viet Nam has surpassed many Asian economies. In 1990, about 180 kilograms of oil equivalent of energy was required to generate $1,000 of GDP (at constant 2011 purchasing power parity [PPP]), while in 2011, only 148 kilograms of oil equivalent of energy was required to generate $1,000 of GDP. Figure 1 shows that Viet Nam had improved its energy intensity by 2011 (from a base year of 1990) more than many Asian nations, except for People's Republic of China, India, and the Philippines. However, highly developed economies that could be Viet Nam's future clients for high value-added production are progressing even more consistently (see Figure 2), which may indicate a possible slow erosion of competitiveness.

Despite this improvement in energy intensity, Viet Nam exhibited the fastest growth in carbon dioxide equivalent (CO_2e) emissions intensity in the region over this same period, largely because of a growing dominance of coal in the energy mix. Viet Nam's total emissions increased seven times and per capita emissions more than tripled while the carbon intensity of GDP increased by 78% (Figure 3)—a relative increase in CO_2e emissions greater than that observed in all regional comparators including the People's Republic of China, India, and the Republic of Korea.

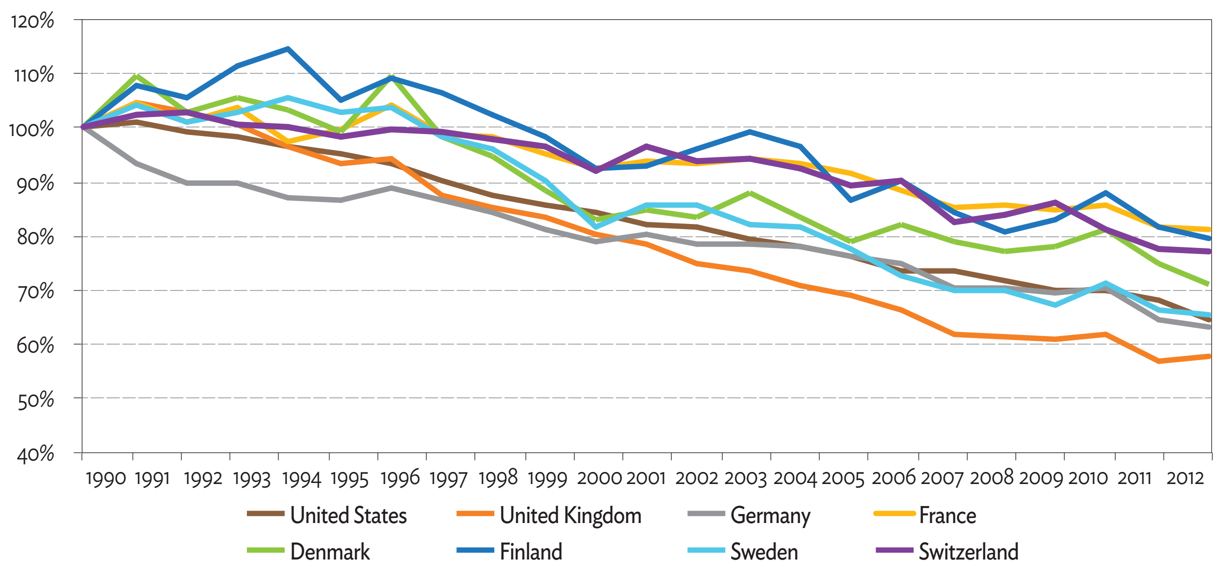
This means that Viet Nam's greenhouse gas (GHG) emissions are rising rapidly (Table 1), albeit from low per capita levels. In 2010, GHG emissions per capita were below the global average at 2.84 tons of carbon dioxide equivalent (tCO_2e). At the same time, non-land-use emissions grew by 12% annually between 2000 and 2010, more rapidly than the 8% growth between 1994 and 2000. This increasing growth is attributed to emissions from energy, particularly in the power sector and other energy industries, manufacturing, and transportation, all of which have annual growth rates of 10% or more, as well as growth in emissions from industrial processes. These sectors generate the bulk of emissions, with 65% of 2010 emissions from energy and industry. Unless Viet Nam takes action toward low-carbon development, it may become a much bigger contributor to climate change in the future.

Figure 1: Relative Trend in Energy Intensity of GDP Compared with 1990 in Asia



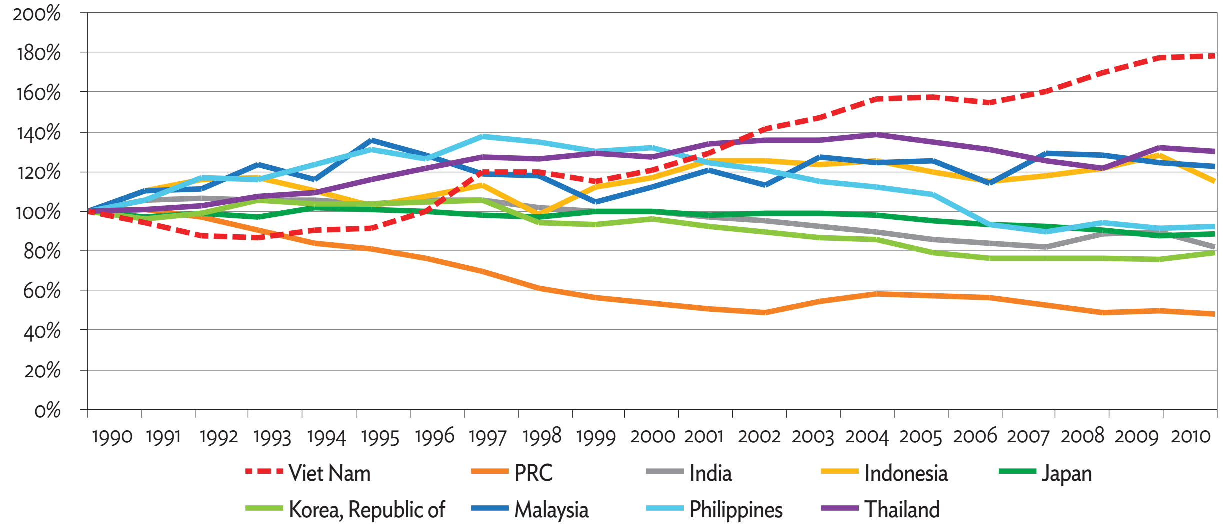
PRC = People's Republic of China, GDP = gross domestic product.
Source: World Bank. World Development Indicators. http://data.worldbank.org/data-catalog/world-development-indicators (accessed 10 December 2015).

Figure 2: Relative Trend in Energy Intensity of GDP Compared with 1990 in Europe



GDP = gross domestic product.
Source: World Bank. World Development Indicators. http://data.worldbank.org/data-catalog/world-development-indicators (accessed 10 December 2015).

Figure 3: Relative Trend in CO_2e Emissions Intensity of GDP Compared with 1990 in Asia



PRC = People's Republic of China, CO_2e = carbon dioxide equivalent, GDP = gross domestic product.
Source: World Bank. World Development Indicators. http://data.worldbank.org/data-catalog/world-development-indicators (accessed 10 December 2015).

Table 1: Greenhouse Gas Emissions in Viet Nam
($MtCO_2e$)

Category	1994	2000	2010	Share of Total Emissions, 2010	Change from 1994 to 2010	Annual Growth Rate from 1994 to 2000	Annual Growth Rate from 2000 to 2010
1. Energy	25.63	52.77	141.17	57.2%	115.54	12.8%	10.3%
1.1. Energy industries	4.13	11.20	41.06	16.6%	36.96	18.1%	13.9%
1.2. Manufacturing and construction	7.70	15.11	38.08	15.4%	30.37	11.9%	9.7%
1.3. Transport	3.66	11.95	31.82	12.9%	28.16	21.8%	10.3%
1.4. Other	10.14	14.51	30.22	12.2%	20.08	6.2%	7.6%
2. Industrial processes	3.81	10.01	21.17	8.6%	17.36	17.5%	7.8%
3. Agriculture	52.45	65.09	88.35	35.8%	35.91	3.7%	3.1%
4. LUCF	19.39	15.10	(19.22)	n. a.	(38.61)	(4.1%)	n. a.
5. Waste	2.56	7.92	15.35	6.2%	12.79	20.7%	6.8%
TOTAL GHG emissions (with LUCF)	**103.84**	**150.90**	**246.83**		**142.99**	**6.4%**	**5.0%**
TOTAL GHG emissions (without LUCF)	**84.45**	**135.79**	**266.05**		**181.59**	**8.2%**	**11.9%**

( ) = negative, GHG = greenhouse gas, LUCF = land-use change and forestry, $MtCO_2e$ = million tons of carbon dioxide equivalent, n. a. = not available.
Source: United Nations Climate Change Secretariat. Emissions Summary for Viet Nam. https://unfccc.int/files/ghg_data/ghg_data_unfccc/ghg_profiles/application/pdf/vnm_ghg_profile.pdf.

1.3 Current Climate Change and Green Growth Policies

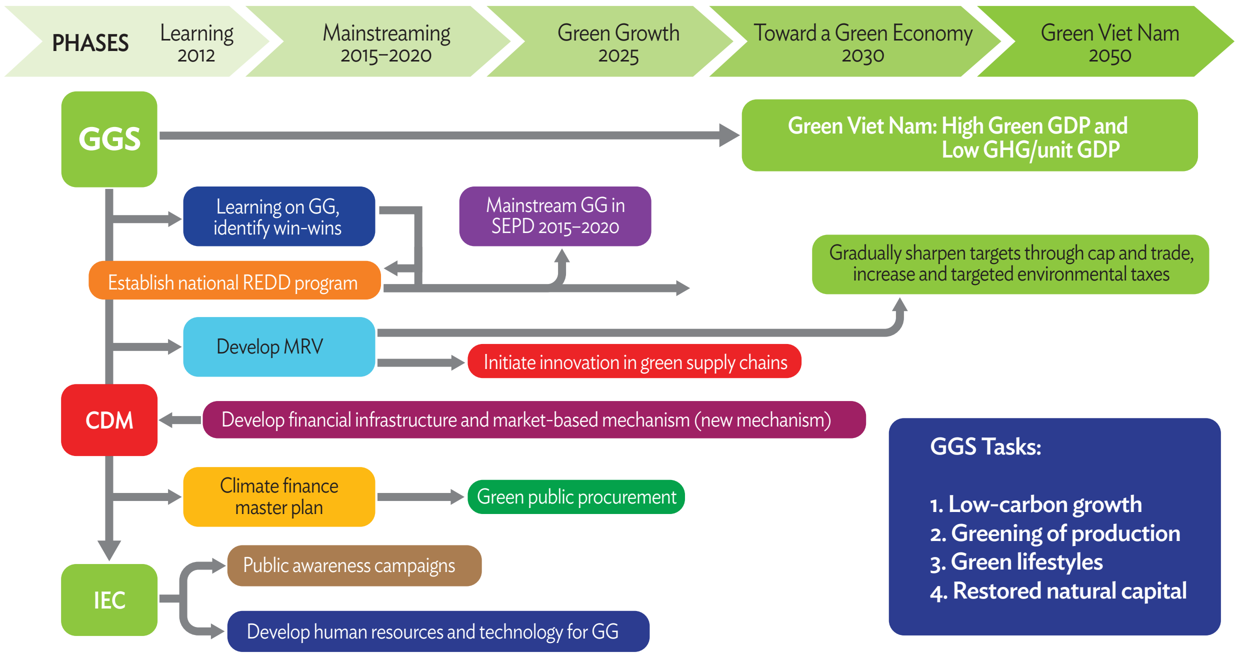
1.3.1 Viet Nam's Mitigation Measures

The Government of Viet Nam recognizes this challenge. In 1994, it ratified the United Nations Framework Convention on Climate Change (UNFCCC), and became a signatory of the Kyoto Protocol in 2002. In 2008, it promulgated its National Target Program to Respond to Climate Change to assess climate change impacts and develop adaptation and mitigation measures. The Ministry of Natural Resources and Environment acted as the main focal point and coordinator of all these activities and programs. In 2003, Viet Nam submitted its first National Communication to the UNFCCC, reporting its first official national 1994 GHG inventory, which was later updated at its Second National Communication in 2010.

In 2011, the National Climate Change Strategy was created, outlining the country's objectives for 2011 through 2050. Most strategy measures relate to adaptation, but there is a strong mitigation component as well, which focuses on developing and deploying advanced energy technologies, promoting public transport and low-carbon fuels for transportation, and improving energy efficiency and afforestation.

In 2012, the Government approved the Viet Nam Green Growth Strategy (VGGS), which includes mitigation goals. It focuses on improving energy efficiency, changing the fuel structure in industry and transportation, and increasing the proportion of new and renewable energy sources. The VGGS is to be achieved through an action plan that was approved in 2014, which comprised 66 specific actions to be implemented over 2014–2020. Figure 4 shows the proposed road map for achieving the VGGS.

Figure 4: Proposed Green Growth Strategy Road Map



CDM = Clean Development Mechanism; GDP = gross domestic product; GG = Green Growth; GGS = Green Growth Strategy; GHG = greenhouse gas; IEC = International Electrotechnical Committee; MRV = measurement, reporting, and verification; REDD = reducing emissions from deforestation and forest degradation; SEDP = Socio-economic Development Plan.
Source: Asia LEDS Partnership. http://www.asialeds.org/.

The VGGS specifies the following targets to reduce the emissions intensity of the economy:

- For 2011–2020:
  Reduce the intensity of GHG emissions by 8%–10% as compared with the 2010 base, energy emissions by 10%–20% compared with business as usual (BAU) with the upper bound dependent on international support, and energy consumption per unit of GDP by 1%–1.5% per year.

- Orientation toward 2030:
  Reduce GHG emissions by 1.5%–2% per year, reduce GHG emissions in the energy sector by 20%–30% compared with BAU (the upper bound is dependent on international support).

- Orientation toward 2050:
  Reduce GHG emissions by 1.5%–2% per year.

It also aims to adjust sectoral master plans to ensure that (i) natural resources are used economically and efficiently; (ii) development of green industry and green agriculture is encouraged; (iii) investment in natural capital is enhanced; and (iv) pollution is actively controlled and treated. A critical master plan for this present study, the National Master Plan on Power Development (PDP-VII), is the outcome of this process. This was later updated in 2016 (PDP-VII-Revised) with changes to macroeconomic and demand assumptions and power plant construction plans.

Key goals toward 2020 are as follows:

- Increase the value of high-tech and green-tech products to 42%–45% of GDP.

- Increase the proportion of manufacturing facilities that meet environment standards to 80%.

- Apply clean technology and development investment to protect the environment and enrich natural capital to a value of 3%–4% of GDP.

At the 21st Conference of the Parties to the UNFCCC in Paris, the Government reaffirmed its goal to contribute actively to the global objective of climate change mitigation, based on domestic capacity and international support. In the Nationally Determined Contribution (NDC), Viet Nam has defined its mitigation goals over 2021–2030, with the unconditional objectives of (i) 8% reduction in emissions by 2030 relative to a BAU scenario; and (ii) a 20% reduction in emissions intensity (emissions per unit of GDP) against 2010 levels. With international support in the form of financing, capacity building, and technology transfer, this may rise to as much as a 25% reduction. Under this conditional target, the emissions intensity reduction increases to 30%.

To define how mitigation goals will be achieved, 10 measures were identified in the NDC (Table 2), of which 3 relate to the energy sector, 2 to land use, 1 on waste, and the other 5 are crosscutting. The energy measures focus on adoption of improved technology for energy efficiency in the residential, trade, and services sectors; shifts of transport modalities toward public transport and increased use of rail; and improved transport fuel efficiency and emissions standards. These are complemented by encouraging the use of cleaner fuels, increased use of natural and liquid petroleum gas in public transport, and elimination of fossil fuel subsidies. Promoting renewable energy by developing the renewable energy technology market and supporting research and deployment of advanced energy technologies will in part diversify energy use away from fossil fuels.

Table 2: Viet Nam's Priority Mitigation Actions to Meet Nationally Determined Contribution Pledges

1.	Strengthen the leading role of the state in responding to climate change.
2.	Improve effectiveness and efficiency of energy use, reducing energy consumption.
3.	Change the fuel structure in industry and transportation.
4.	Promote effective exploitation and increase the proportion of new and renewable energy sources in energy production and consumption.
5.	Reduce greenhouse gas emissions through the development of sustainable agriculture, and improve the effectiveness and competitiveness of agricultural production.
6.	Manage and develop sustainable forests, and enhance carbon sequestration and environmental services; conserve biodiversity associated with livelihood development and income generation for communities and forest-dependent people.
7.	Waste management.
8.	Communication and awareness raising.
9.	Enhance international cooperation.
10.	Monitoring and evaluation.

Source: UNFCCC (2016). Available at http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Viet%20Nam/1/VIETNAM'S%20 INDC.pdf.

1.3.2 Energy Sector Policies

In 2011, Viet Nam approved the PDP-VII, which lays out a scenario of rapidly increasing electricity demand, supplied mostly by fossil fuels. Under PDP-VII, power generation rises from between 194 and 210 terrawatt-hours (TWh) in 2015, to between 695 and 834 TWh in 2030. Most of this rapid growth is to be fed by fossil fuels, which are to account for 73.6% of 2030 domestic generation, with coal dominant at 58.6%. The rationale for rapid expansion is 8.0% GDP growth from 2016 to 2020, followed by 7.8% GDP growth thereafter, combined with an elasticity of electricity demand to GDP that is above 1 until 2020.

It has been increasingly recognized that PDP-VII overestimated increases in power demand, largely due to overoptimistic GDP growth assumptions. From 2013, adjustments to PDP-VII started to be assessed. These led, in mid 2016, to PDP-VII-Revised to reflect lower levels of demand resulting from lower rates of economic growth than previously anticipated. By 2030, power generation is expected to rise to 572 TWh, rather than approximately 700 TWh under the original PDP-VII. However, the revised version retains a fossil-fuel–dominated mix. Even under the revised version, by 2030, 53% of power generation will be from coal, with only 132 TWh from hydropower and renewable energy sources.

At the same time, the Government recognizes an ambition to develop renewable energy, although this is not yet framed as a commitment. In 2015, the Viet Nam Renewable Energy Development Strategy (VREDS) to 2030 and outlook up to 2050 was approved. According to this new strategy, the development and upscaling of renewable energy sources will help the country achieve its mitigation and green growth goals.

VREDS aims to maintain renewable energy's share of primary energy constant at approximately 32% through 2050, even as energy generation rises rapidly to 44% by 2050. Of this share, a large portion is to be achieved in the electricity sector, where the renewable (including hydropower) share is constant at more than 30% through 2030 and will grow to 43% by 2050. Within electricity, rapid scaling up of biomass, wind, and solar power offsets a declining share of hydropower over time, as hydropower development cannot keep pace with increasing electricity demand. Outside of electricity, solar heating, biomass heating, and biofuels make up increasing shares of primary energy.

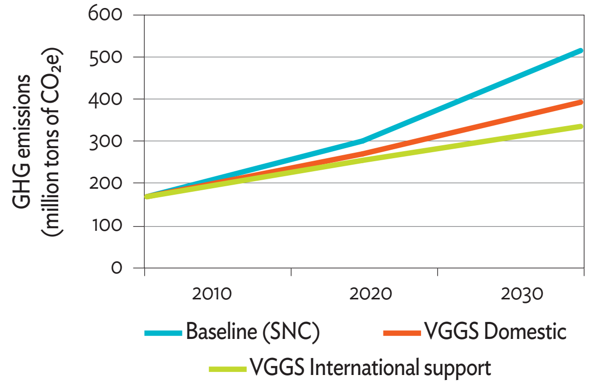
The 2011 Law on Economical and Efficient Use of Energy and Measures, the Viet Nam Energy Efficiency and Conservation Program, and the National Target Program for Energy Efficiency and Conservation which was passed in 2012, are intended to promote demand-side energy-efficiency targets, such as saving 5%–8% of total national energy consumption in 2012–2015. This would be achieved by promoting the use of energy-efficient equipment, enforcing energy-efficiency management for new buildings, and establishing minimum energy performance standards for industries and public transport development.

Viet Nam thus faces a crossroad—it can continue on a pathway to energy-intensive, fossil fuel–driven growth, with a rapidly rising carbon footprint, as illustrated in plans under the original PDP-VII. Or it can follow an alternative potential future driven by green growth, as enumerated in the ambitions of the VGGS, the NDC, and VREDS. Better understanding of what the green growth pathway entails, how it can be achieved, and what it means for the economy is important for identifying how and with what consequences the country can pursue the low-carbon path.

1.4 Results of Recent Low-Carbon Analytical Work

This study is not the first effort to investigate low-carbon development options for Viet Nam. As part of the VGGS formulation, Viet Nam undertook a bottom–up analysis of key sectors that showed significant win-win options in the energy and agriculture sectors and large cost-effective opportunities in the forestry sector. With appropriate levels of investment, the study revealed that Viet Nam's GHG emission reduction targets could be achieved while maintaining an acceptably high level of GDP growth (see Figure 5).

Figure 5: Greenhouse Gas Emissions and Potential for Mitigation through the Viet Nam Green Growth Strategy



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, SNC =Second National Communication, VGGS = Viet Nam Green Growth Strategy.
Source: Climate and Development Knowledge Network. http://cdkn.org/about/?loclang=en_gb (accessed 15 July 2015).

The Government has worked with international and bilateral agencies to assess low-carbon development options as part of several assessments, such as Viet Nam's 2nd National Communication to the UNFCCC (MONRE 2010); the draft Technical Working Paper on GHG Emissions, Scenarios, and Mitigation Potentials in the Energy and Transport Sectors of Viet Nam (von Hippel et al. 2013); and the Background Analysis of Marginal Abatement Costs for the Green Growth Strategy (UNDP–MPI unpublished).

In 2016, the World Bank produced a report (Audinet et al. 2016) using a version of the Energy Forecasting Framework and Emissions Consensus Tool (EFFECT) produced in collaboration with this study, but with a focus on the period through 2030. A comparative analysis between these studies and the World Bank's study suggests (i) a broad convergence of results—pointing to a consistent set of low-carbon actions, and (ii) the complementarity of the studies that can be viewed as a sensitivity analysis of one another. Table 3 provides a snapshot of key features and outcomes of the four studies.

Table 3: Comparison of Recent Low-Carbon Studies

Study	Coverage	Model	CO_2 Emission in 2010 ($MtCO_2e$)	CO_2 Emission in 2030 under BAU ($MtCO_2e$)	Mitigation Potential during 2010–2030 ($MtCO_2e$)	Number of Low-Carbon Options Analyzed	Assessed Energy Sector Measures Sufficient to Reach VGGS Target in 2030
MONRE (2010)	Energy end use in transport, industry, agriculture, residential, and commercial and energy production	LEAP	113	471	192	15	Insufficient
ADB (2013)	Energy end use in transport, industry, agriculture, residential, and commercial and power generation and energy transformation	LEAP and EFFECT	approx. 150	approx. 640	1,200	35	Sufficient
UNDP–MPI (2012)	Energy end use and power generation	MACC Builder Pro+ IPCC guidelines	129	615	227	35	Insufficient
World Bank (Audinet et al. 2016)	Energy end use in transport, industry, residential, and commercial and power generation	EFFECT	110	495	845	66+ additional energy-efficiency improvement	Sufficient

ADB = Asian Development Bank, BAU = business as usual, CO_2 = carbon dioxide, EFFECT = Energy Forecasting Framework and Emissions Consensus Tool, IPCC = Intergovernmental Panel on Climate Change, LEAP = long-range energy alternatives planning, MACC = marginal abatement cost curve, MONRE = Ministry of Natural Resource and Environment, $MtCO_2e$ = million tons of carbon dioxide equivalent, UNDP–MPI = United Nations Development Programme–Ministry of Planning and Investment, VGGS = Viet Nam Green Growth Strategy.
Note: MONRE (2010) and UNDP–MPI (2012) also cover greenhouse gas emissions in agriculture and land use, land-use change, and forestry sectors. However, only results from the energy sector are used here for comparison across the studies.
Source: Adapted from Audinet, P., B. Singh, D. T. Kexel, S. Suphachalasai, P. Makumbe, and K. Mayer. 2016. *Exploring a Low-Carbon Development Path for Vietnam. Washington, DC: World Bank.*

All studies show that Viet Nam has mitigation options that can *reduce growth* in GHG emissions in varying degrees. For example, the World Bank study portrays a low-carbon pathway in which GHG emissions *increase* by only a factor of 3.5 times by 2030, compared with a BAU scenario with 5 times growth.

1.5 Objectives and Approach

These recent analyses evaluate the mitigation potential to 2030 and the probability that Viet Nam may reach its VGGS targets in that year. The year 2030 is not long into the future, which severely limits mitigation possibilities that can be reported considering infrastructure life and stock turnover. This modeling time frame is not long enough to fully evaluate the reduction in emissions that can result from changes in technology or efficiency improvements implemented at some near future date. For example, a power plant may have an operating life of 40 years; thus, in 2030, the majority of currently operating plants will still be active—unless they are prematurely scrapped, which would have severe cost implications. Likewise, appliances and vehicles are generally not replaced with more efficient units until they reach the end of their useful life, and changes in user habits—such as modal shift to nonmotorized transport and mass transit—do not exhibit full benefits immediately since it takes time for infrastructure changes to be fully rolled out.

This study adds value by taking a longer-term perspective to 2050, which enables such substitution impacts to be better evaluated. It also allows forecast changes in fossil-fuel prices and technology costs to be considered in the analysis. The recent studies did not include impacts of longer-term fuel price and changes in technology cost and how these might affect choice decisions. In addition, whereas other studies (including by the World Bank) have been rooted in analysis of the original PDP-VII, this study takes into account more recent revisions that change the energy outlook considerably.

In line with the longer-term focus, this study also adds more consideration of technical improvement even in the absence of low-carbon specific policies. Thus, this study starts from a scenario in which the energy efficiency of energy-consuming appliances and industrial facilities increases over time, as a result of spillover effects from other markets with more stringent energy regulations.

This study takes a pragmatic, technically rooted approach to evaluating a goal of stabilizing emissions at around 500 million tons of CO_2e ($MtCO_2e$) by 2050—which is consistent with the VGGS long-term goals—with reductions over future decades, in the understanding that this is considerably more aggressive than the goal of any recent study.

The overall objectives of the study are to

(i) identify medium- to long-term energy sector mitigation opportunities for Viet Nam;

(ii) assess what abatement can be achieved at what cost through different mitigation opportunities; and

(iii) identify policy and technical measures that can help realize mitigation potential.

This report describes two possible scenarios covering Viet Nam's development from a base year of 2010 to 2050. The reference scenario is based on PDP-VII-interim-revision (as per a draft available in late 2014 from the Institute of Energy) and current sector plans while the low-carbon scenario investigates further migration opportunities to reduce GHG emissions and evaluates the costs and some of the benefits of following this development pathway. Each scenario portrays a plausible path of evolution for four sectors: on the supply side, electricity generation; and on the demand side, household electricity demand, transport, and industry.

This study focuses on sectors that generate the majority of GHG emissions in Viet Nam, and those that are the fastest-growing sources of emissions. However, the scenarios do not cover Viet Nam's complete emissions inventory. Specifically, this bottom–up analysis does not include

- agriculture sector emissions or fuel use other than electricity in agriculture;
- land use and land-use change;
- waste;
- fuel usage other than electricity in buildings, construction, and small and medium-sized enterprises (SMEs); and
- process emissions other than those from the selected large, energy-consuming industries.

2. METHODOLOGY

The model used for this study was the Energy Forecasting Framework and Emissions Consensus Tool (EFFECT), an Excel-based, inventory-style tool with some built-in optimization that can be opened and used easily by multiple stakeholders. The tool facilitates transparent sharing of data and assumptions used to model future scenarios, so as to help foster consensus on future actions.

The model consists of five main modules (power generation, land transport, household electricity consumption, nonresidential, and industry) of which three were used in this study. A fourth sector, industry, was later added under a sharing agreement with the World Bank, using the work performed by Ernst & Young Calcutta, and reported by Audinet et al. (2016).

EFFECT had been successfully used in many different national and subnational low-carbon development studies. It is designed to evaluate and compare different development scenarios in the specific areas focused by the modeling where important mitigation impacts can be achieved. Thus, bottom–up modeling is usually not used to model the whole economy, but to evaluate the benefits of a specific policy and/or investment implementation by comparing scenarios:

(i) A **reference scenario** portrays what is likely to happen under a normal development process in which no special emphasis is placed on reducing the climate change impacts of development.

(ii) A **low-carbon scenario** assesses options to achieve the same or better development progress than in the "reference scenario" but with lower greenhouse gas (GHG) emissions.

The differences between these scenarios allow the evaluation of the mitigation opportunities, their associated co-benefits, barriers to adoption, and the cost of achieving them.

The reference scenario considered by the study is the Power Development Master Plan for 2011–2020 with outlook to 2030 (hereinafter referred to as PDP-VII) developed by the Institute of Energy (IEVN). As described in more detail subsequently, a 2014 revision of the plan is utilized.

The low-carbon scenario was prepared by analyzing the mitigation options in the power, household, and industry sectors, using 2010 as a baseline year for starting low-carbon efficiency cost and carbon dioxide equivalent (CO_2e) emissions, and extended to 2050.

As portrayed in the reference scenario over the decades between 2010 and 2050, the CO_2e emissions are likely to increase by a factor of over 10 times, from 113 million tons to 1,073 million tons, driven by an economic growth—in real terms—of almost 14 times. The low-carbon scenario shows an alternative in which emissions grow less than five times over this modeling period for a mitigation (or annual savings) in 2050 of 574 million tons of CO_2e ($MtCO_2e$). This mitigation effort is additional to the mitigation actions already reflected in the power sector plans of the reference scenario.

2.1 Data and Assumptions in the Reference and Low-Carbon Scenarios

Bottom–up models by definition need a wealth of microlevel detailed historic data to populate the base year, and EFFECT is no exception. The need to locate appropriate data for the model is important to low-carbon development research, since without a correctly built base year, it is impossible to generate a meaningful analysis of the reference and low-carbon alternative scenarios over the modeling period. This study uses 2010 as its base year to be consistent with PDP-VII.

Substantial assumptions are needed to build out the reference and low-carbon alternative scenarios to 2050. National policy documents, development plans, and related studies provided the basis for the shorter term (5- to 10-year horizon) development plans and most of the medium-term plans (to 2030) but offer little guidance as to longer-term possibilities. National institutes were consulted extensively to produce the longer-term trajectories.

This study fundamentally draws on PDP-VII in a draft revised form shared in late 2014 by IEVN, which predicated the official revision of PDP-VII (PDP-VII-Revised, approved by Prime Minister Decision No. 428/QĐ-TTg) in 2016, as the official revised version was not yet approved at the time of modeling. The draft revision has a similar level of generation and capacity of fossil fuel and nuclear plants to PDP-VII-Revised, but the latter includes more renewable capacity from the mid 2020s. The version used here is termed PDP-VII-interim-revision in this study, and can be viewed as the power development plan as it stood prior to Viet Nam's NDC submission in 2016, which is relevant as a without-climate policy reference for evaluating mitigation measures.

IEVN experts provided detailed vision and guidance on energy-efficiency targets, industry, and the electricity supply technology mix to 2050. The study team from the Transport Development Strategy Institute (TDSI) gave detailed plausible pathways for transport. Modeling by the Central Institute of Economic Management (CIEM) underpinned the choice of macro indicators and the targeted improvement in income per capita for all strata of the economy.

In this study, the reference scenario is aligned with the current sector plans and policies as laid out in Annex A, except where specifically noted. With critical input from the CIEM, IEVN, and TDSI study teams, the reference scenario for 2030–2050 was modeled as a continuation of current plans and policies, taking into account the agreed macroeconomic projections (for gross domestic product [GDP] growth, sectoral mix, population, among others). The low-carbon scenario maintains consistency in all macro variables with the reference scenario, including annual GDP growth, sectoral contribution to GDP, exchange rate, demographics, fuel and electricity prices, and industrial production.

The analysis is performed using constant 2010 prices. In the current sector plans, electricity prices are increasing over the short term to remove subsidies and these price changes are reflected in both the reference and low-carbon scenarios. All the prices used in this study to 2030 were given by the IEVN study team in accordance with the PDP-VII-interim-revision, and it is assumed that after the period of adjustment to bring them in line with true costs, these will remain constant.

Although increasing energy prices—via carbon taxes or other adjustments—are likely to be important policy levers that drive low-carbon development, these have not been reflected in this study because bottom–up modeling is not an appropriate methodology for modeling substitution and consumption responses to price signals. Here, the focus is on an engineering-style analysis of technical options.

The low-carbon scenario is more aggressive in the mitigation of GHG emissions than the country's current policies because it includes alternatives that become viable only when greater effort to remove barriers is applied, and when future international technical and financial support are available. However, because of this model's detailed engineering-style approach, care has been exercised to not include "technical solutions" that do not have a scientific or practical basis.[1]

2.2 Methodology to Evaluate Energy Efficiency in Household Electricity Consumption

The study assesses household electricity consumption by projecting household size and income by location (urban, rural). For each location, households are further separated into 100 centiles containing an equal number of people, in order of increasing expenditure, as a surrogate for income. The study forecasts the change in the number of electrified households and the expenditure levels of each centile during each year of the modeling period based on historical data and projections from the computable general equilibrium (CGE) modeling work of CIEM. It evaluates appliance ownership for each centile as a regression-based function of household income, and usage patterns for lighting and for each of the 18 appliances. Income growth is forecasted based on GDP growth, and ownership is projected on the basis of changes in income over time.

The study uses a stock model to derive new appliance sales each year from the overall annual growth in ownership and the replacement of appliances in service that have been scrapped. The energy consumption of the new appliances that enter service each year is determined from forward-looking assumptions on appliance technology and their size, and other features that affect energy consumption. The appliance ownership by location and centile—a combination of the number of households owning each appliance with the number of appliances per household—and assumptions about appliance energy efficiency and usage produce the aggregated household electricity demand.

The demand for household electricity is based on changes in household income in real terms that come from the national CGE analysis conducted under CIEM, which is consistent with the PDP-VII-Revised electricity-demand projections. These projections take into account the increase in electricity prices contained in the various versions of PDP-VII over the period to 2030.[2] Although the low-carbon scenario exhibits a lower direct cost of electricity generated than the reference scenario, it is assumed that these savings do not translate to lower electricity prices.

2.3 Methodology to Evaluate Energy Efficiency in Industry

The industry sector is extremely diverse and includes a wide range of activities, many of which are particularly energy intensive, as they require energy to extract natural resources, convert them into raw materials, and manufacture finished products. This module evaluates some of the most energy-intensive industries:

- Iron and steel (both integrated steel plants and small producers)
- Cement
- Fertilizer
- Petroleum refining
- Pulp and paper

To establish levels of production activity that result in energy consumption and process emissions, each subsector is considered according to national demand (which should increase in some measure with population and economic development), modified by the import and export of the intermediate and finished product, and obeying competitive considerations in the regional market.

[1] For example, refrigerators in 2001 consumed 75% less electrical energy than in 1974 but this does not imply that this tendency may be projected as a straight line for the following 52 years.

[2] Details are documented in Annex D - Principal Input Data and Assumptions, available on request.

The next step involves defining the fraction of this national production for each subsector, which can be done by using existing installations and determining the capacity and start-up date for new productive installations that are needed to meet the demand. As new facilities are brought online, these can be expected to comply with, or be close to, the international energy-efficiency standards for new plants at the time they are built. Existing facilities typically have higher energy consumption but can be retrofitted with different energy-efficiency measures. An existing retrofitted plant is unlikely to achieve the energy-efficiency levels that are close to those of a new installation.

Light industries (such as food processing, textiles, wood products, printing and publishing, and metal processing) and small and medium-sized enterprises (SMEs) are outside the scope of this study, despite their importance in economic growth. However, many energy-efficiency measures for these can be handled in the same way as efficiency standards for household appliances. Transformers, pumps, motors, and fans are some of the most energy-consuming appliances in SMEs given the large number in use, which can benefit directly from the implementation of standards and other policy measures.

Fossil fuel prices for industry and power generation used in the study are given by the IEVN to 2030 for the PDP-VII-interim-revision. These were further increased by the study team to 2050 in real terms using normalized average annual price change for 2030–2050 from the *EU Energy, Transport and GHG Emissions Trends to 2050 Reference Scenario 2013*. Natural gas prices used in the study from 2015 onward are based on landed liquefied natural gas price.

2.4 Methodology to Evaluate Power Sector Supply-Side Assessment

The study first models the electrical energy end-user annual demand, imports, exports, and captive generation over the modeling period within the reference scenario. This may contain any mixture of grid-supplied electricity, off-grid, and minigrid solutions. The end-user demand calculation makes use of the other demand-side modules in EFFECT (household, nonresidential, industry, and transport) and estimates residual demand (which is not explicitly modeled within EFFECT) by determining an implicit elasticity of GDP growth. The second step is to evaluate over the modeling period transmission and distribution losses and programs to reduce them, together with identifying the demand that must be supplied via off-grid or minigrid solutions. This allows the amount of electricity that must be generated and supplied to the grid to be determined annually.

Drawing on the PDP-VII-interim-revision, as communicated by IEVN in late 2014, the model includes every existing generating unit within the reference framework, detailing its type, size, fuel, efficiency, commissioning date, expected life, efficiency reduction over time, operation and maintenance costs, midlife extension dates and costs, and planned and probabilistic down time. A second database models the PDP-VII-interim-revision's future planned plant construction and retirement using the incorporated 74 types of technology and to the same level of detail, including land, construction, installation, and equipment-projected costs plus commissioning and contingency costs. A third construct evaluates the plant mix, which the model may build annually over the modeling period for periods beyond the planning horizon of the PDP-VII-interim-revision.

A load-duration curve and changes to its shape are constructed across the modeling time frame for the grid-supplied demand. This is used to load dispatch all the plants on a merit order low-variable cost basis. For each year, first the hydro availability (taking into account seasonal variation) is located at 50 percentile "knee" of the load duration curve, and the amount of "must-run" nondispatchable renewables, and nuclear energy is determined. Then the lowest variable cost base load is dispatched up to the start of hydro, which is dispatched plant by plant. Above hydro, the lowest variable cost dispatch continues until the curve is topped out by low latency generation. Off-grid or minigrid generating plants are not dispatched and are handled separately via unique modifiable utilization factors. Outputs are calculated for each year of the modeling period. As generation is an output of the model, but plant construction is an input, while the capacity mix aligns with the PDP-VII-interim-revision, generation may differ from Government targets.

The analysis has two significant additions as compared with other recent studies:

(i) The increase in fuel prices in real terms over the modeling period, referred to above. Previous studies maintained fuel prices as constant.

(ii) A learning-curve effect that reduces capital costs for generating equipment over the modeling period in real terms. Other studies maintained capital costs constant. CAPEX trends to 2050 from the study, *EU Energy, Transport and GHG Emissions Trends to 2050 Reference Scenario 2013* (European Commission 2014) were used while respecting any current cost differences between capital costs for projects in Viet Nam and international experiences.[3]

To 2050, the investment cost for nonrenewable generation falls in real terms to less than that for renewable, with utility scale photovoltaic (PV) and solar thermal showing the greatest improvement. Combined with rising fossil fuel costs, this changes the dynamics for adopting renewables in generation. Both scenarios use the same fuel and capital cost projections, which for consistency come from the same sources.

2.5 Methodology to Evaluate Sustainable Transportation and Urban Planning

The starting point for this study's reference scenario is "Adjustments to the Transport Development Strategy 2020 with a Vision toward 2050," also known as "Transport Strategy 2020." This document stresses the importance of developing transportation in a sustainable manner, and promotes infrastructure development for transport, including mass transit. To translate this reference into a concrete scenario, the following transport modes are assessed:

Private vehicle (car and motorcycle) ownership is taken as a function of household income, using nonlinear regressions based on the Viet Nam Household Living Standards Survey (VHLSS) 2010 data (General Statistics Office of Viet Nam n.d.). Household income by centile is projected over time as a function of overall GDP growth, and growth in vehicle ownership is forecasted on the basis of relationships between income and ownership.

To this, the additional (nonhousehold) ownership of cars and motorcycles—by private commercial, industrial enterprises, and other institutions—is identified and added. The baseline vehicle population is then disaggregated—by vehicle type, subtype, engine displacement, technology, gross vehicle weight, age, and fuel use—for EFFECT to determine by using historic vehicle sales through a vehicle stock (or mortality) model the applicable

[3] Described in Annex D - Principal Input Data and Assumptions, available on request.

fuel consumption and emissions factors. Using industry information, the percentage sales mix of new vehicles is projected at the same level of disaggregation. A vehicle mortality calculation using a modified Winfrey S3 survival curve is applied to determine the number of vehicles in the active population that must be replaced annually, project annual sales volumes of new vehicles, and the annual changes to the vehicle population mix.[4] The annual per-vehicle age-sensitive usage (kilometers [km] per year) by vehicle type and subtype is determined from surveys or estimated from cross-country comparisons. By projecting average ridership by vehicle type and subtype, the number of passenger-kilometers traveled per year (PKT) in private vehicles may be estimated.

For other on-road passenger vehicles (light duty vans, multiuse vehicles, buses, and coaches), the base-year vehicle population is disaggregated as above and the annual per-vehicle age-sensitive usage (kilometers per year) is surveyed or estimated, which together with average vehicle ridership or goods transported, will give the PKT and freight-ton-km-transported (FTKT) in the base year. The fractional sales mix of new vehicles at the level of disaggregation is also estimated from industry sources for future years.

Rail and waterborne modes of transportation are treated in the same way as trucks and buses. Their total activity is determined in the base year, which together with estimates (or survey data) on goods and passengers carried will determine the PKT and FTKT on a per-transportation-unit basis. Future expansion plans are used to evaluate carrying capacity over future years.

Modeling transport demands: Total PKT and total FTKT are then forecast over the modeling period based on population and economic growth indicators using cross-country comparisons where necessary to estimate probable changes in PKT and FTKT travel distance at different levels of economic development. The forecast car and motorcycle PKT in each future year is subtracted and the mass transport remnant is apportioned to each travel mode under differing investment and transport expansion scenario. New vehicle prices and in-use (nonfuel) operating costs are estimated.

Average local operating conditions—for on-road vehicles considering percentage of vehicle-kilometers-traveled under different urban, rural, and highway road speed conditions; biofuel usage; vehicle load and average road grade; ambient temperature; and the impact of inspection and maintenance programs on vehicle maintenance quality—are then determined for each modeled year. This additional information helps to determine the fuel consumption and emissions factors for each mode and specific vehicle type and usage per year using the international COPERT4 model, which is then calibrated to local conditions.[5] Scenarios are elaborated with improvements in infrastructure and vehicle efficiency to evaluate the impact of these on energy consumption and emissions for each mode and vehicle type.

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4 The Winfrey function is used to estimate vehicle mortality based on the calibrated average maximum vehicle scrappage age.

5 COPERT 4 model is a model to calculate road transport emissions in accordance with the requirements of international conventions and protocols and the EU legislation.

3. ANALYSIS AND RESULTS OF ENERGY EFFICIENCY IN HOUSEHOLD ELECTRICITY CONSUMPTION

3.1 The Reference Scenario

In alignment with the Prime Minister's Instruction 22/CT-TTg, the reference scenario considers a gross domestic product (GDP) growth rate of 6.9% from 2016 to 2020, which increases to 7% over the period to 2030 and descends to 6.4% for 2041 onward. This generates an economy that is, by 2050, in real terms 13.6 times larger than in the 2010 base year. Over this time frame, the population increases from 85.2 million in 2010 to 105.9 million. In 2010 constant dollars, GDP per capita increases over 10 times from $1,250 detailed to $12,900.

This growth is fueled by industry and services, as over 2010–2050, the contribution to GDP of the former increases from 38% to 46% while the latter expands from 43% to 49% at the expense of agriculture, which shrinks in its contribution to GDP from 19% to 5%.

By 2039, Viet Nam becomes a primarily urban economy. The urban population percentage, which was 30% in 2010, expands to 60% by 2050 with a corresponding decrease in the rural percentage. This gives a rural population that contracts from 60 million to 43 million people but because of diminishing household size, the number of rural households remains stable, contracting slightly from 15.8 million to 14.6 million in 2050.

Over this period, however, the number of urban households grows dramatically from 6.9 million to 22.7 million. At the same time, their income grows at a higher rate than that of rural households. In fact, the top four urban quintiles can expect an income that grows faster than GDP, according to the national computable general equilibrium (CGE) modeling performed by the Central Institute of Economic Management (CIEM), which was used in this study.

Consequently, the accelerated increase in disposable income and uptake of electrical appliances gives rise to a vibrant urban economy, in which the urban 50th centile enjoys, over the 4 decades, a 10 times increase in household income, while the rural 50th centile obtains a 7 times increase.

This study evaluates the ownership and use of the 18 appliances and lighting that are shown in Table 4, using primarily the data obtained in the 2010 Viet Nam Household Living Standards Survey (VHLSS). Some appliances covered by this study, however, were not included in this survey, and data from the previous survey (General Statistics Office of Viet Nam 2008) and surrogate data from a neighboring country (National Statistical Office Thailand 2011) were used for selected parameters to fill the gaps. A fitted Gompertz or Logistic curve allows ownership to be evaluated in relation to income. Project income levels for each of the urban and rural centiles over

Table 4: Household Appliances Included

Group	Appliance Type
Lighting	Fluorescent, incandescent, CFL, and LED lights
Entertainment	Radio, stereo, CD, TV, DVD, computers, printer
Kitchen Appliances	Refrigerator, washing machine, water pump, thermo pot, cooking pot, iron, vacuum cleaner, microwave
Heating and Cooling	Water heater, fan, air conditioning

CD = compact disk, CFL = compact fluorescent lighting, DVD = digital video disk, LED = light emitting diode.
Source: Authors.

each of the 40 years then allows for ownership over time to be projected.

As can be expected, the results of such projections are quite dramatic. In 2010, there were almost as many television sets in Vietnamese homes as the number of households (20.4 million TV sets distributed among 22.4 households with electricity) but, by 2050, a population of 52.8 million in-use TV sets can expect to be installed in 37.1 million households (of which 22.6 million are urban households).

The total household ownership of computers increases from 4.1 million in 2010 to 37 million in 2050; the in-use population of clothes washers increases from 4 million to 23 million; the number of fans grows from 31 million to 99 million; and the number of in-use air conditioners grows from 2 million to 43 million. This increase in appliance ownership and use, and particularly the 20 times increase in ownership of air conditioners has a major impact on household electricity demand (see Table 5).

Of course, electricity demand is not determined only by the ownership of appliances—usage (hours) and specific energy consumption (kilowatt-hours [kWh]) are also needed. Two principal sources were consulted to determine appliance usage. The Viet Nam Energy Service Company 2009 study supplied data for historic 2010 usage while the Australian market survey for the Viet Nam Energy Efficiency Standards and Labelling Program (Mark Ellis & Associates 2012) provided important insights into current usage patterns. For most appliances, the available data do not clearly indicate that the daily usage in hours increases with disposable income; hence, there could be no justifiable reason to reduce usage through energy price effects particularly since over the modeling period income increases by greater than an order of magnitude (1,000%) while the included removal of subsidies on electricity prices together with generating-cost increases add up to less than 57%.

Appliance-specific energy usage (kWh) was determined using data from the two previously mentioned surveys to define historic levels, a survey of appliances currently being sold for new appliance energy consumption today, and a projection based on expected changes in consumer demand and future technology levels.

Increasing incomes lead consumers to increasingly adopt larger appliances over time, such as larger and frost-free refrigerators from smaller, direct-cooled units; to larger LCD-panel TVs; and to enjoy more liters of hot water in the home over more days per year. These all tend to increase per-unit power consumption. Air conditioning (AC) is a special case because with low disposable income, a family might only turn on the AC to cool a bedroom for a couple of hours before going to sleep. However, as disposable income rises (and urban household income increases in real terms by an order of magnitude of the modeling

Table 5: In-Use Numbers of Selected Appliances in 2010, 2030, and 2050

		Number of Units			Growth in Percentage	
		2010	2030	2050	2010–2030	2030–2050
		millions of units			%	%
Entertainment	TV	20.4	34.9	52.8	71.3	51.3
	Computer	4.1	20.0	37.2	385.5	86.5
Kitchen Appliances	Refrigerator	9.2	23.0	32.9	151.3	43.2
	Cooking pot	16.3	27.2	37.8	67.0	38.5
Heating/Cooling	Fans	30.9	63.3	99.5	104.9	57.2
	Air conditioning	2.0	17.5	43.2	776.9	146.4

Source: Authors.

period), AC usage extends in time and coverage until it improves the comfort of the whole house or apartment continually over extended periods.

Other appliance adoption patterns (such as from desktop computers to laptop) have opposite tendencies. At the same time, appliance efficiency will increase over the coming years even if Viet Nam does not make any concerted effort, or enact a policy to promote this. Earlier studies have demonstrated a clear relationship between appliance energy efficiency and the age of the manufacturing plant. Thus, the assumption in the reference case is that appliance energy efficiency will improve but more slowly than could be achieved through a focused national policy to promote energy efficiency in new appliance sales.

The reference case assumes that appliances sold in 2011 met, on average, the equivalent Energy Star 2002 standard applicable to each appliance type. This implies a weighted sales mix of more efficient units together with others whose market attractiveness is based primordially on price. Similarly, the reference case assumes that appliances sold in 2015 will meet on average, the equivalent Energy Star 2008 standard applicable to each appliance type.[6] To assume sales-weighted appliance efficiency in future years, a study was made of all appliances worldwide (by type) that currently meet the Energy Star standard. For many appliance types, this consisted of hundreds or thousands of discrete models from different manufacturers from which three specific power consumption levels were determined:

- Energy Star 75%: The average power consumption of the most efficient 75% of the appliances exceeding 2010 efficiency standards
- Energy Star 50%: The average power consumption of the most efficient 50% of the appliances exceeding 2010 efficiency standards
- Energy Star 25%: The average power consumption of the most efficient 25% of the appliances exceeding 2010 efficiency standards

Although even the most stringent level (Energy Star 25%) requires no technological breakthrough for implementation (as such products are already in the market), substantial effort may be required to attain such efficiency. Local manufacturing plants may need time, technical assistance, and access to financing to update their production technology to meet this upcoming average power requirement. In the reference scenario, it is assumed that market forces by themselves will allow future appliance sales to meet three average power levels: Energy Star 75% in 2025, 50% in 2033, and 25% in 2041.[7]

Table 6 shows for selected appliances the combined effect of changes in size, technology, and the stock model that incorporates new sales into the in-use population on average per-unit power consumption over the modeling period. Although air conditioning units become much more efficient, they exhibit an increase in power consumption driven by a move to larger whole-house units in the upper household centiles particularly over the later years of the modeling period.

Figure 6 presents the overall impact of increasing ownership and use of appliances coupled with the improved energy efficiency that can be expected in the market, assuming no specific efforts from the Government to improve appliance energy efficiency in Viet Nam.

Over the 40-year period to 2050, household energy consumption increases by 7.9 times, driven by average urban household income growing in real terms by 10.5 times and a 3.3 times increase in the number of urban households from 2010 to 2050.

6 Energy Star is an international standard for energy efficient consumer product.

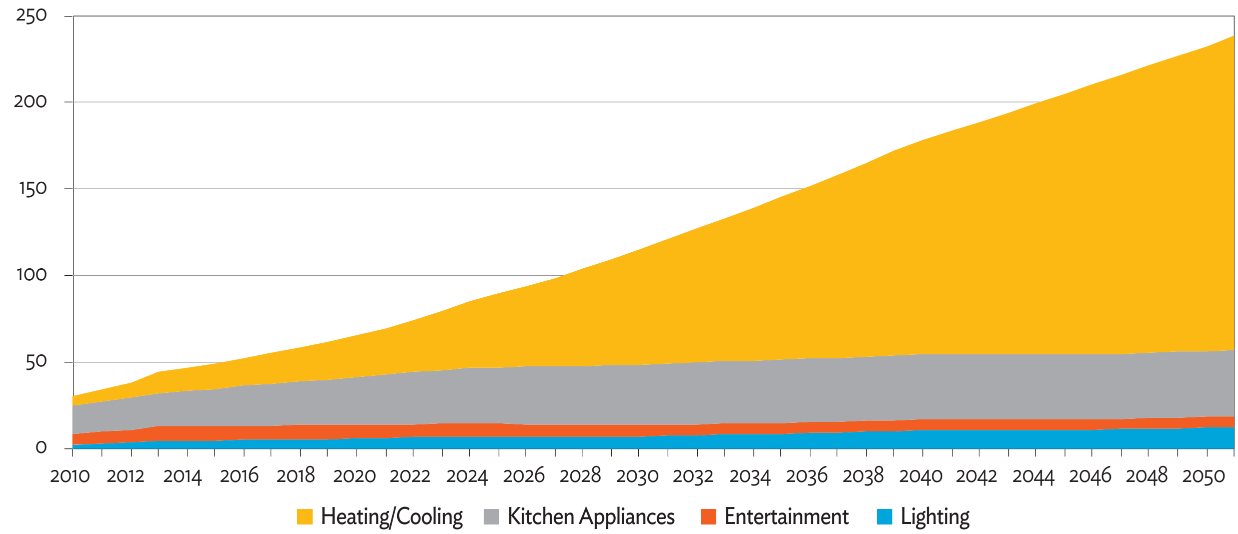
7 Annex D, Household Module gives full details for each of the 18 appliance types and lighting, available on request.

Table 6: Average Per-Unit Power Consumption of Selected In-Use Appliances

		Unit	Average Operating Unit Power Consumption 2010	2030	2050	2010–2030 %	2030–2050 %
Entertainment	TV	Wh	76.9	49.1	32.5	(36.1)	(34.0)
	Computer	Wh	140.5	40.9	25.5	(70.9)	(37.7)
Kitchen appliances	Refrigerator	kWh/unit	492.1	511.4	289.0	3.9	(43.5)
	Cooking pot	Wh	650.0	604.9	383.8	(6.9)	(36.5)
Heating/Cooling	Fans	Wh	39.4	28.7	23.7	(27.2)	(17.5)
	Air conditioning	Wh	1,972.8	2,092.7	2,383.2	6.1	13.9

( ) = negative, kWh = kilowatt-hour, Wh = watt-hour.
Note: Combines the effects of usage, size, technology, and the stock model that incorporates new sales into the in-use population.
Source: Authors.

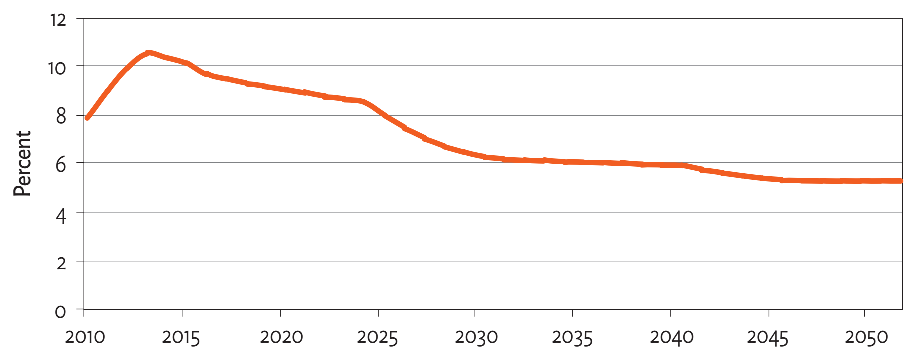
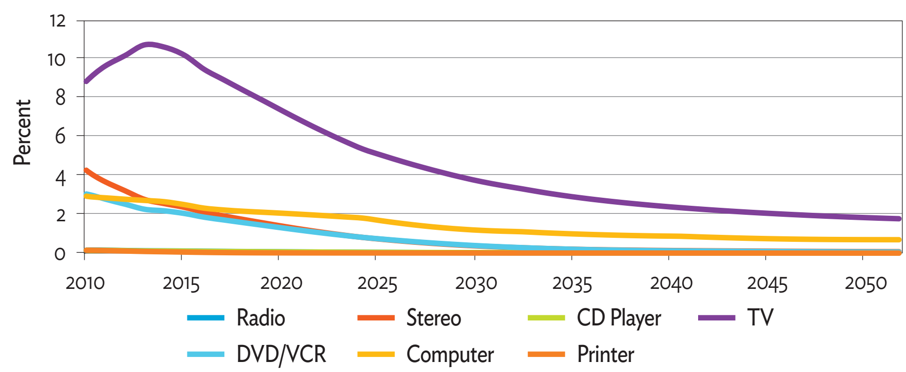
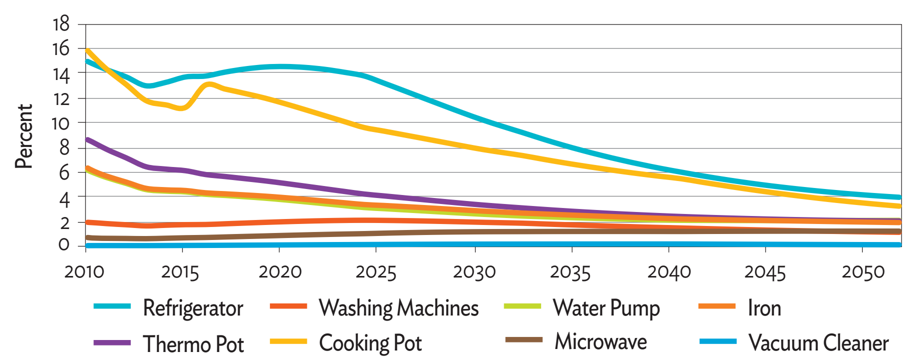
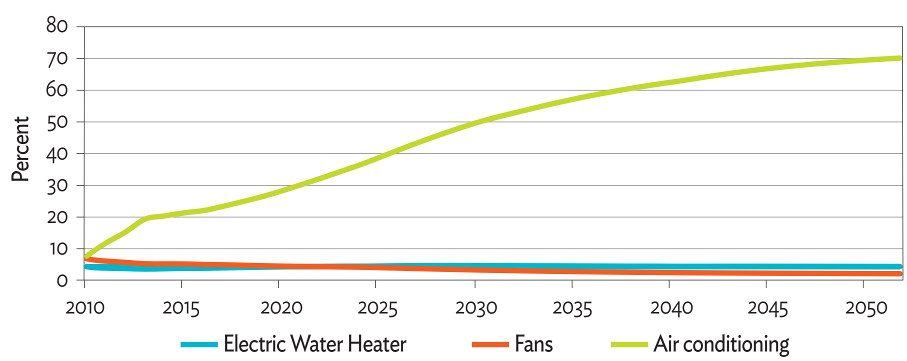
Figure 6: Household Electricity Demand in the Reference Scenario
(TWh per year)



TWh = terawatt-hour.
Source: Authors.

Figure 7 shows household electricity demand by appliance type in the reference case (as a percentage of total household electricity demand), identifying the most important 18 appliances for enacting long-term efficiency standards and targets within lighting, entertainment, kitchen appliances, and heating and cooling. Air conditioning is the dominant use of electricity in the future.

Figure 7: Household Electricity Demand by Appliance Type in the Reference Scenario
(as a percentage of total household electricity demand)

Lighting (as percent of total household electricity consumption)	
Entertainment Appliances (as percent of total household electricity consumption)	
Kitchen Appliances (as percent of total household electricity consumption)	
Heating and Cooling (as percent of total household electricity consumption)	

CD = compact disk, DVD = digital video disk, VCR = video cassette recorder.
Source: Authors.

3.2 The Low-Carbon Development Scenario and Mitigation Opportunities

In the low-carbon scenario, appliance ownership and use patterns remain unchanged from the reference scenario because no changes have been made to any of the macroeconomic indicators (or to electricity prices). However, it is assumed that the Government enacts policies and regulations to incorporate quickly more efficient appliances into the new appliance sales.

The underlying assumption is that in the global market for household appliances, manufacturers will always attempt to make best use of their manufacturing facilities, and often have at their disposition newer manufacturing lines that produce the most recent—and efficient—models, and older lines that are worth keeping in operation while there is a market for less efficient and older underlying technology models. The models that are offered in any specific marketplace will depend on consumers' level of sophistication and any regulatory restrictions or standards to which new appliances offered for sale must comply.

A total of 23 appliance types in four groups (see Table 7) were appraised in improvement of potential efficiency. Specifically, in the low-carbon scenario, it is assumed that an average weighted-sales efficiency equivalent to Energy Star 75% could be accelerated by 5 years from 2025 (in the reference scenario) to 2020; reaching Energy Star 50% could be accelerated by 8 years to 2025; and Energy Star 25% could be accelerated to 2030 instead of by 2041 in the reference case. To achieve this, a mixture of policies, regulations, and possibly assistance to consumers would be required.

Table 7: Household Appliances Considered in the Study

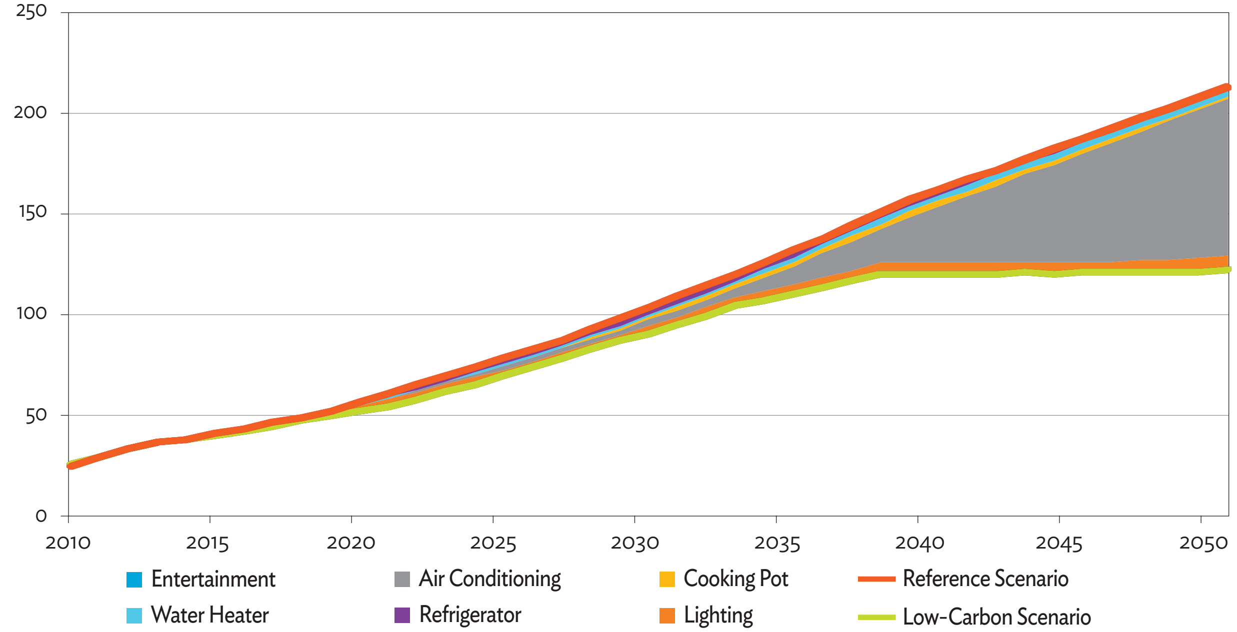
Group	Appliances
Lighting	Fluorescent, CFL, LED, and incandescent
Entertainment	Radio, stereo, CD player, TV, DVD/VCR, computer, and printer
Kitchen (white) Appliances	Refrigerator, washing machines, water pump, toaster, thermo pot, cooking pot, iron, vacuum cleaner, and microwave
Heating/Cooling	Water heater, fans, and air conditioning

CD = compact disk; CFL = compact fluorescent lighting; DVD = digital video disk; LED = light emitting diode.
Source: Authors.

By 2050, the promotion of energy-efficient technologies could cut much of residential electricity consumption by nearly 50% (see Appendix for more details). More efficient cooling will achieve the bulk of reductions, as air conditioning is a leading driver of increased electricity consumption in the baseline scenario. The modeled approach includes initially accelerating air conditioning efficiency, then supplementing this with building efficiency measures, such as low-e glass and deployment of ceiling fans. More efficient lighting, including more rapid adoption of more efficient light-emitting diode (LED) lamps, follows, after which higher efficiency cooking appliances, water heaters, entertainment devices, and refrigerators make additional contributions (Figure 8).

There is a vast expansion of mitigation potential from improved cooling after the mid 2030s, as air conditioning becomes widely adopted under higher incomes. Achieving more efficient cooling depends on both efficiency in air conditioning units and on efficiency of building construction. This suggests an important role for green building codes in realizing this potential.

Figure 8: Reduction of Household Electricity Demand in the Low-Carbon Scenario
(TWh per year)



TWh = terawatt-hour.
Source: Authors.

4. ANALYSIS AND RESULTS OF ENERGY EFFICIENCY IN INDUSTRY

4.1 The Reference Scenario

The reference scenario is based on existing master plans related to industry (see Annex A for more details) and consultation with industry. This analysis concentrates on five energy-intensive industries: iron and steel including integrated steel plants (ISP) and small-scale producers (SSP), cement, fertilizer, petroleum refining, and pulp and paper.

There is a significant gap in the availability of energy audit data for small and medium-sized enterprises (SMEs) that defines recent energy usage, so they were not included in this analysis. However, fans, motors, lighting, computers, and other tools and appliances can benefit from similar regulations and financial incentives as household appliances (see Chapter 3).

4.1.1 Iron and Steel

Viet Nam's steel market has already evolved into Asia's seventh largest with a per-capita steel consumption of approximately 150 kilograms annually, ranking it ninth in Asia.[8] Construction steel products produced mainly from imported scrap make up domestic production. High-grade steel and flat-plate products have been mainly imported. Total domestic production of finished iron and steel products is projected to increase from 9.2 million tons (Mt) in 2010 to 23 Mt in 2030 and 36 Mt by 2050, registering an average annual growth rate of 3.5%. The targets set in Viet Nam's master plan on the development of its steel industry include an increase in export volumes of finished steel products over the next 2 decades. As Viet Nam's production becomes more sophisticated as projected in the steel sector plan, the share of flat steel products in the product mix is likely to increase by ~50% by 2020.[9]

The reference scenario considers that the future growth of this industry will be via ISPs through the blast furnace–basic oxygen route (Credit Suisse 2012) and that the production from imported scrap via small-scale producers will not exhibit growth. Future capacity additions are not envisaged in this route because of global scrap unavailability (Credit Suisse 2012). See Table 8 for the Viet Nam Industry Steel Development Plan.

Table 8: Viet Nam Steel Development Plan
(million tons)

	2010	2015	2020	2025
Domestic demand	15.3	16.0	21.0	25.0
Export	1.2	1.9	2.4	2.9
Import	7.2	5.6	7.4	8.8
Total production	9.2	12.2	16.1	19.1
Integrated steel plant	0.8	4.0	7.8	10.9
Small-scale producers	8.4	8.2	8.2	8.2

Source: Ministry of Industry and Trade. 2007. Viet Nam Industry Steel Development Plan for the period 2007–2015 with Outlook to 2025. Hanoi.

8 After (in descending order) the People's Republic of China; Japan; India; the Republic of Korea; Taipei,China; and Thailand.

9 Decision No. 145/2007/QD-TTg dated 4 September 2007 of the Prime Minister, approving the Master Plan on the Development of Viet Nam's Steel Industry in the 2007–2015 Period, with the 2025 Vision Taken into Consideration; and SBS Research. Steel Industry Outlook 2011.

Production by small-scale producers is scrap based and is assumed to remain practically constant over the modeling period. However, the energy intensity of the existing ISP plants is considered to be 29.5 gigajoules per ton (GJ/t).[10] Most of the future capacity is expected to come under the blast furnace–basic oxygen furnace route.

4.1.2 Cement

Rapid industrial and urbanization in Viet Nam have contributed to a cement sector where domestic production is expected to continue to grow, making Viet Nam self-sufficient in cement supply from about 2025 onward (Table 9).

As in the case of iron and steel, the cement industry in Viet Nam uses relatively older technologies (Thu An 2011).Investing in energy efficiency in this sector would not only improve the sector's competitiveness, but reduce carbon dioxide equivalent (CO_2e) emissions as well (see Figure 9). Of the five industry sectors, cement contributed around 75% of total industrial greenhouse gas (GHG) emissions, the highest of the sectors in 2010.

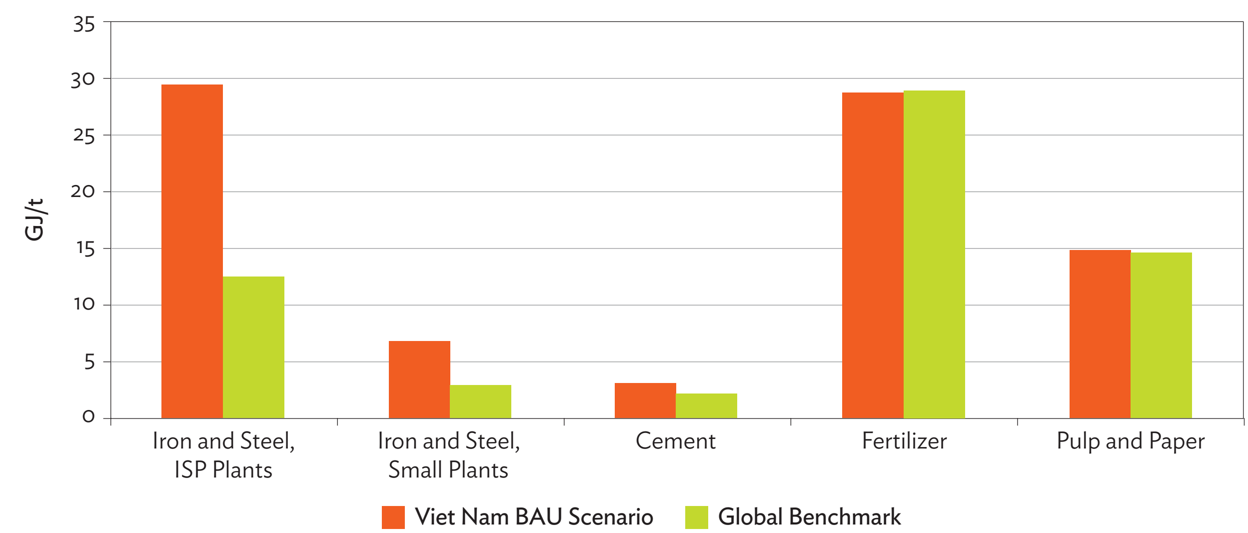
Table 9: Demand–Supply Scenario in the Cement Industry
(million tons)

	2010	2015	2020	2025
Domestic demand	53	75	96	106
Export	6	12	16	18
Import	3	0	0	0
Total production	56	87	112	124
Ordinary portland cement	2.4	1.6	1.3	1.5
Pozzolanic portland cement	53	86	111	123

Source: Discussions between the Institute of Energy and Ernst & Young; Sectoral Master Plan.

In 2010, the share of ordinary portland cement (OPC) declined from 4% while production of pozzolanic portland cement (PPC) increased. PPC cement contains pozzolanic material, which offers much better strength over the long term, and is thus favored by the construction industry. In 2010, the ratio of clinker (sintered limestone and alumino-silicate materials) to nonclinker components for OPC cement plants was 95% while that for PPC plants was 80%. By 2030, this is expected to decline to 75% for old and new

Figure 9: Comparison of Energy Intensity of Selected Viet Nam Industry Sectors to Global Benchmarks



BAU = business as usual, GJ/t = gigajoule per ton, ISP = integrated steel plant.
Source: Ernst & Young estimates.

10 Discussions with Institute of Energy experts.

plants. With no annual efficiency improvements, energy intensity is assumed to be 3.04 GJ/t (World Bank 2010) of cement for old plants. With new technologies, however, new plants can be expected to have efficiency improvements at par with global best practice. Their energy intensity will gradually improve toward the global benchmark of around 2.26 GJ/t (European Environment Agency n.d).

4.1.3 Fertilizer

With a total import value of around $1.35 billion in 2009 (Table 10), the fertilizer industry has played a dominant role in Viet Nam's imports. Agriculture is still an important sector in Viet Nam although urbanization is accelerating. As fertilizer demand rises, major expansion of the fertilizer industry is expected. The fertilizer sector is principally dependent on natural gas to meet its energy requirements and therefore the abatement options have been selected to reduce the natural gas consumption of this industry sector. The energy intensity of natural gas per ton of product is around 28.7 GJ/t of product in 2010.[11]

Table 10: Demand–Supply Scenario in the Fertilizer Industry
(million tons)

	2010	2015	2020	2025
Domestic demand	2	2.5	3.3	4.0
Export	0.003	0.003	0.003	0.003
Import	1	0.9	1.2	1.4
Total production	1	1.6	2.1	2.6
Production of biofertilizer	0.00	0.002	0.003	0.007
Total production facilities excluding biofertilizers	1	1.6	2.1	2.6

Source: Discussions between the Institute of Energy and Ernst & Young, the Ministry of Agriculture and Rural Development, and the Ministry of Industry and Trade.

4.1.4 Petroleum Refining

The expansion of Viet Nam's refinery sector is expected to make production more complex and, consequently, increase energy consumption in the near future (Table 11). Petro Viet Nam, for example, needs to scale up and upgrade its petroleum refining capacity to supply EURO 4 quality auto fuels in the market by 2017. This involves significantly high investment accompanied by an expansion in capacity from the present level of 6 million tons per year planned from 2016–2017 onward.

Table 11: Demand–Supply Scenario in Refineries
(million tons)

	2010	2015	2020	2025
Domestic demand	13.4	19.3	28.9	40.6
Export	2.0	2.2	2.8	3.6
Import	9.9	11.4	16.4	23.5
Production	5.5	10.0	15.4	20.7

Source: Japan International Cooperation Agency (JICA). 2009. The Study on National Energy Master Plan in Viet Nam. Tokyo.

To meet its power requirements, this sector primarily depends on crude oil, and the abatement options have been selected to reduce the consumption of this energy source.

4.1.5 Pulp and Paper

Paper plants are categorized as integrated mills (based on wood-based representing 23% of total production) and small plants (based on waste paper pulping representing 77% of the total production). Energy intensity for integrated mills is approximately 22.2 GJ/t and that of waste paper pulping 12.5 GJ/t. Both plants consume coal and electricity. Annual growth in domestic demand is projected to be around 11%, and domestic pulp production is around 37% of total paper and pulp production (Table 12).

Table 12: Demand–Supply Scenario in the Pulp and Paper Industry
(million tons)

	2010	2015	2020	2025
Domestic demand	2.0	4.0	6.9	10.4
Export	0.1	0.1	0.1	0.1
Import	1.0	1.1	1.1	1.1
Production	1.1	3.0	5.9	9.4

Source: Discussions between the Institute of Energy and Ernst & Young.

11 Discussions between Ernst & Young and the Institute of Energy.

Viet Nam imports almost 63% of pulp for paper production. The pulp and paper industry of Viet Nam sources almost 88% of its total energy requirement from thermal energy (heavily dependent on coal) and the energy intensity of the sector is higher than the global benchmark.

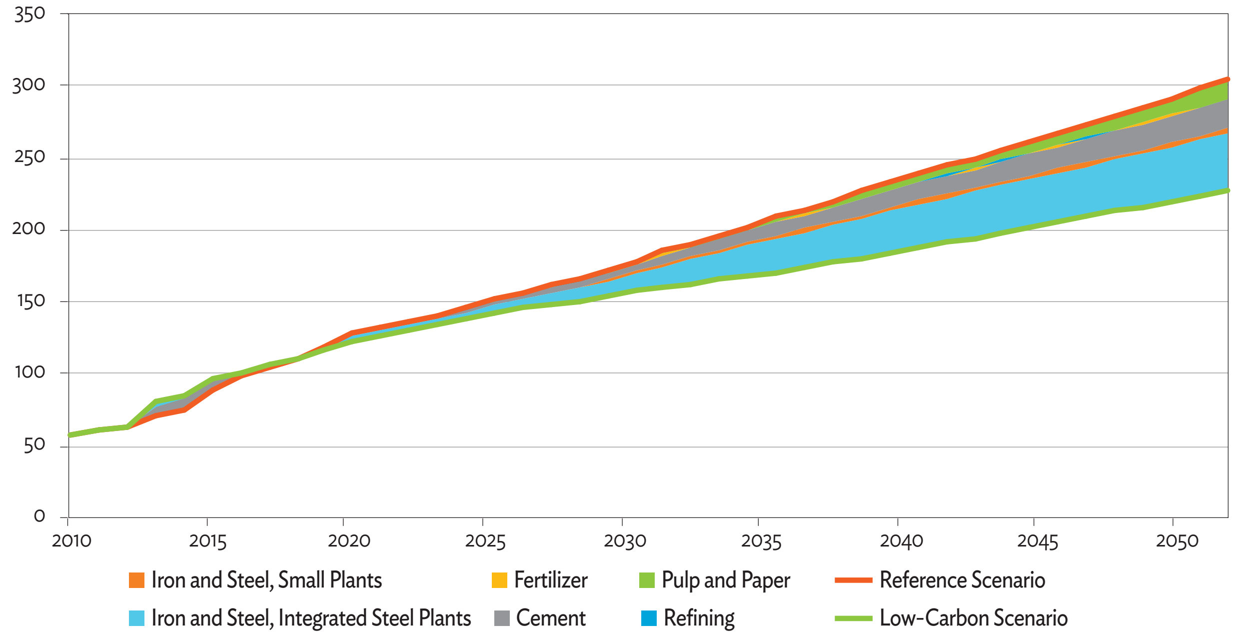
4.2 The Low-Carbon Development Scenario and Mitigation Opportunities

The 41 measures in the low-carbon scenario reduce greenhouse gas (GHG) emissions from industry by 23% from 310 million tons to 239 million tons of carbon dioxide equivalent ($MtCO_2e$). As shown in Figure 10 (more details in the Appendix), the leading source of mitigation is from improvements to integrated iron and steel plants (ISPs). With the ISPs' recent energy intensity at well above the global benchmark of 12.5 GJ/t (UNIDO 2010), there is considerable potential for improvement. In the low-carbon scenario, significant gains can be made through continuous casting, pulverized coal injection, and heat recovery for the process and for generating electricity.

Cement is the next most important source of mitigation and a sector where capital costs for more efficient technologies are relatively low. Waste heat recovery is a primary source of cement mitigation. More efficient technologies for the production of pulp and paper, fertilizer, petroleum refining, and small-scale steel make much smaller contributions.

Much of the mitigation potential is only fully realized over medium or longer-term time frames. Substantial mitigation only becomes possible after 2030, due to the fact that these technologies have adoption that takes decades to saturate the industry. The concentration of mitigation potential in a few selected sectors also suggests that attention in industry may benefit from intensive focus on a few selected high potential technologies.

Figure 10: Mitigation from Five Industry Subsectors ($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

5. ANALYSIS AND RESULTS OF POWER SECTOR SUPPLY-SIDE ASSESSMENT

5.1 The Reference Scenario

5.1.1 Electricity Demand

Electricity demand was modeled using the household, industry, and transport modules of Energy Forecasting Framework and Emissions Consensus Tool (EFFECT). In 2010, this accounted for 51% of the total grid demand as shown in the base year in National Master Plan on Power Development (PDP-VII).[12] A demand curve was calculated for the residual—non-explicitly modeled power demand such that the sum of the explicitly modeled and the residual elasticity of electricity to gross domestic product (GDP) growth matched the power demand elasticity in PDP-VII. In the initial years, this resulted in an annual increase in demand elasticity for the residual that was higher than for the directly modeled sectors, although the elasticity converged with that of the modeled sectors midway through the modeling period (see Figure 11).

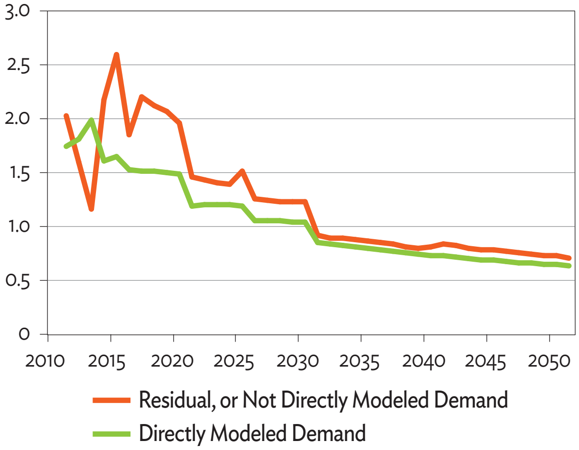
Electricity demand defined in accordance with PDP-VII takes into account the price elasticity effect of eliminating subsidies and moving end-user electricity costs toward sustainable values for the power sector, based on the international trend in fossil fuel prices.[13]

The electricity end-user demand in the reference scenario (Figure 12) grows to 1,280 terawatt-hours (TWh) by 2050. Transmission and distribution technical losses are reduced from 9.8% in 2010 to 8.4% in 2030 and beyond. By 2050, these represent 115

12 Compared with the energy balance for 2010 developed by the International Energy Agency and the 2010 value supplied by the Institute of Energy study team.

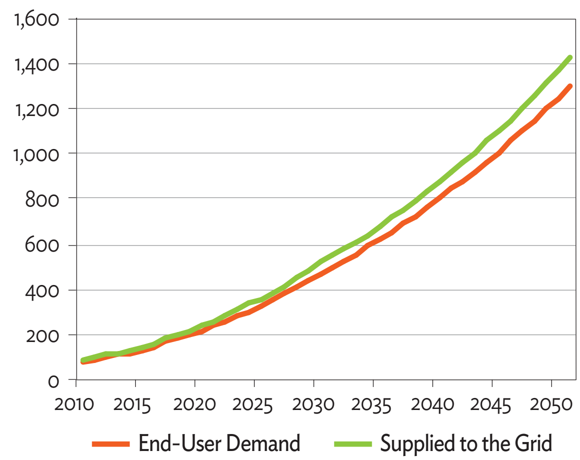
13 Note that aggregate demand in this analysis omits imports and some forms of captive and off-grid generation. Hence, total electricity supply is slightly lower than PDP-VII-Revised.

Figure 11: Elasticity of Electricity Demand to GDP Growth for the Reference Scenario



GDP = gross domestic product.
Source: Authors.

Figure 12: Electricity Demand and Grid Supply in the Reference Scenario (TWh)



TWh = terawatt-hour.
Source: Authors.

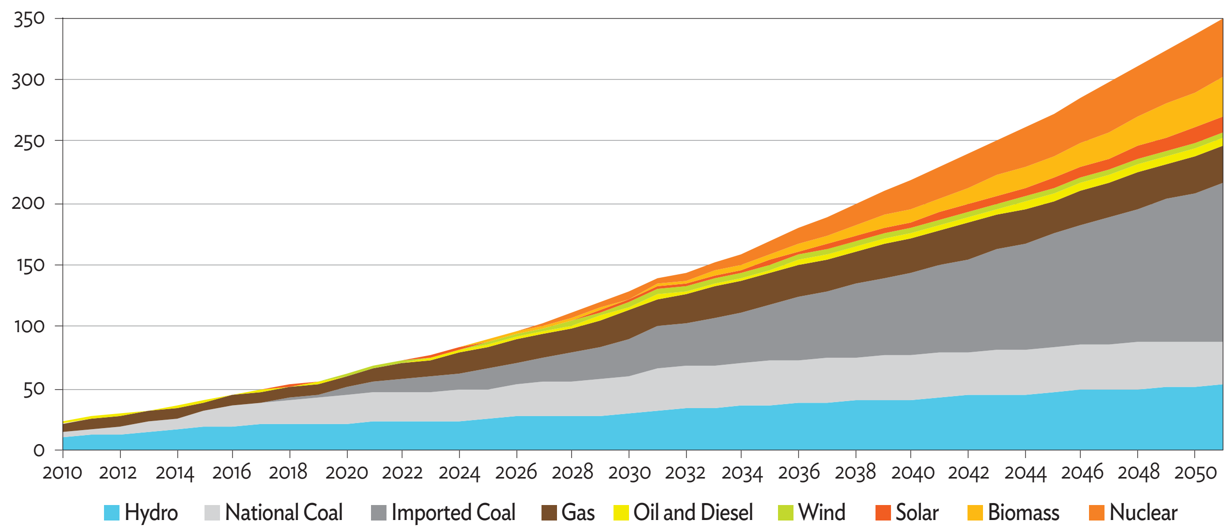
TWh. In both scenarios, imports are reduced from 5.6 TWh in 2010 to 3.2 TWh for 2027 and beyond, and increases captive from 3.4 TWh in 2010 to 27 TWh in 2036 and beyond. The resultant demand for electricity to be generated and supplied into the grid grows from 87.3 TWh in 2010 to 1,363 TWh in 2050.

5.1.2 Installed Capacity

Consistent with PDP-VII-Revised, installed capacity increases from 23 gigawatts (GW) in 2010 to 128 GW in 2030. This further increases to about 350 GW by 2050 (Figure 13). The installed capacity of hydro increases from 29 GW in 2030 to 52 GW in 2050, but this expansion is slower than that of overall capacity, so its share declines from 23% to 15% of the capacity mix. There is growth in low-carbon alternatives, such as nuclear, biomass, solar, and wind, which together in 2050 have installed capacity of 91 GW (27% of capacity; Figure 14). Over half of this (nonhydro) low-carbon capacity is nuclear.

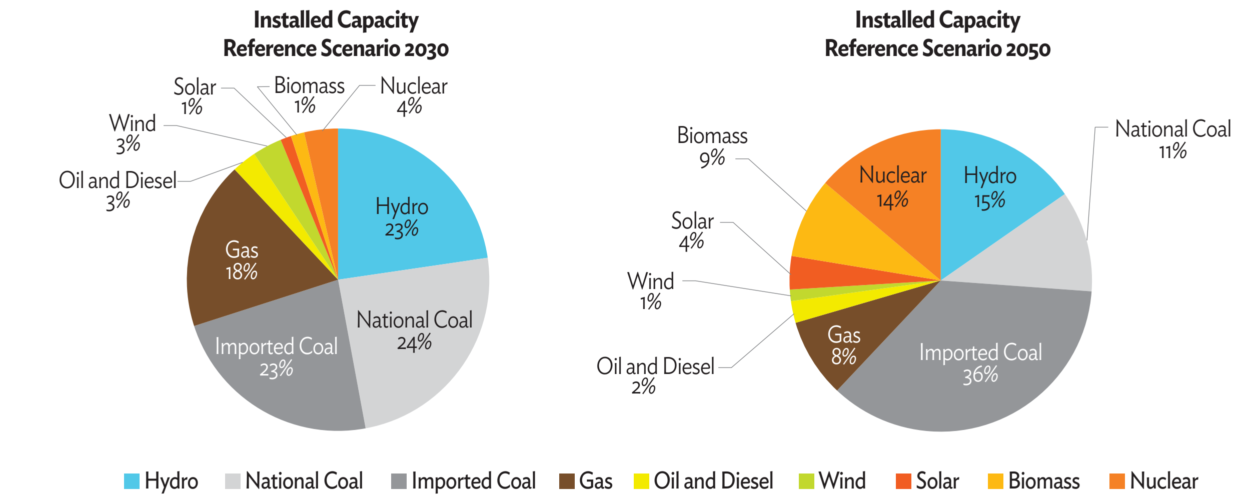
However, the greatest growth is in imported coal, which has approximately the same installed capacity as hydro in 2030, increases to 121 GW in 2050, or 36% of installed capacity. National coal in absolute terms also grows slightly from 31 GW to 36 GW installed capacity in 2050, but its share in the mix drops to 11%.

Figure 13: Installed Capacity, Reference Scenario (GW)



GW = gigawatt.
Source: Authors.

Figure 14: Installed Capacity Mix in 2030 and 2050, Reference Scenario



Source: Authors.

5.1.3 Electricity Generation

To meet electricity demand, the grid has to generate 87.3 TWh in 2010, which increases to 1,363 TWh by 2050. Using the capacity mix given by the planned plants in the PDP-VII-interim-revision and continuing that trend in EFFECT finds electricity generation that is increasingly dependent on imported coal (Figure 15).[14]

In the reference scenario, between 2030 and 2050 a substantial amount of low-carbon generation is added: nuclear increases from 31 TWh to 309 TWh to occupy 23% of the generation mix (see Figure 16). Biomass increases to 137 TWh to represent 10% of generation, and hydro, despite increasing from 91 TWh to 117 TWh, sees its participation cut in half from 18% to 9%.[15]

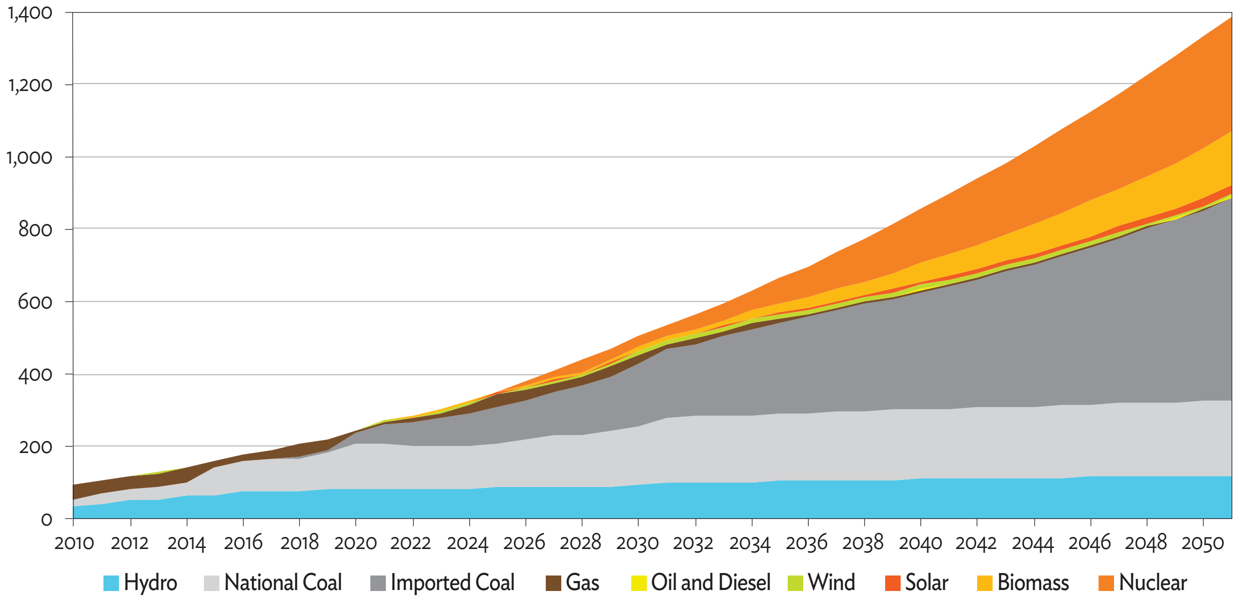
With only slight contributions from wind, solar, gas, and oil, the remainder is supplied by coal. In 2030, the amount from national and imported coal is practically the same (32% and 34%, respectively). By 2050, the amount from imported coal has increased substantially, while national coal increases only slightly (7% growth over the 20 years) such that the mix becomes 16% from national and 39% as imported. As almost 55% of generation (733 TWh) comes from coal in 2050—of which two-thirds is from imported coal—and with rising coal prices, this not only increases carbon dioxide equivalent (CO_2e) emissions but also could place a burden on the exchequer and raise energy security concerns.[16]

14 The generation mix found by EFFECT to minimize generation costs, drawing on the PDP-VII-interim-revision powerplant commissioning and decommissioning schedules differs from the PDP-VII-Revised generation targets. In particular, EFFECT finds more 2030 coal generation than is targeted by PDP-VII-Revised (64% versus 53% of domestic generation), even though the capacity mix is similar. This may be due to differences in how the load duration curve is modeled.

15 It is important to note that "hydro" includes run-of-river, storage, pumped, and mini/micro hydro.

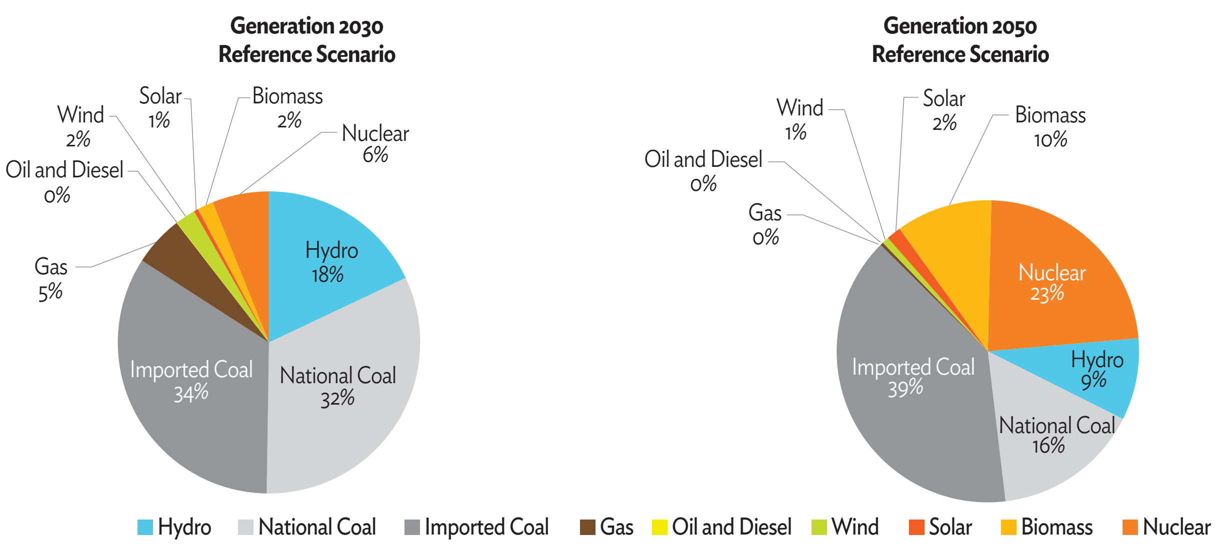
16 Coal prices used in this analysis, in 2050, range between $171.5 per ton for imported coal and $84.5 per ton for national sub-bit coal (Dust 6a).

Figure 15: Generation by Category, Reference Scenario (TWh)



TWh = terawatt-hour.
Source: Authors.

Figure 16: Generation Mix in 2030 and 2050, Reference Scenario



Source: Authors.

5.2 The Low-Carbon Development Scenario and Mitigation Opportunities

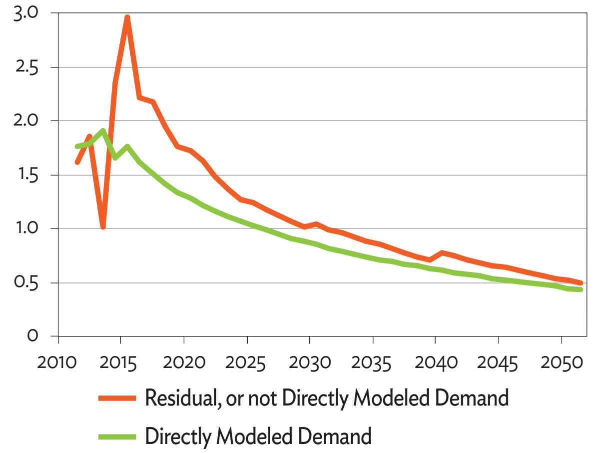
5.2.1 Electricity Demand

In the reference scenario, the elasticity of growth of electricity demand to GDP in those sectors that are explicitly modeled already falls from 1.9 to 0.65 by 2050. In the low-carbon scenario, additional levers that reduce the demand for electricity are included. Accordingly, the elasticity is further brought down to 0.45 by 2050 for those sectors that are explicitly modeled, and 0.52 for the residual un-modeled sectors, which are likely to take longer to achieve the same specific energy savings (see Figure 17).

The underlying assumption is that policies will be enacted and investments will be made to achieve energy-efficiency improvements covering electricity demand in small and medium-sized enterprises (SMEs), but that these will take longer to impact electricity consumption. Many of the needed measures will be similar to those discussed in this report: appliance standards for the commercial-use equivalents of household appliances plus transformers, electric motors, fans, and a careful appraisal of building standards from this energy-efficiency perspective. Since the residual not-directly-modeled electricity demand includes parallel economy and other demand, much of which is highly fragmented, often cash-strapped, and often not easily subject to credit, this slower improvement is to be expected.

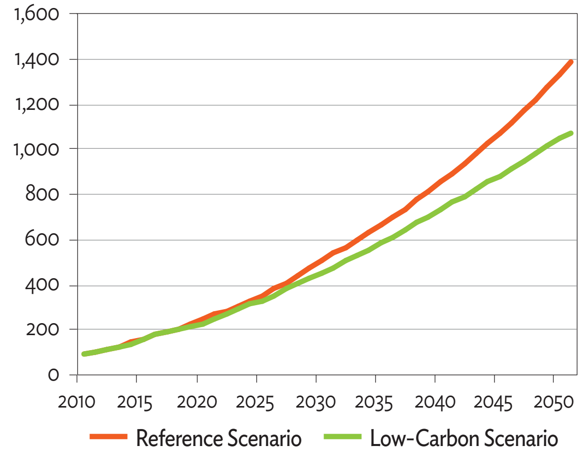
Greater energy efficiency results in a lower end-user demand for electricity and a lower requirement for generation to feed the grid. The assumptions for imports, captive, and transmission and distribution technical losses are the same as in the reference scenario. Figure 18 shows that by 2050 the annual generation needs drop from 1,400 TWh to under 1,100 TWh.

Figure 17: Elasticity of Electricity Demand to GDP Growth for the Low-Carbon Scenario



GDP = gross domestic product.
Source: Authors.

Figure 18: Generation in the Reference and Low-Carbon Scenarios (TWh)



TWh = terawatt-hour.
Source: Authors.

5.2.2 Installed Capacity

A lower level of electricity demand means that less electricity generation capacity is needed. In addition, Viet Nam has potential for developing power generation capacity that is more diversified than under the reference scenario.

5.2.2.1 Potential for Power Development

Viet Nam has substantial potential for renewable energy deployment, which defines the limits of renewable capacity additions. Solar, wind, and biomass have particularly high potential capacity, as is outlined below.

Solar potential: Solar energy is available all year round, is rather stable, and distributed widely over different eco-geographic areas. In the southern and central regions of Viet Nam, solar energy can be used on average 300 days per year, making it a nation with high solar potential (Polo et al. 2015). Solar energy intensity on the average is 5 kilowatt-hours per square meter per day (kWh/m^2/day). It is lower in the north at about 4 kWh/m^2/day because of the annual winter–spring cloudy sky and drizzle. Average sunshine at 150 kilocalorie per square meter (kcal/m^2) in Viet Nam is between 2,000–3,000 hours, which leads to a theoretical potential of 43.9 billion ton of oil equivalent (To Quoc Tru 2010 and Trinh Quang Dung 2010). When land usage is taken into account, the practically achievable potential is reduced to 8 TWh per year of electricity.[17]

Wind potential: In 2010, the Ministry of Industry and Trade (MOIT), with support from the World Bank, created a new wind resource atlas of Viet Nam (Nguyen 2014). The atlas shows promising areas for wind development along the southern and south–central coast and in mountain gaps in central Viet Nam with mean wind speed at 80 meters (m) height of 6.5 meters per second (m/s) to 7.0 m/s along the exposed coastal areas of south–central Viet Nam, and 6.0 m/s to 6.5 m/s in the broad mountain gap west of Binh Dinh along the Dac Lac and Gia Lai provincial border. The study identified an estimate of the wind resource technical potential of 26,800 MW.

Biomass potential: Viet Nam's large agricultural production gives it good potential for biomass energy (Zafar 2015). Agricultural wastes are most abundant in the Mekong Delta region, which covers approximately 50% of the amount of the whole country, and the Red River Delta with 15%. Major biomass resources include rice husk from paddy milling stations, bagasse from sugar factories, coffee husk from coffee processing plants in the Central Highlands, and wood chip from wood processing industries. The annual biomass resources of Viet Nam in the base year (2010) are understood to be as follows: (i) rice husk: 8 million tons (at moisture content of 14%); (ii) rice straw: 32 million tons (at moisture content of 22%); (iii) bagasse: 6 million tons (at moisture content of 49%); (iv) and others (coffee husk, corn residues, coconut, peanut, cassava, wood wastes, fuelwood, etc.): 40 million tons.[18] These resources adequately cover the generating needs of the low-carbon scenario to 2040. But the scope of this study does not allow a detailed evaluation of biomass availability for power generation in future years. Although agricultural production is expected to grow and biomass can be harvested specifically for power generation, power from biomass in future years particularly beyond 2040 could be considered a surrogate for other base-load-ready, low-carbon-emitting, energy-generating sources, such as geothermal, tidal and wave power, clean coal or gas with carbon capture and storage.[19]

Geothermal potential: Conventional geothermal energy is estimated (Kirby n. d.) to have a potential generation capacity of 1,400 MW—more than 300 hot streams are already recorded with temperatures from 30°C to 150°C (Agentschap 2011).

17 Author's calculations.

18 From a consultant's report submitted under the TA by Nguyen Duc Cuong, Institute of Energy, Ministry of Industry and Trade.

19 The reference and low-carbon scenarios currently contain the same nuclear-generating capacity.

Enhanced (hot dry rock) systems also have high potential, with a temperature of approximately 100°C available at a depth of around 2 kilometers (km) throughout most of Viet Nam (VietnamNet n.d.).

Wave and tidal power potential: The East Sea offers excellent potential to harness energy through tidal and wave power (VietnamNet 2010) of at least 100 MW per year. This technology is not yet mature but may be an important element to the energy mix in a couple of decades.

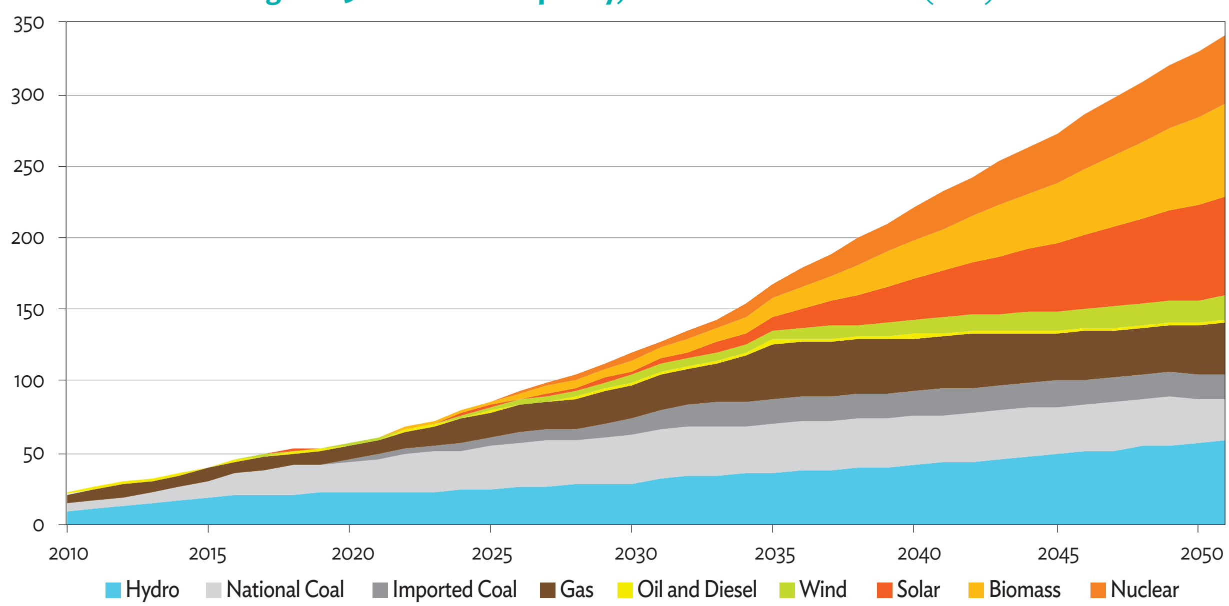
Carbon capture and storage potential: The application of clean coal or gas with carbon capture and storage could be another means of providing low-carbon base load, but this has not been included in this study because it is not yet considered mature enough for costs to be well understood under wide deployment. However, this may change in future years.

5.2.3 Capacity Development

The reference case includes the addition of 2,400 MW of nuclear capacity per year contained in this plan (in agreement with Institute of Energy study team), which without further investment represents 29% of generation in 2050 in the low-carbon scenario. To preserve diversity in the generation mix, no further nuclear capacity was added in the low-carbon scenario, but biomass-based generation was increased to a similar proportion (from 10% of generation in the reference case to 28% in the low-carbon scenario).

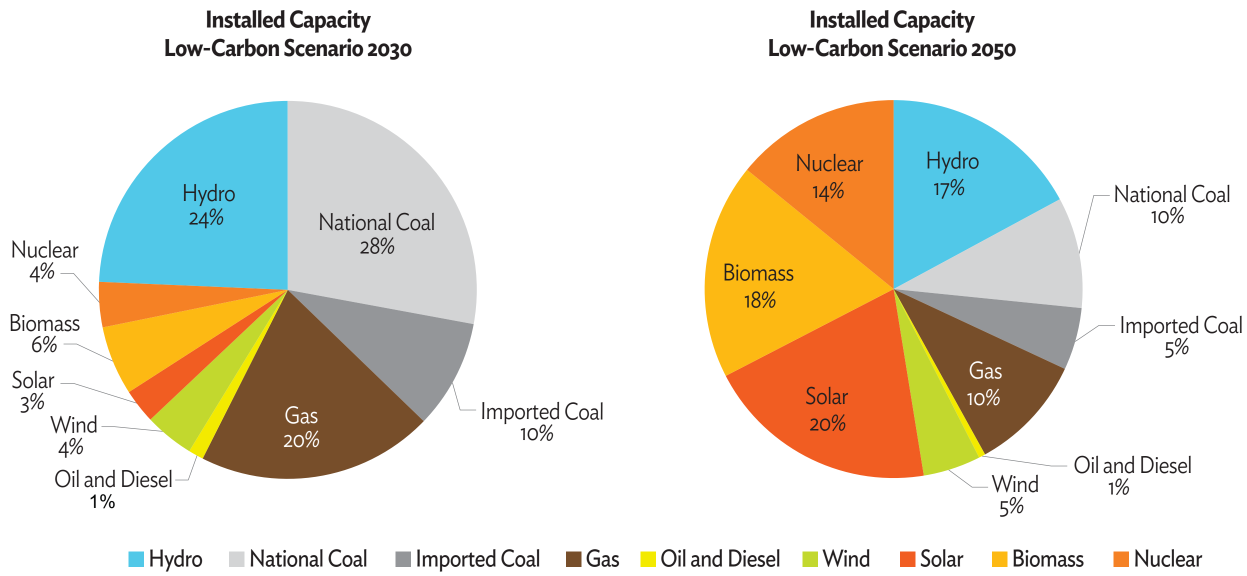
The low-carbon scenario replaces imported coal with a diverse array of energy sources (Figure 19 and Figure 20). By 2050, the low-carbon scenario has an additional 5 GW of hydro (57 GW compared with 52 in the reference scenario);

Figure 19: Installed Capacity, Low-Carbon Scenario (GW)



GW = gigawatt.
Source: Authors.

Figure 20: Installed Capacity Mix in 2030 and 2050, Low-Carbon Scenario



Source: Authors.

66 GW of solar compared with 12 GW in the reference scenario; 16 GW of wind (compared with 4 GW); and 61 GW of biomass against 29 GW in the reference scenario. Nuclear remains unchanged (46.6 GW), oil and diesel is reduced from 8 GW to 2 GW; and gas increases from 28 GW to 33 GW. National coal is reduced slightly from 36 GW to 31 GW, while imported coal is reduced significantly from 121 GW in the reference case to 18 GW in the low-carbon scenario.

In 2030, the installed capacity of hydro is the same in both the reference and low-carbon scenarios. Large hydro (storage and run of river) accounts for 20 GW, mini and micro hydro 4 GW, and pumped storage 5 GW. By 2050, large hydro expands to 25 GW in the reference case and 26 GW in the low-carbon case. Mini and micro hydro drop to less than half their 2030 effective installed capacity (1.5 GW), while pumped storage increases to an installed capacity of 25 GW in the reference case and 29 GW in the low-carbon case. Pumped storage does not contribute generating capacity to the grid but does reduce the high cost and amount of LNG-based gas needed for peak demand and load balancing of renewables. This increase in pumped storage capacity from 2030 onward can be seen as a placeholder for other electricity storage options that are expected to be cost-effective by then, such as distributed batteries, which are likely in the future to play a big role in managing renewables through a smart grid.

5.2.3.1 Generation in the Low-Carbon Scenario

The low-carbon scenario has several principal differences from the reference scenario. First, imported coal peaks by the mid-2030s, after which it is phased out, rather than become the lead energy source as in the reference scenario (Figures 21 and 22). In its place, biomass, solar, and hydropower are ramped up to make major contributions to generation. National coal is unaffected, whereas natural gas is reduced.

Solar photovoltaic: Very little additional photovoltaic (PV) capacity is constructed before 2030. In the reference case, generation is 2.3 TWh, which increases in the low-carbon scenario to 5.1 TWh. After 2030, more PV is brought on line as its internal rate of return increases and it becomes more cost-effective than coal. By 2050, the low-carbon scenario includes 113 TWh compared with 20.7 TWh in the reference scenario, equating to 10.8% of generation.

Wind: In 2030, the generation from wind is slightly higher than the reference scenario (13 TWh instead of 10.9 TWh). By 2050, the low-carbon scenario includes 35 TWh (3% of generation) compared with 9 TWh in the reference scenario.

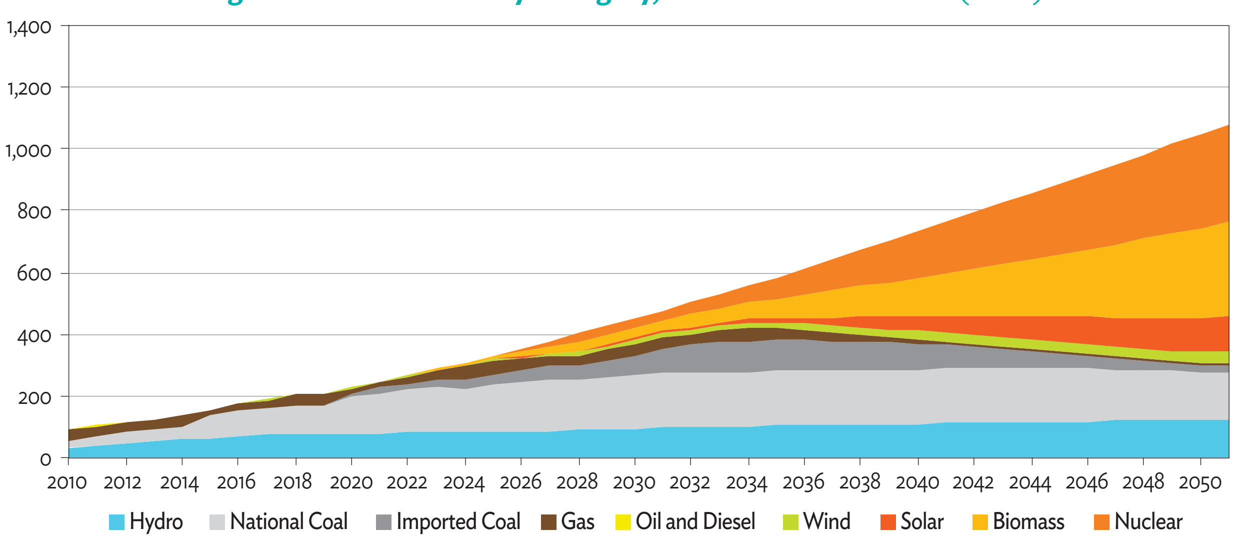
The rationale for building more solar than wind is illustrated by the load-duration curve, which according to the Institute of Energy in 2010 had an area of 64.4%. In the reference case, due to the energy-efficiency measures incorporated, this can be expected to improve to around 74% by 2050, despite the radically increased use of air conditioning. Even in 2050, this demand curve represents 20% of the load being applied during less than 5% of the time. In the low-carbon scenario, due principally to the measures to reduce the energy consumed by air conditioning, the load-duration curve improves further to 75.4% by 2050. For this peak load, solar PV has a distinct advantage and although the low-carbon scenario includes sufficient low latency generating capacity (based on gas) to meet peaking demands and to stand in for the nondispatchable power sources of wind and solar, its use is not expected to likely be less than 15% and may be as low as 7%–9%. However, this cannot be determined within the present study because the detailed spatial and time-dependent information needed for such analysis is lacking. Figure 20 (right panel) illustrates how, in the low-carbon scenario, the installed capacity of wind and solar combined reach 25% of the total installed capacity by 2050.

An additional situation driven by the load-duration curve is that the EFFECT model dispatches based on a load-duration curve that is defined in 20 time intervals. With over 20% of generation occurring in one interval, the fuel-use mix in this last interval may present variations—a 1% time variance could assign 8% more coal or oil where, in practice, gas would be expected.

Biomass: Prior to 2030, some biomass-fueled thermal power plants are built in the low-carbon scenario instead of imported coal. By 2030, 33.4 TWh of biomass is generated instead of 8.7 TWh in the reference scenario. By 2050, the low-carbon scenario includes 288 TWh biomass compared with 137 TWh in the reference scenario.

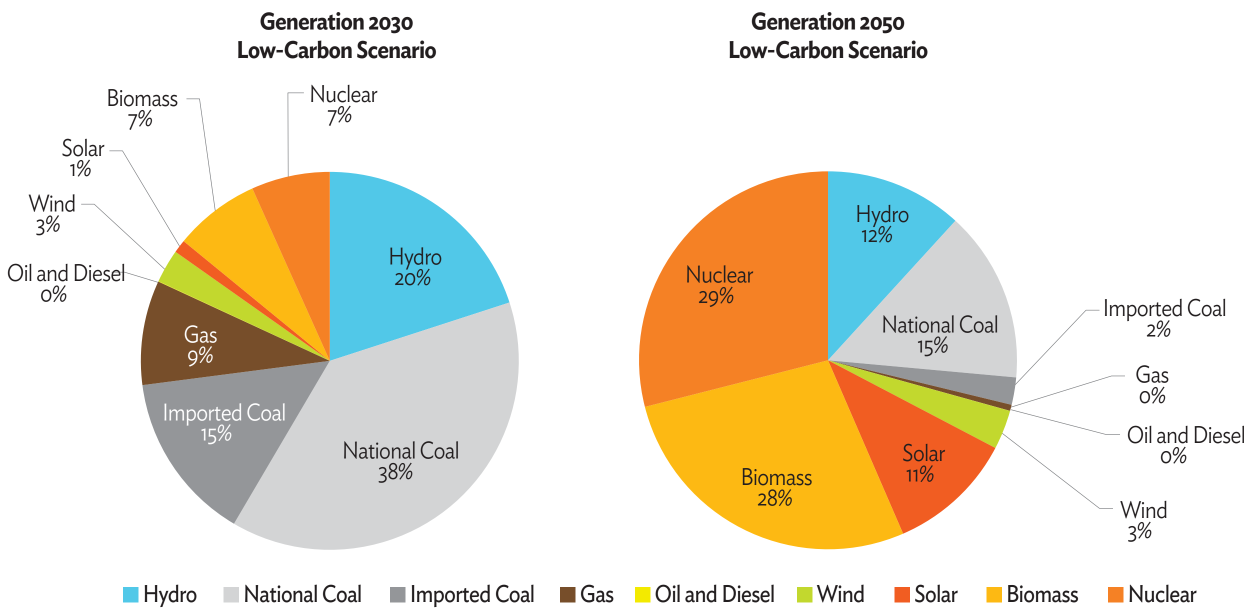
National coal: In 2030, slightly more generation comes from national coal in the low-carbon scenario (175 TWh versus 163 TWh in the reference case). By 2050, the low-carbon scenario has significantly less generation from national coal (153 TWh versus 209 TWh in the reference scenario).

Figure 21: Generation by Category, Low-Carbon Scenario (TWh)



TWh = terawatt-hour.
Source: Authors.

Figure 22: Generation Mix in 2030 and 2050, Low-Carbon Scenario



Source: Authors.

Imported coal: Starting prior to 2030, a reduction in generation from imported coal is included in the low-carbon scenario. In 2030, the reference scenario includes 171 TWh from imported coal, while the low-carbon scenario has only 66 TWh. By 2050, the difference is 523 TWh in the reference scenario and 24 TWh in the low-carbon scenario. In the low-carbon scenario, imported coal can be seen as a stopgap fuel, phasing in around 2018 and phasing out around mid-century as other renewable fuel options become relatively cheaper. This implies a high risk of imported coal plants becoming stranded assets and should open a discussion about the merits of avoiding the use of imported coal by accelerating the renewable fuel programs.

Nuclear: Nearly no change is reflected in the low-carbon scenario from the reference scenario. In 2030, 31 TWh is in both scenarios and, in 2050, 309 TWh is in the reference and 303 TWh in the low-carbon scenarios.

Gas: The model gives 27 TWh in the reference scenario in 2030 versus 41 TWh in the low-carbon scenario. By 2050, it shows 4–5 TWh in both scenarios although this is likely to be understated (and a different fuel overstated for the reasons given above). The installed capacity in gas in both scenarios was defined to cover peaking needs. In the low-carbon scenario, higher intermittency of added solar generation increased the installed capacity, although this does not necessarily show in the generation numbers because of the modeling granularity situation that was earlier discussed.

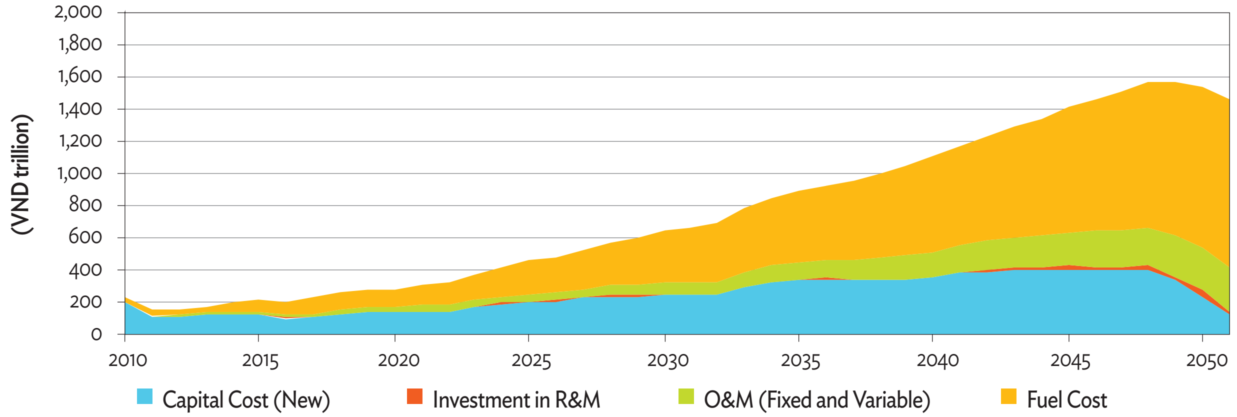
Oil and diesel: These energy sources are not significant in either scenario for on-grid electricity production.

Hydro: In 2030, generation from hydro is the same as in the reference scenario at 90.8 TWh. By 2050, additional large hydro (storage and run of river) increases generation from 117 TWh in the reference scenario to 123 TWh in the low-carbon scenario, despite reduced generation from mini/micro hydro in both scenarios from 4 TWh in 2030 to 1.5 TWh in 2050 because of competing usage of water. Pumped storage—which does not contribute additional generation—increases from 4 TWh in both scenarios in 2030 to 18 TWh for the reference scenario and 21 TWh for the low-carbon scenario by 2050.

5.2.4 Cash Flow

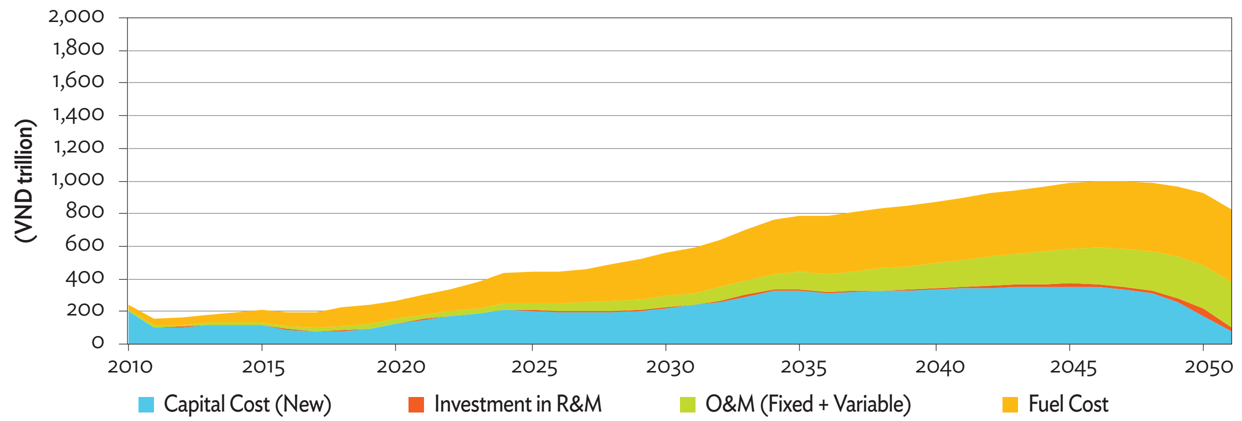
The change in generation mix also has a positive effect on the sector's cash flow. Taking into account capital expenditure, investment in repair and mid-life extension, fixed and variable operation and maintenance expenses, and fuel cost, Figure 23 shows the overall cash flow of the reference scenario, and Figure 24 shows that for the low-carbon scenario. Helped by the reduction in generation as a result of end-user efficiency measures and the difference in fuel expenditures, the low-carbon scenario requires a significantly lower cash flow outlay than the reference scenario.

Figure 23: Cash Flow Expenditure in the Reference Scenario



O&M = operation and maintenance, R&M = repair and midlife extension, VND = Viet Nam Dong.
Source: Authors.

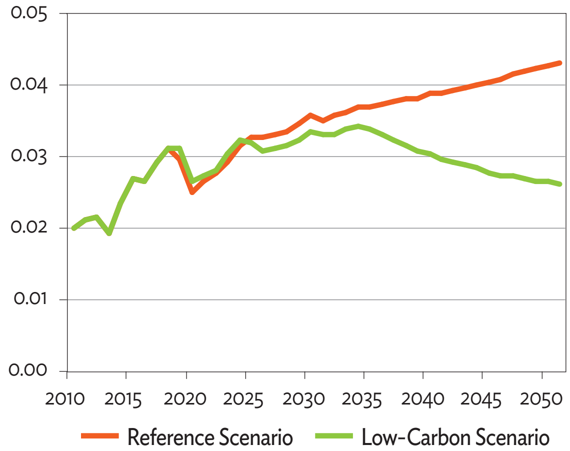
Figure 24: Cash Flow Expenditure in the Low-Carbon Scenario



O&M = operation and maintenance, R&M = repair and midlife extension, VND = Viet Nam Dong.
Source: Authors.

In the low-carbon scenario, the variable cost of generation (operation, maintenance, and fuel) stabilizes in 2050 at around $0.03 per kWh, while in the reference scenario it continues increasing to almost $0.05 per kWh (see Figure 25).

Figure 25: Variable Cost of Generation in Both Scenarios
($/KWh)



kWh = kilowatt-hour.
Source: Authors.

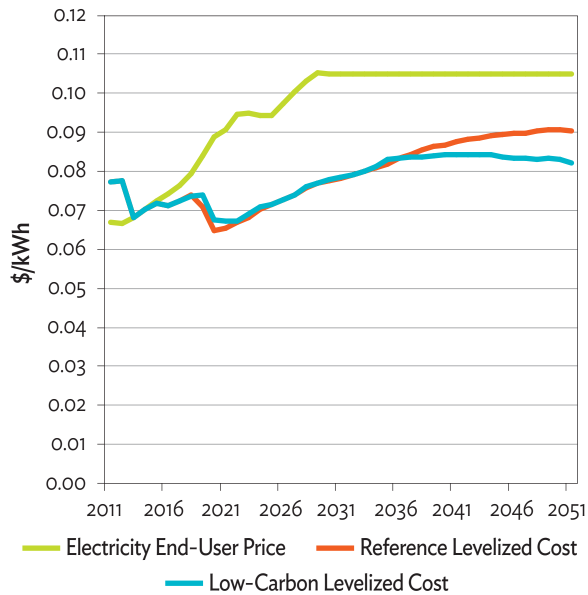
5.2.5 Cost of Electricity

The total levelized fixed cost of each new generating plant (capital expenditure [CAPEX], including equipment, installation management, insurance, and spares but without site accommodation and land) was calculated under both scenarios using an average real discount rate of 10%.

The variable cost of operation of each new generating plant (operating expense [OPEX], including fuel, and operation and maintenance expenses) was also determined under both scenarios and added to the above. In both scenarios, it is assumed that this 2030 price will remain unchanged until 2050 in real terms. Figure 26 shows how both CAPEX and OPEX vary over the modeling period when compared with the average end-user electricity price that is given in PDP-VII-interim-revision to 2030.

Although the low-carbon scenario has a higher levelized cost of investment, the reduction in variable expenses (including fuel) more than compensates, putting less pressure on the price of electricity than under the reference scenario.

Figure 26: Electricity Levelized Cost (Capital Expense, Operating Expense, and Fuel) **and Price for the Reference and Low-Carbon Scenarios**



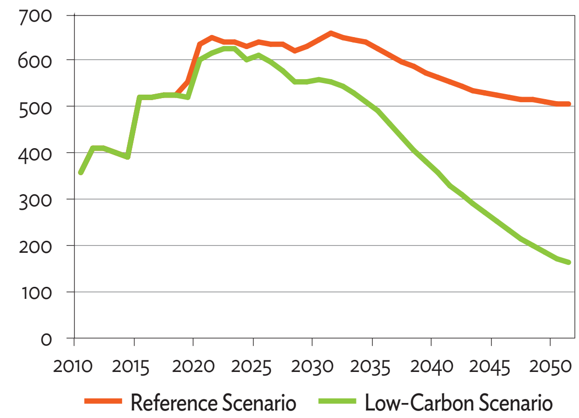
kWh = kilowatt-hour.
Source: Authors.

5.2.6 Mitigation Achieved

The emissions impact of these changes is substantial. In the reference scenario, the percentage of generation from low-carbon sources (hydro, wind, solar, biomass, nuclear) stabilizes at around 44% in 2050; in the low-carbon scenario, it reaches 83% with a significant reduction in the carbon intensity of generation.

In the reference scenario, the carbon intensity of grid electricity (grams of carbon dioxide equivalent per kilowatt-hour [gCO_2e/kWh]), which in 2010 was 358 g/kWh, peaks in 2021 at 649 g/kWh, and drops by 2050 to 505 g/kWh. In the low-carbon scenario, from a peak in 2022 of 626 g/kWh, it drops to 172 g/kWh by 2050, around one-third that of the reference scenario (Figure 27).

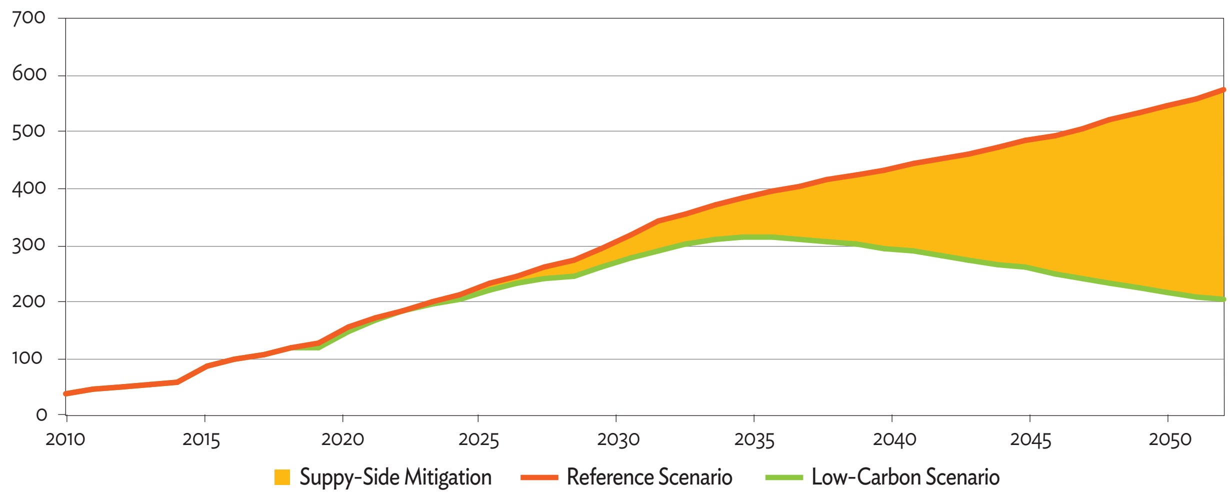
Figure 27: Carbon Dioxide Equivalent Emissions Intensity of Both Scenarios (g/kWh)



g/kWh = grams per kilowatt-hour.
Source: Authors.

The replacement of fossil fuel power with low- carbon sources has substantial abatement potential. While the reference case emissions rise rapidly and continuously, the low-carbon scenario peaks power emissions in 2035, after which they fall. By 2050, reference-case emissions are cut by nearly 65% in the low-carbon scenario (Figure 28).

Figure 28: Reduction of Emissions from Electricity Generation (Supply-Side Measures Only) **in the Low-Carbon Scenario** ($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

6. ANALYSIS AND RESULTS OF SUSTAINABLE TRANSPORTATION

6.1 The Reference Scenario

The reference scenario is based on Transport Strategy 2020, as well as recent master plans (see Annex A for more details), and vehicle usage and ownership trends driven by economic growth. Vehicle fuel prices have been adjusted to eliminate subsidies and are identical in both the reference and low-carbon scenarios. The prices to 2030 are as per the power sector reference scenario, and are projected from 2031 to 2050 with a price increase proportional to oil-based fuels.

6.1.2 On-Road Transportation

In Viet Nam as in most other developing countries, the transport sector is a rapidly growing source of greenhouse gas (GHG) emissions. Much of this is due to increasing transport demand. Freight increased by over 12% per year between 1995 and 2006 in terms of ton-kilometers (ton-km) transported. Passenger traffic grew by slightly less than 10% per year during the same period. Over the study period (2010 to 2050), both will grow at a lower average rate with an annual growth rate for freight of 6.6% and for passengers of 3.8%—but over 40 years, these "low" growth rates give large absolute values that will require extensive investments just to keep pace.

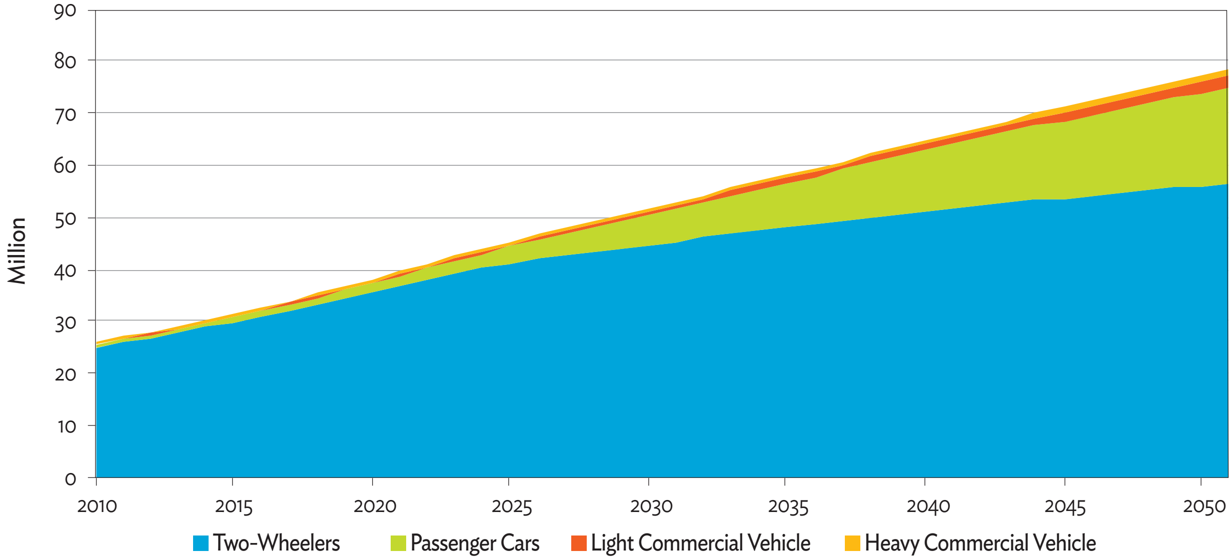
Road traffic concentrates mainly on national roads and around the major urban centers. Even though vehicle ownership is rising very quickly, car ownership is still low and motorcycles still dominate road traffic. Viet Nam had approximately 1 million vehicles (with 4 or more wheels) and 25 million motorcycles in 2010. By 2050, economic growth can lead to an in-use population of almost 23 million vehicles (with 4 or more wheels) plus 56 million two-wheelers. Private car ownership can be expected to grow from 500,000 in 2010 to 17.8 million in 2050.

The number of on-road vehicles over 2010–2050, as shown in Figure 29, grows from 26 million in 2010 to over 77 million in 2050. Passenger cars exhibit the highest growth because of rising income and a substitution effect of cars for two-wheelers once incomes surpass threshold levels. Light commercial vehicles and heavy commercial vehicles also show significant growth. Over the modeling period, the number of light commercial vehicles grows 10 times to 2.1 million vehicles, while heavy commercial vehicles grow by a factor of two and a half to 1.2 million trucks and buses.

Light commercial vehicles are generally used in pickup and delivery and for short-haul types of operation, whether for passengers, freight, or mixed use. Some of the heavy commercial vehicle segment, such as trucks from the 7 ton to 12 ton gross vehicle weight range, have a similar usage style but this class also includes longer-haul vehicles (rigid trucks and articulated units—tractor-trailer combinations—plus long-distance buses and coaches). Over the modeling period, their load factors and efficiency of operations are expected to increase, resulting in higher annual usage. Figure 30 shows the expected increase in annual average kilometers (km) for the heavy commercial vehicle segment while the other segments remain more or less stable. Long-distance on-road transportation has to increase its annual mileage for its freight costs to be competitive; and this is the driving reason behind the lower population growth for this class of vehicles.

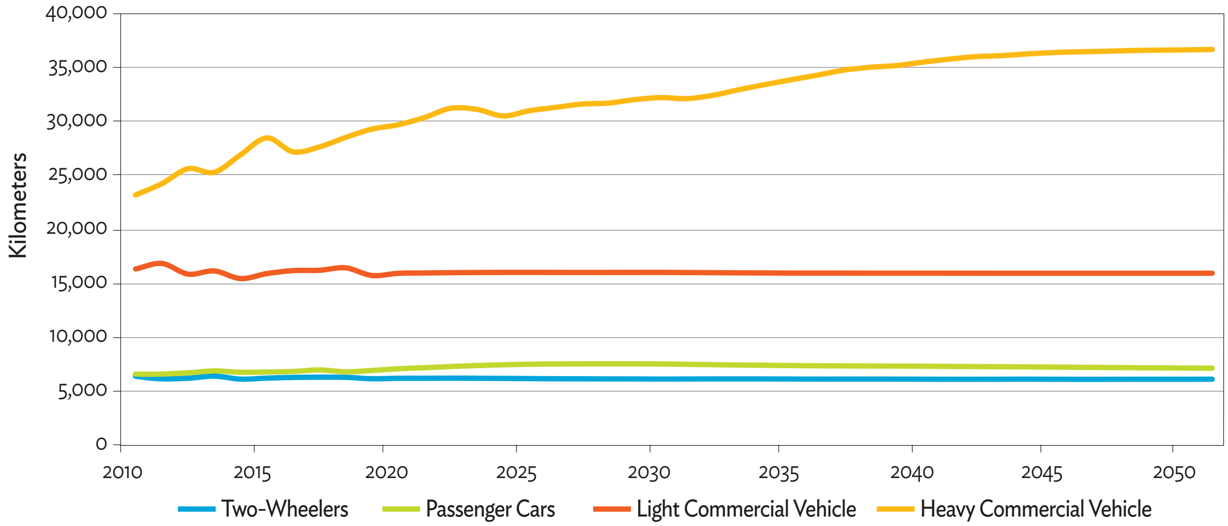
This results in a total on-road vehicle-kilometers-traveled that increases over three times from

Figure 29: Projected Number of Vehicles, Reference Scenario



Source: Authors.

Figure 30: Average Annual Kilometers per Vehicle

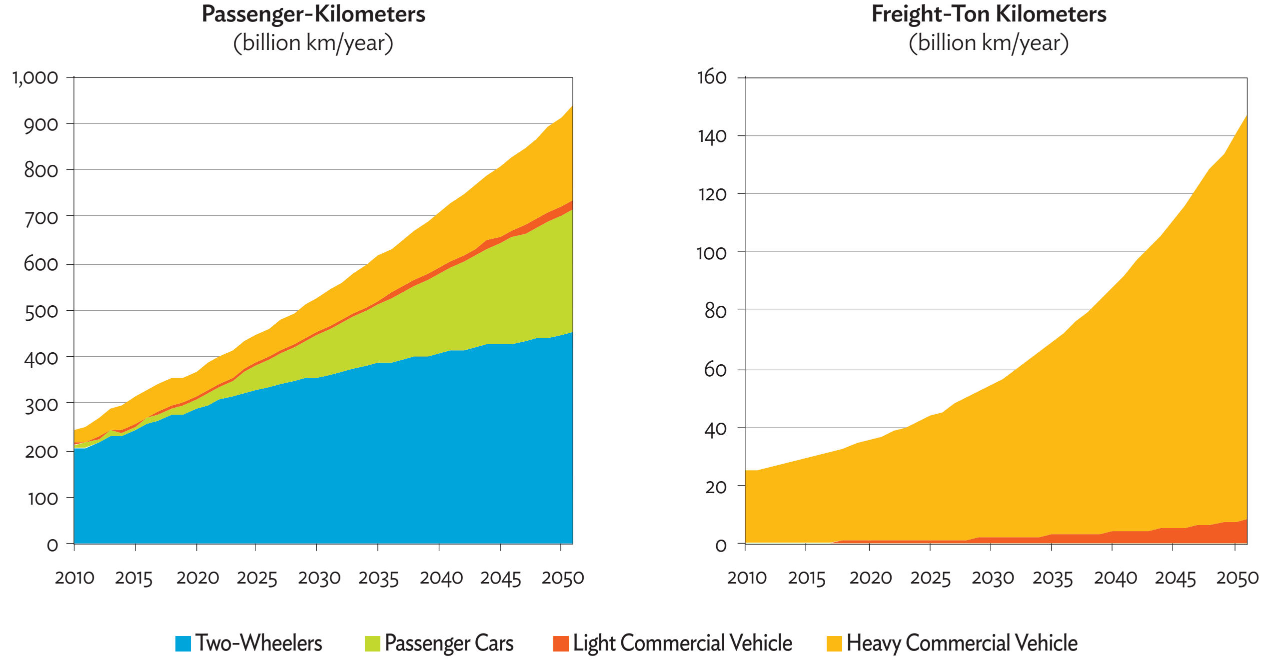


Source: Authors.

176 billion to 548 billion vehicle-kilometers per year between 2010 and 2050. More than half of this travel is by two-wheelers in predominantly urban environments.

Figure 31 shows the passenger- and freight-tons transported. While growth of transportation demand is needed, it is virtually impossible to expand infrastructure at an even faster rate such that congestion diminishes. The solution has to embrace other policies that avoid the need to travel and shift travel to more sustainable modes to protect economic growth, the urban environment, and quality of life.

Figure 31: Passenger-Kilometers and Freight-Ton-Kilometers Traveled by On-Road Vehicle Class



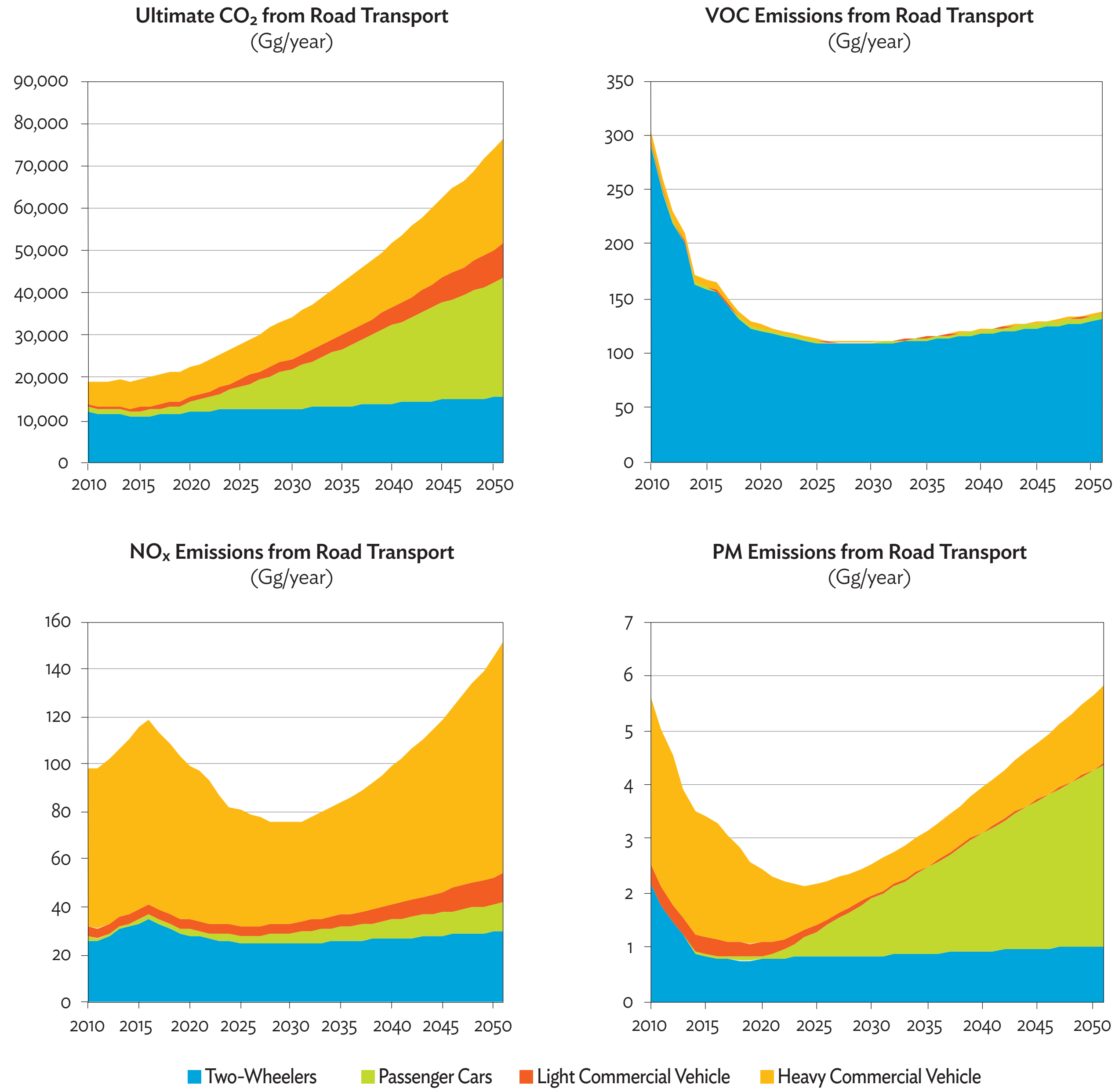
km = kilometer.
Source: Authors.

The reference scenario assumes that new vehicles for sale will meet the EURO 4 emissions standard in 2017 and EURO 5 in 2022.[20] This technology improvement provides a welcome reduction in exhaust pollution emissions. Figure 32 shows the carbon dioxide (CO_2) and local pollutant emissions from these vehicles. Particulate matter (PM) emissions particularly in urban streets have the highest health cost. The epidemiological evidence of the effects of particulates shows good correlation between PM_{10} concentrations and mortality or morbidity (EPAQS 1995, 2001). Although the EURO 4 and 5 standards are sufficient to offset the increase in the in-use vehicle population over the short term, emissions levels start to increase over time as increasing vehicle usage overcomes the technological gains. Nitrogen oxide (NO_x), together with volatile organic compounds (VOC), is an aggressive precursor of ozone, and unless other control actions are taken toward the end of the modeling period, ozone could become a critical pollutant in the major urban environments.

Figure 33 shows the resultant consumption of gasoline and diesel in on-road, rail, and waterborne transport. For on-road transportation, the consumption of diesel in the reference scenario is always less than the consumption of gasoline, but including the other two subsectors results in diesel consumption being higher from 2018 onward.

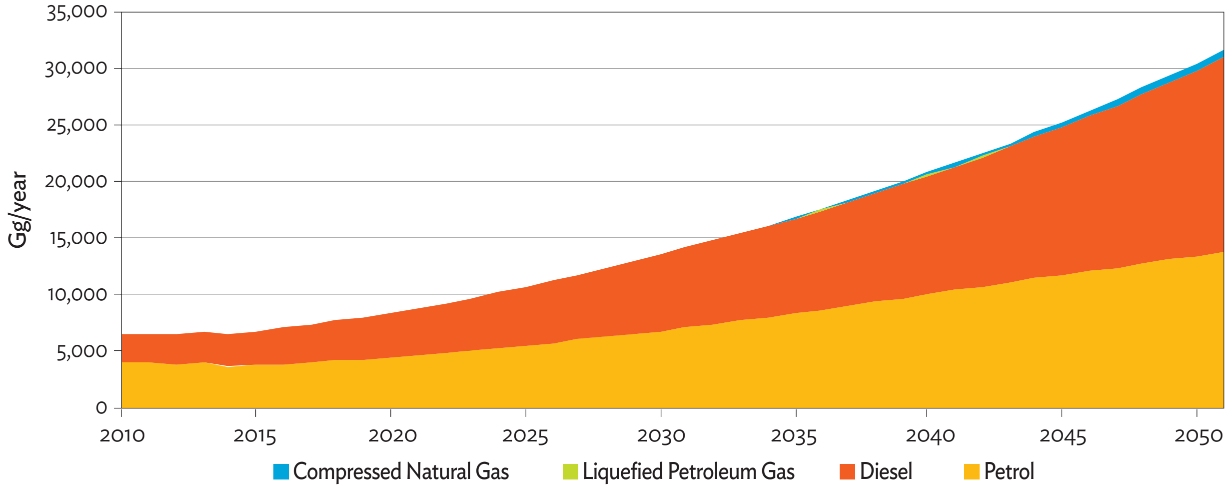
20 Two-wheelers met EURO 3 in 2011 and it is expected that 40% of two-wheeler sales by 2050 will be electric; the mini car subsegment is expected to meet EURO 4 standards in 2016.

Figure 32: Carbon Dioxide, Hydrocarbon, Nitrogen Oxide, and Particulate Matter Emissions from On-Road Transportation



CO_2 = carbon dioxide, Gg = gigagram, NO_x = nitrogen oxide, PM = particulate matter, VOC = volatile organic compound.
Source: Authors.

Figure 33: Fuel Consumption of On-Road Transportation



Gg = gigagram.
Source: Authors.

6.1.2 Rail and Waterborne Transportation

6.1.2.1 Inland and Coastal Shipping

Viet Nam has an extensive network of more than 41,900 kilometers (km) of inland waterways, which includes 3,260 km of coastline that permits waterborne transport to reach most cities, towns, neighborhoods, and the central economic region.[21] Managed by the central agencies, provinces or cities, and district governments, this system has played an important role in the country's transport sector, especially for freight.

State-owned companies provide significant inland waterway transport services in the north, while private operators predominate in the south. Inland water services have increased and growing private sector investment has made them more efficient. But weak waterway management; poor data on the condition of existing waterways and facilities; inadequate maintenance dredging and navigational support to allow safe operation of efficient, larger vessels; and poor port facilities and services constrain further development of these waterways.

Gasoline and diesel are used primarily to fuel inland waterways (plus fuel oil for coastal shipping). But fuel use efficiency is generally low mainly because of poor infrastructure conditions (notably, narrow passages) and weak maintenance (inadequate dredging of riverbeds), which slow the average speed of vessels and limit their size in many of the smaller channels. In the south, inland waterway vessels are typically small, usually less than 100 tons, increasing the consumption of fuel per ton of freight carried to values that are higher than on-road transport.

Growth has been hindered by policies that have not focused on creating the conditions for developing multimodal transport (road to water), which complicates the business-to-business freight connection. Waterway transport costs are almost half those of on-road transport costs, and the system has not been able to break away from its traditional market of transporting principally low-value bulk shipments such as sand.[22]

21 Viet Nam Inland Waterways Administration. http://en.viwa.gov.vn/.

22 Water transport from Ha Noi to Viet Nam Tri costs D145,000/ton, and the road is D260,000/ton according to Deputy Minister of Transport Truong Tan Vien's presentation on 15 October 2014.

An Origin-Destination survey in 2008 conducted by JICA (2009) shows the modal share mix for freight by road and inland waterway in Table 13 and the volume of freight transported by coastal shipping in Table 14. Once short haul (mainly urban and peri-urban) freight is included, the mode share of inland waterways drops to around 38%. For coastal shipping, the survey reported a typical round-trip distance of 1,700 nautical miles (3,150 km).

Table 14: Freight Transported by Coastal Shipping in 2008

	Tons of Freight per Day (diagonal and intraregional flows omitted)		
	North	South	Total
North		11,694	11,694
South	10,515		10,515
Total	10,515	11,694	22,208

Source: Japan International Cooperation Agency. 2009. The Comprehensive Study on the Sustainable Development of Transport System in Viet Nam (VITRANSS-2). Ha Noi.

6.1.2.2 Rail

As of 2015, the rail network covers seven major routes connecting 35 cities mainly with a 1-meter standard gauge single track. The main trains ply the Ho Chi Minh City–Ha Noi route at an average speed of 50 to 60 km per hour, while the interprovincial trains have average speeds of only 30 to 40 km per hour. These low average speeds result in low fuel efficiency.

In 2010, the railway system had 1,043 passenger wagons (8 were for the wider 1,435-millimeter gauge track) operating a total of 72 million wagon-km over the year, transporting 4.4 billion passenger-km. For freight, the system occupied 4,860 wagons in 2010 (with 352 of the 1,435-millimeter gauge) to transport 3.9 billion freight-ton-km.

6.1.2.3 Results for All Modes

As Figure 34 shows, on-road transportation serves the vast majority of passenger trips, accounting for 97% of passenger-kilometer traveled (PKT) in 2010, with the remaining 3% split pretty evenly between water and rail. By 2050, waterborne passenger transport is expected to increase from 1.2% to 2% and rail from 1.7% to 13.5%. This diminishes the modal share of on-road to 84%, and giving a growth in PKT by waterborne from 3 billion in 2010 to 22 billion PKT by 2050. For rail, the expected growth in the reference scenario is from 4 billion to 136 billion PKT while on-road expands from 246 billion to 914 billion PKT.

For freight, the pattern is different. The modal share of inland waterways remains constant at 27% and coastal at 20%. On rail, the modal share doubles from 7% in 2010 to 15% in 2050 and the freight modal share of on-road decreases from 46% to 38%.

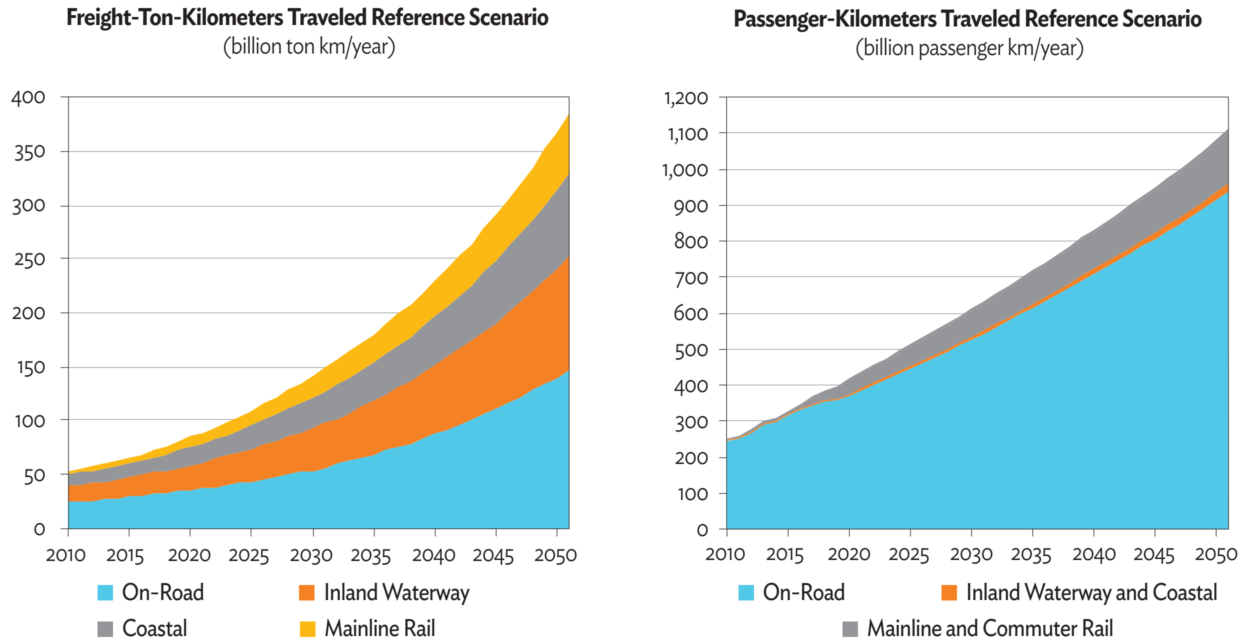
This gives a growth in freight-ton-km-transported (FTKT) by coastal shipping from 11 billion FTKT in 2010 to 73 billion FTKT in 2050. Inland waterways expand from 15 billion FTKT in 2010 to 101 billion FTKT in 2050. For rail, the expected growth in the reference scenario is from 4 billion to 53 billion FTKT while on-road expands from 25 billion to 140 billion FTKT.

Table 13: Mode Share Mix for Freight by Road and Inland Waterway in 2008

	Tons of Freight per Day			Average Single Trip Distance (km)	
	Road	IWT	Share IWT	Road	IWT
All routes/corridors in the North	256,203	374,616	59%	64	134
All routes/corridors in the South	205,661	260,663	56%	96	115

IWT = inland waterway transport, km = kilometer.
Source: Japan International Cooperation Agency. 2009. The Comprehensive Study on the Sustainable Development of Transport System in Viet Nam (VITRANSS-2). Ha Noi.

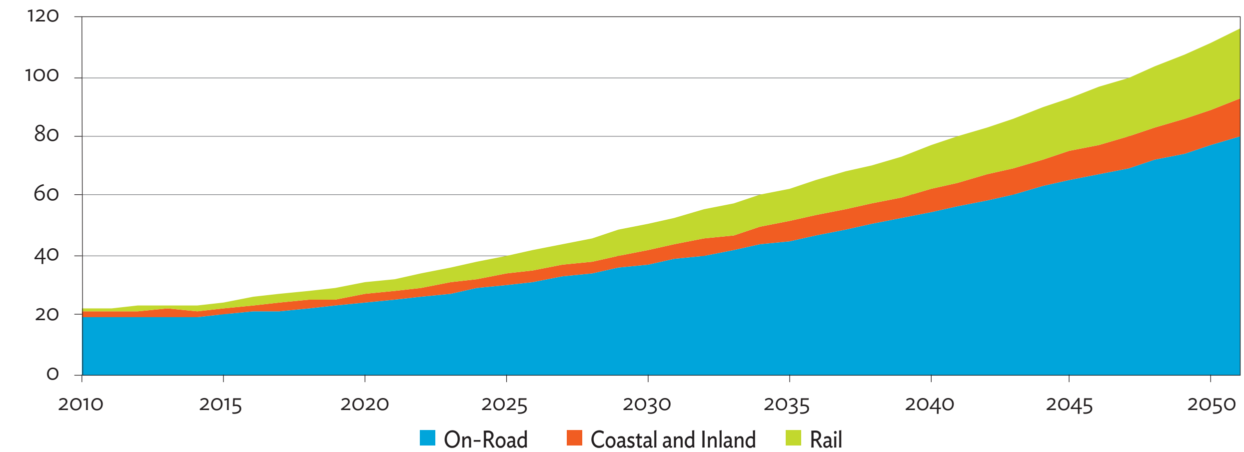
Figure 34: Transport Mode Share of Road, Rail, Coastal, and Inland Waterways



km = kilometer.
Source: Authors.

Figure 35 shows the total carbon dioxide equivalent (CO_2e) emissions from these modes of transport in the reference scenario. In 2010, on-road transportation accounts for 85% of the sectors' CO_2e emissions[23] and, by 2050, its share can be expected to drop to 69% on account of the efficiency measures in the reference scenario—which includes updating vehicle technology to EURO 5 and 40% of two-wheeler sales being electric from 2030 onward.

Figure 35: Reference Scenario Emissions by Mode
($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

[23] National and regional air is not included in this total.

6.2 The Low-Carbon Development Scenario and Mitigation Opportunities

While the increase in mobility and in the use of private transport is advantageous on a personal/family level, it does create several problems for society, which include the following:

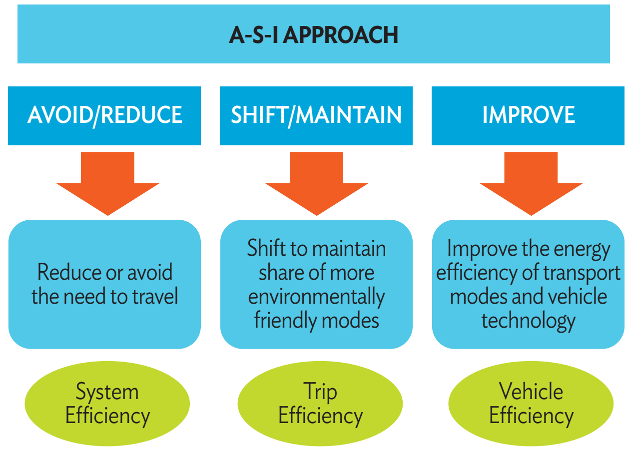
- **Congestion:** The rapid growth of vehicle ownership and usage in urban than in rural areas leads to greater traffic jams and a significant reduction in average vehicle speed, which further increases fuel consumption and emissions.

- **Energy consumption and greenhouse gas emissions:** Greenhouse gas (GHG) emissions will rise in proportion to fuel use and transport emissions are likely to exhibit an ever-increasing share of the total national emissions profile. The expanding use of imported fuel may also have energy security and balance-of-trade implications.

- **Air pollution and health:** Air pollution and its effects on health are growing concerns in many metropolitan areas. In many developing countries, it is estimated that the transport sector contributes more than half toward ambient air pollution, followed by industry and the household sectors. Of the different contaminants, suspended particulate matter is associated with the highest health cost. In Viet Nam, diesel consumption over the modeling period grows faster than gasoline consumption, and diesel engines are the main source of ultra-fine particulate matter, which penetrates deeply into the lungs. Although the old-technology (EURO II or earlier) diesel engines contaminate greatly, the international automotive industry has developed very much cleaner vehicle specifications—such as EURO VI and EPA Federal 2007 standards as required by the European Union (EU), the United States Environmental Protection Agency, and other regulations—which reduce the health cost by over two orders of magnitude. EURO 3 and EURO 4 requirements provide only limited relief.

Resolving this suite of issues requires many actions, which together can lead toward sustainable mobility. It has been widely proven that just providing additional road space by means of new and larger infrastructure will not solve the problem and, in fact, exasperates it over the medium and/or long term. Vehicle usage will always expand to fill all available space. The Avoid–Shift–Improve approach seeks to achieve significant reductions in GHG, energy consumption, and congestion and time lost (Figure 36).

Figure 36: The Avoid–Shift–Improve Approach



Source: GIZ. sutp.org. Sustainable Urban Transport: Avoid-Shift-Improve (A–S–I). http://www.sutp.org/files/contents/documents/resources/E_Fact-Sheets-and-Policy-Briefs/SUTP_GIZ_FS_Avoid-Shift-Improve_EN.pdf.

- **"Avoid"** policies address transport-energy use and emissions by slowing travel growth via city planning and managing travel demand. These policies also include initiatives such as virtual mobility programs (e.g., tele-working) and implementation of logistics technology.

- **"Shift"** policies enable and encourage movements from motorized travel to more energy-efficient modes, such as public transit, walking, cycling, freight rail, and waterborne transport. For example, increases in affordable, frequent, and seamless public transport can alleviate local congestion while improving access and travel time to destinations and reducing a household's travel expenses.

- **"Improve"** policies can reduce energy consumption and emissions of all travel modes by introducing efficient fuels and vehicles. These policies include tightened fuel-economy standards and increased advanced-vehicle technology sales (e.g., clean diesel trucks and hybrid and plug-in electric cars).

The low-carbon scenario shows transport plans—which include substantial modal shift and mixed land-use policies to reduce the need to travel, and shifting where necessary to more efficient "mass" transit—that align with the VGGS and are even more aggressive in their extent and nature.

The low-carbon plans were grouped into 10 interventions (Table 15) that were identified for inclusion in the analysis. The selected interventions have the potential to reduce CO_2e emissions from the transportation sector and improve overall local air quality in the principal metropolitan regions of the country, with additional environmental improvements in the less populous areas.

6.2.1 Freight Transport Improvements

Both passenger and freight transportation are improved in the low carbon scenario. For freight transportation, measures consist of modal shifts and improved vehicle technology. Among forms of freight transport, road transport is least efficient and is associated with the greatest emissions per ton kilometer traveled. In contrast, water and rail transport are more fuel efficient, cause less congestion and can potentially be less costly. The competitiveness of both measures depends on improved inter-modal freight logistics and handling, as their use involves greater switching of modes between road and rail or water.

Compared with the reference scenario, which maintains a constant 14.5% share of freight ton kilometers via rail from 2030 through 2050, the low carbon scenario modestly increases the freight share to 15.5% by 2050.

Table 15: Low-Carbon Measures Selected for Inclusion in the Analysis

	Low-Carbon Development Measures
1	Inland waterways improvement: Low-carbon scenario includes replacement of smaller vessels with larger ones at the rate of 2% per year and that the share of push barges in the fleet grows at 15% per year (from a very low initial share in 2010) to replace self-propelled barges; Reference scenario assumes recent fleet.
2	Coastal freight: Low-carbon scenario includes replacement of smaller ships/vessels with larger ones at the rate of 2% per year; Reference scenario assumes recent fleet mix.
3	Freight modal shift from road to coastal: The coastal share of freight ton-kilometers stays constant in the reference scenario at 19.8% from 2030 through 2050, but in the low carbon scenario grows to 20.8% by 2030 and 22.2% by 2050.
4	Motorcycles: 40% of new sales in reference scenario are electric by 2030; in low-carbon scenario, 90% of new sales are electric by 2030.
5	Freight modal shift from road to rail: Reference scenario stabilizes at 14.5% of national freight ton kilometers after 2030, whereas low carbon scenario grows to 15.5% by 2050.
6	Private vehicles: Private vehicles move from Euro 3 to Euro 5 by 2030 in both scenarios; in the low-carbon scenario, the EU standards for CO_2e emissions from cars and light commercial vehicles are enacted with an 8-year lag.
7	Modal shift from private vehicles to buses: In the reference scenario, the bus share of passenger kilometers traveled rises slowly to 11.8% in 2030 and 17.7% by 2050. The low carbon scenario has much more rapid expansion of bus services as usage to allow buses to provide 20.7% and 27.8% of passenger kilometers by 2030 and 2050, respectively.
8	Fuel switching to compressed natural gas for urban buses: The reference scenario has 20% of new urban bus sales as natural gas powered by 2030 and 50% by 2050, while the low carbon scenario increases this to 60% and 70%, respectively.
9	Increasing the use of biofuel: Reference scenario does not include biofuel. Low-carbon scenario increases biofuel blending in all gasoline and diesel to 5% by 2025 and to 10% by 2035.
10	Passenger modal shift from road to commuter and long distance rail: Reference scenario grows to 12.9% by 2030 and 13.5% by 2050 of passenger kilometers traveled by rail. In the low carbon scenario, this grows more rapidly to 15.3% by 2030 and 16.5% by 2050.

CO_2e = carbon dioxide equivalent, EU = European Union.
Note that modal shares here are shares of all surface transport, not only on-road transport, as reported in Figure 37.
Source: Authors.

In the reference scenario, coastal freight maintains a constant 19.8% share of freight ton kilometers from 2030 through 2050, whereas the low carbon scenario increases this to 20.8% by 2030 and 22.2% by 2050.

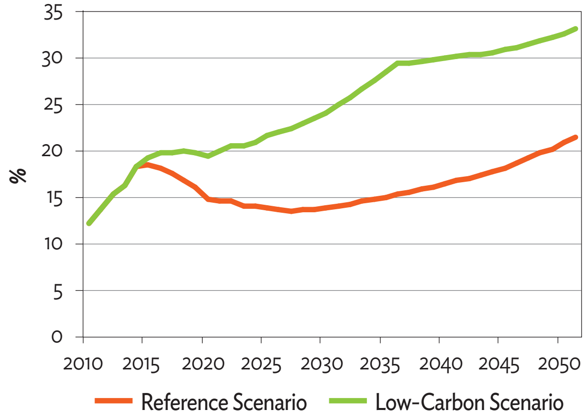
Inland waterway transport is also modernized. The share of push barges in the fleet at the base year is very small at 3% of total inland waterway vessels. This share rises at 15% per year to replace less efficient self-propelled barges. In addition, 2% of the annual fleet of smaller vessels is replaced annually with larger, more efficient vessels.

6.2.2 Modal Shifts

Public on-road transportation in 2010 accounts for 12% of on-road mobility and although this shows large growth, there is still a need for substantial improvement. In Decision No. 71/2004/QD-TTg, the Prime Minister established the priorities to promote public transport with mode share goals for 2010 and 2020 (30% in 2010 and 50% share in 2030) and encourage the participation of the private sector in providing bus services. It is important to note that even in the reference scenario, as can be seen in Figure 37, the ridership of heavy commercial passenger vehicles (buses and coaches) as a percentage of total on-road PKT (which includes two-wheelers, passenger cars, and passenger light commercial vehicles) increases from 12% in 2010 to 21% in 2050. In the low-carbon scenario, the bus modal share increases to 33% of on road PKT by 2050, compared with 22% in the reference scenario.

In addition to modal shifts within road transport from motorcycles and passenger cars to buses, there are modal shifts from private vehicles to rail, both for long distance travel and for urban/suburban commuting. The rail improvements also synergize with bus modal shifts to achieve better displacement of private road vehicle usage. In the reference scenario, rail usage is already growing due to new infrastructure investments, so that it reaches 12.9% of total PKT by 2030 and 13.5% by 2050. The low carbon scenario builds on this to achieve 15.3% of PKT by rail by 2030 and 16.5% by 2050. Together with buses, this implies that 50% of all PKT will be by mass transit.

Figure 37: Modal Share of On-Road Mass Transit (PKT)

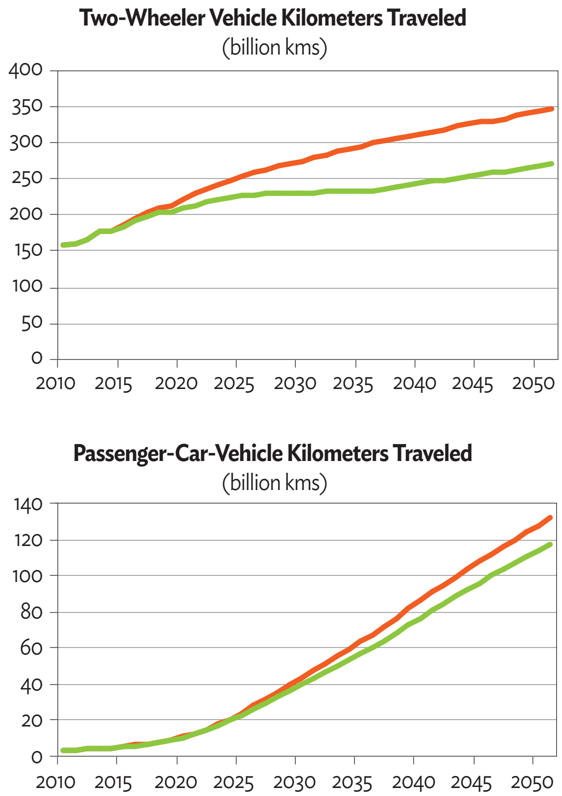


PKT = passenger-kilometer traveled.
Source: Authors.

Measures to achieve such a large shift include policies to further discourage private vehicle ownership and promote travel demand management programs to improve service quality and frequency of public transport and its travel flow, and improve integration with walking and cycling. Improved travel management technology for mass transit vehicles, such as advanced traffic signalization and real-time travel information, can also help to enhance mobility in multimodal cities to maintain or improve travel shares by more efficient transport modes and system flow. Over this longer time frame, land-use initiatives that prioritize dense mixed-use urban cores (for example, transit-oriented development) and transport infrastructure development (e.g., dedicated spaces for pedestrians and public transit networks) become even more important in achieving such modal share goals.

Figure 38 shows the impact of these modal shift policies on the annual mileage of two-wheelers and passenger cars. Two-wheeler usage stabilizes at a level that is approximately 50% higher than in 2010, and passenger-car usage continues to increase, albeit less dramatically. It is evident that even with these measures, congestion will be notably worse than it is today.

Figure 38: Impact of Modal Shift Policies on Two-Wheeler and Passenger-Car Annual Mileage



km = kilometer.
Source: Authors.

6.2.3 Fuel Substitution

The Government has had some fluctuation in biofuel policy, as pilot production was discontinued in 2009 by Project 177 – Project for Development of Biofuel to 2015 with a Vision to 2025.For illustrative purposes, the modeling including modest use of biofuels, with 5% of all gasoline and diesel as biofuel by 2025 and 10% by 2035.

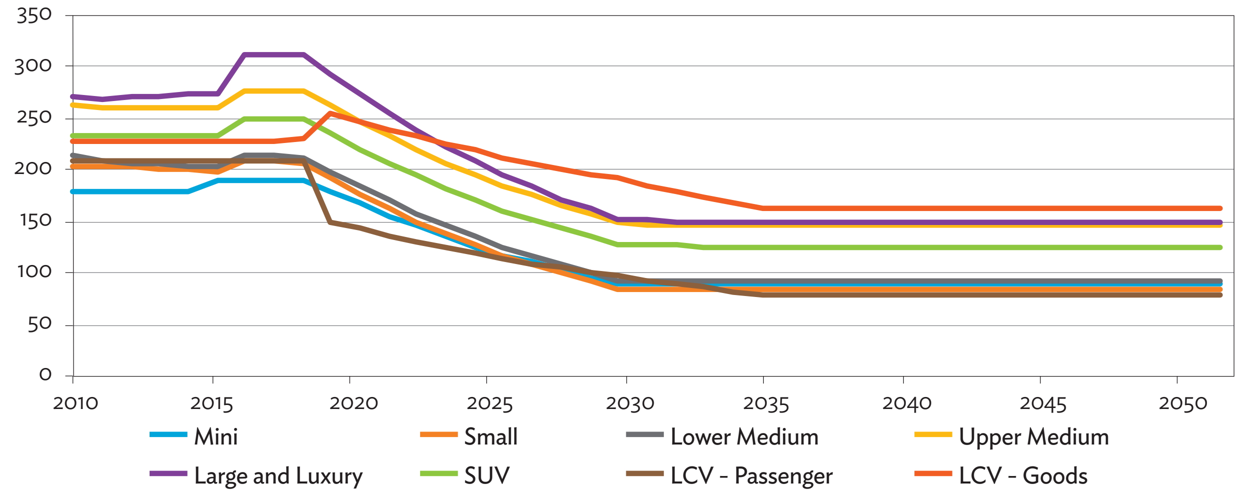
In the reference scenario, there is already a shift towards increased use of natural gas for urban buses, with new bus sales being 20% natural gas by 2030 and 50% natural gas by 2050. The low carbon scenario escalates this shift, so that 60% of sales are gas in 2030 and 70% are natural gas by 2050. The natural gas buses are also considered to be modernized, compared with the units replaced.

There is a large change in CO_2e emissions from urban buses over this period. In 2010, the average emissions per passenger-kilometer were 32.7g/km. In the reference scenario, this drops by 2050 to 21g/km as a result of the buses' improved operation and technology. In the low-carbon scenario, by 2050, the emissions performance of urban buses improves to only 12.8 g/km because of fuel replacement, as well as introduction of bus rapid transit in key cities.

6.2.4 Vehicle Technology

In both the reference and low-carbon scenarios, vehicle emissions are controlled by mandating improvements in vehicle emissions technology, moving from the current EURO 3 to EURO 4 for light duty vehicles and from EURO 3 to EURO 4 for heavy duty vehicles in 2017, and to EURO 5 and EURO 6 in 2022. This represents a 12–13 year lag behind the EU. Figure 39 shows clearly the impact on ambient emissions from the in-use vehicle fleet. These standards applicable to new vehicle sales have a large impact on pollutant emissions but little or no effect on

Figure 39: Sales-Weighted New Car and Light Duty Carbon Dioxide Equivalent Emissions (g/km)



g/km = gram per kilometer, LCV = light commercial vehicle, SUV = sports utility vehicle.
Source: Authors.

CO_2e emissions.[24] For example, in the EU, road transport contributes about one-fifth of the community's total emissions of CO_2 and is the only major sector in the EU where GHG emissions are still rising. Consequently, the EU put in place in 2007 a comprehensive legal framework to reduce CO_2e emissions from new light duty vehicles with manufacturers being obliged to meet sales-weighted fleet average CO_2 emissions from new cars of 95 grams per kilometer (g/km) by 2021, phased in from 2020. This policy allows heavier cars to have higher emissions than lighter cars while preserving the overall fleet sales. If the average CO_2e emissions of a manufacturer's fleet exceed its limit value in any year, the manufacturer would pay a premium for excess emissions for each registered car. For other light duty vehicles, the mandatory target was set at 147 g/km by 2020. The low-carbon scenario includes these provisions but with a 14-year lag behind the EU and finds sales-weighted emissions for cars averaging 96.7 g/km by 2035.

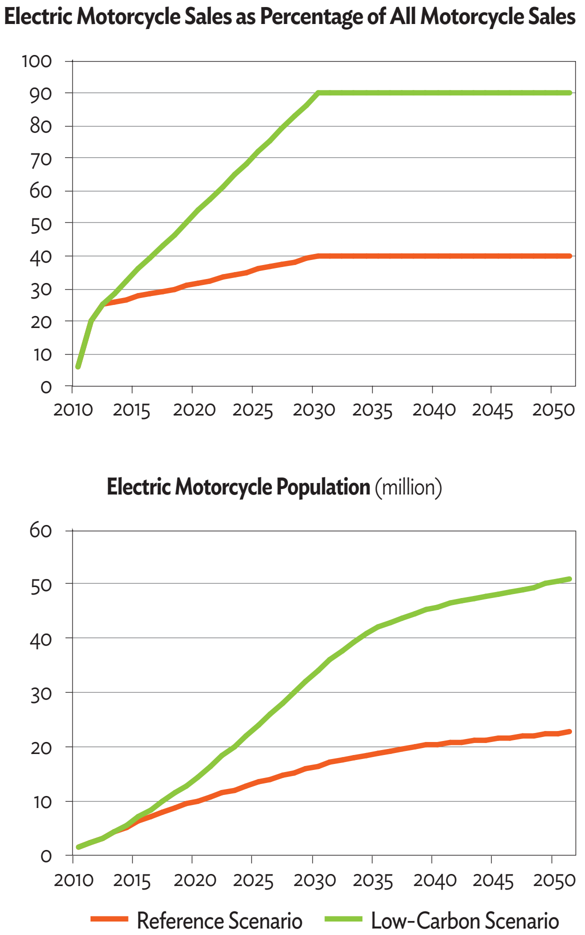
6.2.5 Electric Motorcycles

In the reference scenario, the percentage of electric motorcycles sold rises to 40% by 2030, while in the low-carbon scenario, a series of policy initiatives increases the participation of electric motorcycles among those sold to 90% in the same time frame (Figure 40).

In the reference scenario, the active population of electric motorcycles, which in 2010 was just short of 1.5 million, rises to over 22 million by 2050 while in the low-carbon scenario the active population in 2050 is 51 million. This has a large impact on noise, pollution, and cost of operation, and significant impact on CO_2e emissions.

24 Hydrocarbon (HC), carbon dioxide (CO_2), nitrogen oxide (NO_x), and particulate matter (PM).

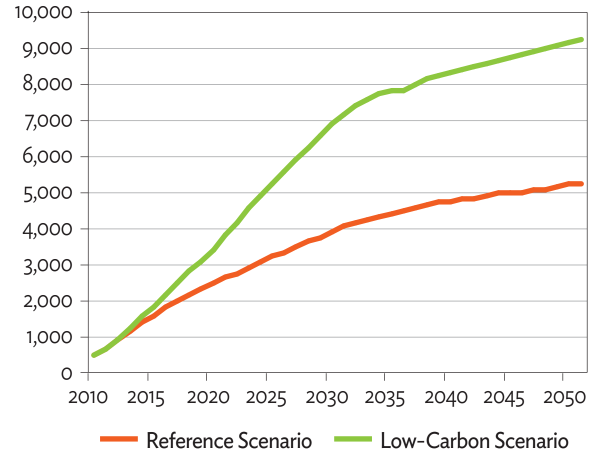
Figure 40: Number of Electric Motorcycles and as a Percentage of Sales



Source: Authors.

The annual total consumption of electricity by these vehicles is greater in the low-carbon scenario as shown in Figure 41. Less power plant investment is possible under this measure if users charge the batteries of electric motorcycles during off-peak hours.

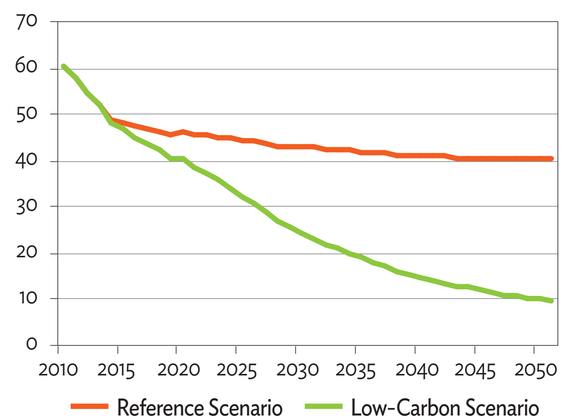
Figure 41: Two-Wheeler Annual Consumption of Electricity (GWh)



GWh = gigawatt-hour.
Source: Authors.

Assessing overall emissions effects requires that changes in CO_2e emissions from transport electricity demand are added to direct emissions from fossil fuel consumption, as presented in Figure 42. In the low-carbon scenario, the specific amount of CO_2e emissions of electricity (expressed in g/kWh) is lower because of the investments and other

Figure 42: Two-Wheeler Emissions per Passenger-Kilometer (CO_2e)



CO_2e = carbon dioxide equivalent.
Source: Authors.

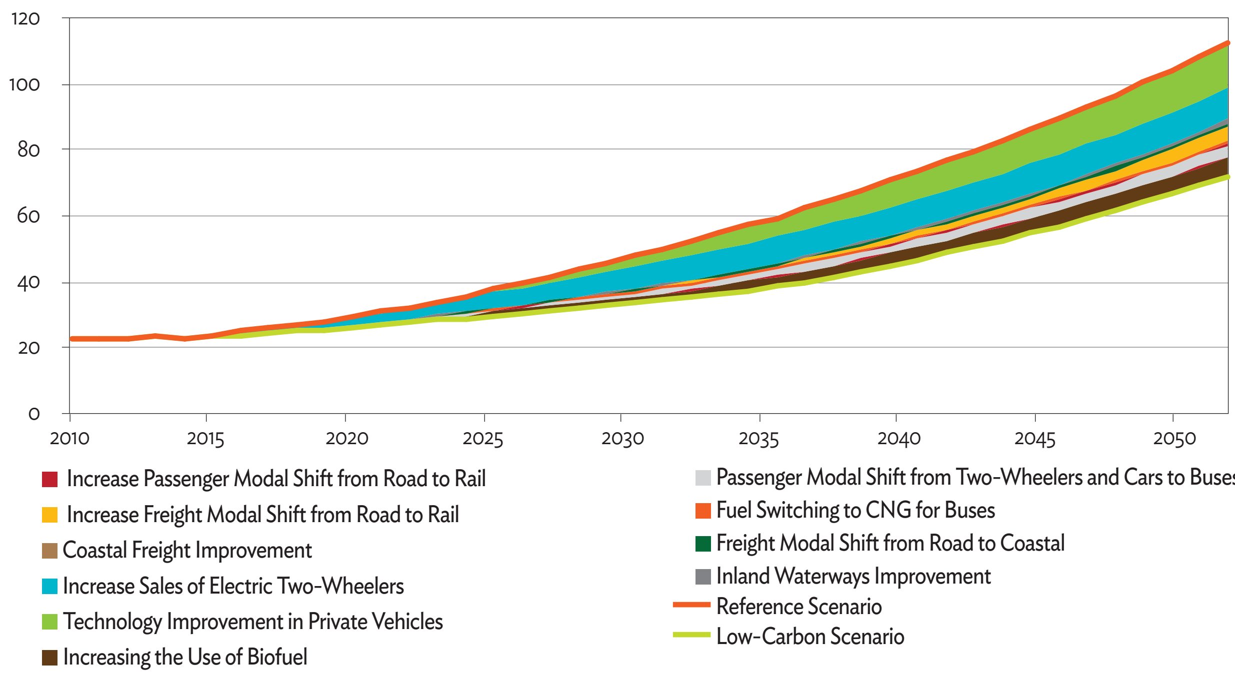
policy decisions taken in the power sector. As a result, two-wheeler CO_2e emissions in passenger-kilometers drop from 60 g/km in 2010 to 40 g/km in 2050 in the reference case and to only 10 g/km in the low-carbon scenario.

This gives a distinct opportunity to preserve private mobility via the use of two-wheelers in the low-carbon scenario, since from 2045 onward, CO_2e emissions per passenger-kilometer are lower in two-wheelers than in urban buses. Having private transport with lower per passenger-kilometer GHG emissions than mass transit is a situation that is forecast in very few societies. However, modal shift from two-wheelers to buses may still be critically important from the standpoint of congestion and road safety.

6.2.6 Overall Effect

The reference case (based on Transport Strategy 2020) already includes substantial "avoid" measures that reduce the need to travel; "shift" measures from private transport to mass transit; and "improve" measures such as increasing the penetration of electric motorcycles in overall motorcycle sales; hence, the 10 measures included in the analysis only evaluate what could be done on top of that already planned. In this respect, two "improve" measures account for 58% of the mitigation, increasing the penetration of electric motorcycles and improving the fuel efficiency of private vehicles in line with EU standards but after a significant time lag. These measures (included in the low-carbon scenario) reduced CO_2e emissions from transport by 36% in 2050 and from 108 million tons to 69 million tons of CO_2e (Figure 43).

Figure 43: Mitigation from Transport
($MtCO_2e$)



CNG = compressed natural gas, CO_2 = carbon dioxide, $MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

7. MARGINAL ABATEMENT COST CURVES

The previous sections have illustrated the potential of different energy and transport options to mitigate emissions. The question then is to compare this potential magnitude with costs. A marginal abatement cost (MAC) curve presents a standard summary of each of the proposed energy-efficiency measures and supply technology by comparing their marginal net cost per unit of abatement and the related abatement potential. The curve is ordered from the intervention with the lowest abatement cost to that with the highest abatement cost.

The MAC is given by

$$MAC = \frac{NPV_a - NPV_b}{CO_2e_b - CO_2e_a}$$

where

PV_A is the net present value of the expenditure cash flow for the activity "A" with higher costs

PV_B is the net present value of the expenditure cash flow for the activity "B" with lower costs

CO_2e_A is the undiscounted cumulative CO_2 equivalent emitted for option A

CO_2e_B is the undiscounted cumulative CO_2 equivalent emitted for option B

All the MAC numbers presented here have the net present value of cash outflows calculated to 2010, the base year of this study. They include the investments, operation and maintenance costs, fuel costs, and emissions over the study time frame (2010–2050). In the case of power plants, they include the investments required for a plant's midlife extension, and also take into account a terminal value for each unit that is operational in the last year of this study. The terminal value is taken to be equal to the proportion of its initial investment in relation to the un-generated electricity that can be expected over the operating life of the plant; the same being recovered into the MAC calculation 1 year after the end of the study time frame.

A discount rate of 10% has been used, calculated at midyear. This rate corresponds to the assumption that the private sector is likely to be a predominant source of investment funds.

7.1 Household Electricity Demand

The study evaluated the electricity consumption of 23 appliance types in four groups. Over 2010–2050, this results in a total mitigation of 405 million tons of carbon dioxide equivalent ($MtCO_2e$) at an average mitigation cost of –\$2.41 per ton of carbon dioxide equivalent (tCO_2e) and allows the electricity demands of a rising, more affluent population to be met without an increase in total household electricity demand.

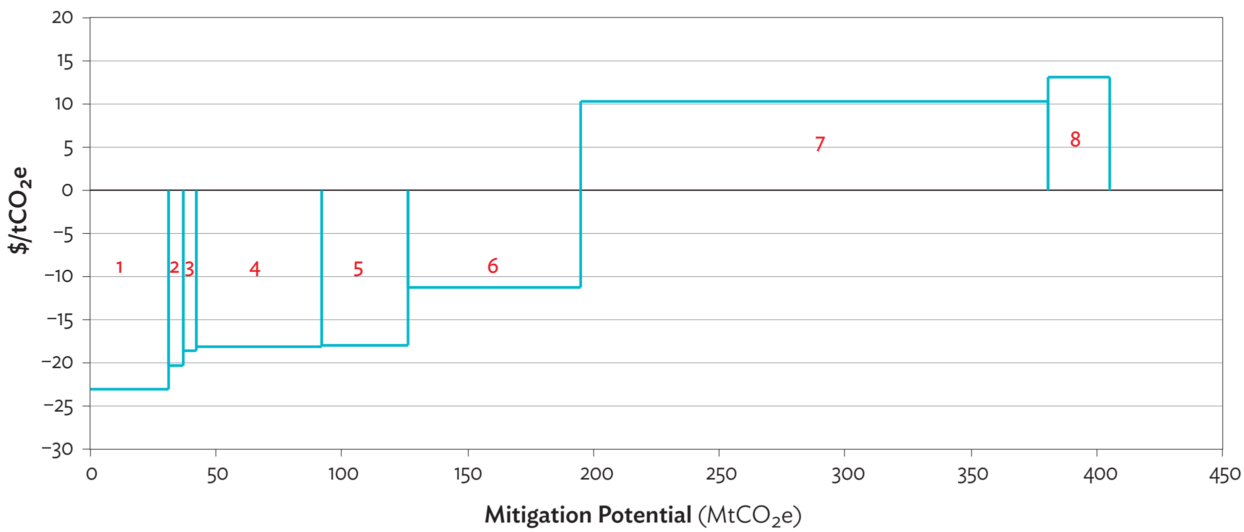
Figure 44 shows the marginal abatement cost curve (MACC) of these measures. Two measures have a positive MAC, while all the others imply a net savings. Improved cooling has a MAC of \$10.3 with a savings of 186 $MtCO_2e$. Since this measure reduces peak load, its additional cost is more than offset by reduced investment in the power sector—which would benefit directly from financing this measure.

The other policy with a positive MAC is hybrid water heating. At a cost of $13.1, this results in a mitigation of 24 $MtCO_2e$ over the study period.

7.2 Industry Sector

The study evaluated the impact of 41 energy- and emissions-saving measures in five high energy-consuming industry subsectors: steel (integrated and small producers), cement, pulp and paper, refinery, and fertilizer. Over 2010–2050, these measures result in a total mitigation of 626 $MtCO_2e$ at an average mitigation cost of $1.88 per tCO_2e. Of the 41 measures, 37 generate a mitigation of 611 $MtCO_2e$ at a marginal abatement cost of less than $10/$tCO_2e$. The 10 measures in integrated steel producers generate 71% of the mitigation as shown in Figure 45.

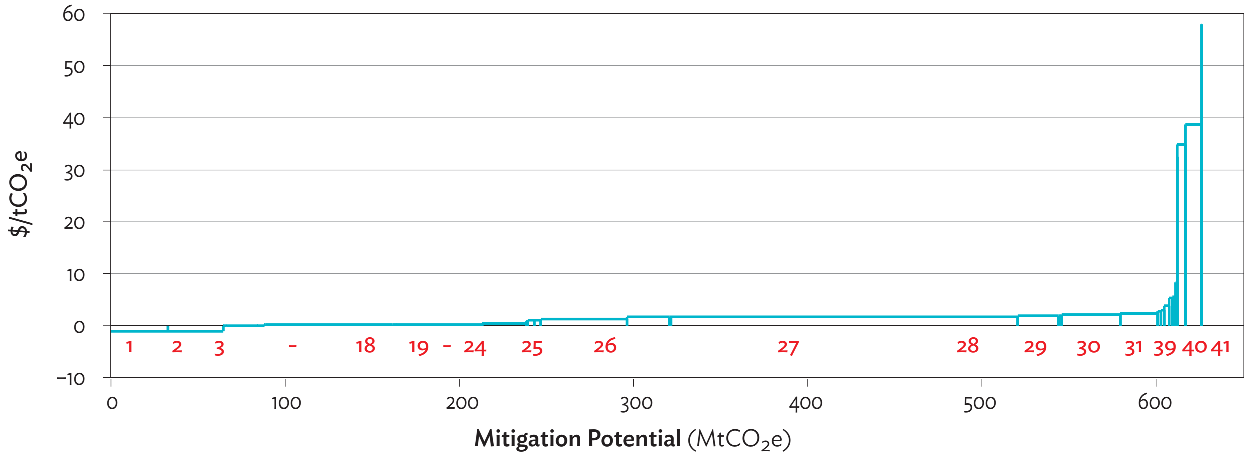
Figure 44: Marginal Abatement Cost Curve for Household Appliances



Code	Sector	Intervention	Mitigation Potential $MtCO_2e$	Abatement Cost $/$tCO_2e$
1	Household	Refrigerator	31	(23)
2	Household	Washing machine	6	(20)
3	Household	TV	6	(19)
4	Household	Air conditioning	49	(18)
5	Household	Other household appliances	34	(18)
6	Household	Lighting	68	(11)
7	Household	Low-e windows or shades and high-efficiency ceiling fan ceiling fan	186	10
8	Household	Water heater	24	13

( ) = negative, $MtCO_2e$ = million tons of carbon dioxide equivalent, tCO_2e = tons of carbon dioxide equivalent.
Source: Authors.

Figure 45: Marginal Abatement Cost Curve for Five Industry Subsectors



Code	Sector	Intervention	Mitigation Potential $MtCO_2e$	Abatement Cost $\$/tCO_2e$
1	Steel ISP	Natural gas injection in blast furnace	33	(1)
2	Steel ISP	Pulverized coal injection in blast furnace	32	(1)
3	Refinery	Steam savings by trap management	1	0
4	Fertilizer	Installation of variable speed drives for cooling tower fans of ammonia and power plant	18	0
5	Refinery	Oil recovery from crude tank bottom sludge by chemical treatment	0	0
6	Fertilizer	Calcium silicate insulation of high pressure steam pipeline	4	0
7	Fertilizer	Steam traps in MP header connected to deaerator in ammonia plant	0	0
8	Cement	Combustion system improvements	73	0
9	Steel SSP	Bottom stirring	2	0
10	Refinery	Installation of low excess air burner	0	0
11	Fertilizer	Energy saving by arresting steam leakages through steam traps	0	0
12	Fertilizer	Heat recovery from MP decomposer vapors in urea plant by installation of pre-concentrator	2	0
13	Pulp and Paper	Heat recovery in thermo-mechanical pulping	8	0
14	Steel SSP	Improved process control	8	0
15	Cement	Kiln shell heat loss reduction	7	0
16	Pulp and Paper	Waste heat recovery from paper drying	15	0
17	Steel SSP	Scrap preheating (FUCHS)	10	0
18	Steel ISP	Sinter plant heat recovery	25	0
19	Steel ISP	Variable speed drives	0	1
20	Refinery	Optimization of power consumption in utility boiler drives and auxiliaries	0	1
21	Refinery	Condensate recovery	0	1
22	Steel SSP	Transformer efficiency	4	1
23	Steel ISP	Heat recuperation from hot blast stoves	4	1
24	Steel ISP	Blast furnace and coke oven cogeneration	49	1
25	Pulp and Paper	Increased use of recycled pulp	25	2
26	Cement	Installation of viable frequency drives	1	2
27	Steel ISP	Thin slab casting and strip casting	198	2
28	Steel ISP	Hot charging in rolling mills	24	2
29	Fertilizer	Isothermal carbon oxide conversion reactor	2	2
30	Steel ISP	Basic oxygen furnace gas sensible heat recovery	33	2

continued on next page

Figure 45 continued

Code	Sector	Intervention	Mitigation Potential $MtCO_2e$	Abatement Cost $/$tCO_2e$
31	Steel ISP	Installation of the top pressure recovery turbine	22	2
32	Pulp and Paper	Extended nip press	2	3
33	Pulp and Paper	RTS pulping	1	3
34	Steel SSP	Oxyfuel burners	3	4
35	Pulp and Paper	Black liquor gasification	2	5
36	Refinery	Flare gas recovery and utilization of recovered flare gas for process heating requirements	2	6
37	Steel SSP	Eccentric bottom tapping	1	8
38	Fertilizer	High conversion rate synthesis reactor	0	33
39	Cement	Vertical rolling mill	5	35
40	Cement	Dry kilns with multistage preheaters and pre-calcination	10	39
41	Refinery	Online cleaning of furnace	0	58

( ) = negative, ISP = integrated steel plant, $MtCO_2e$ = million tons of carbon dioxide equivalent, SSP = small-scale producer, tCO_2e = tons of carbon dioxide equivalent.
Source: Authors.

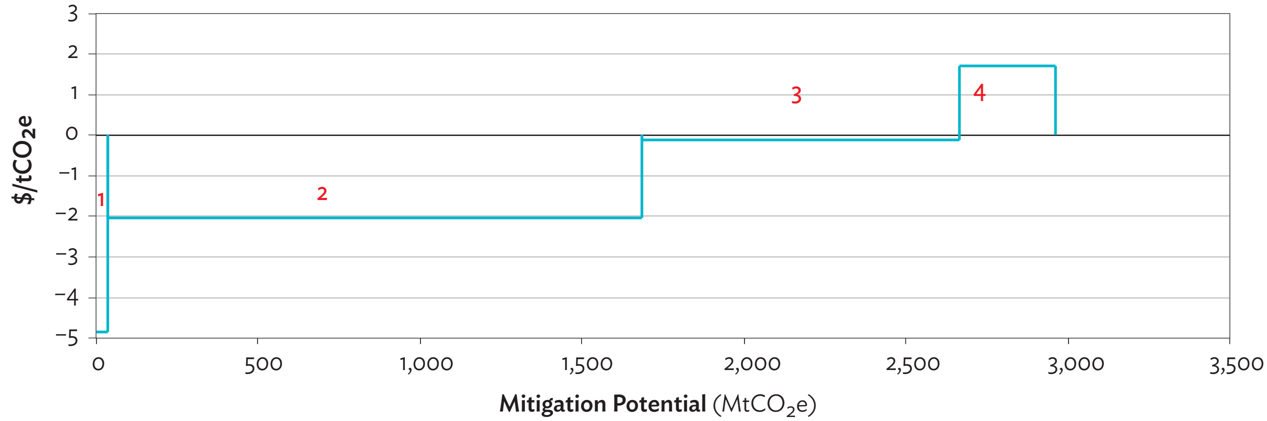
7.3 Electricity Generation – Supply Side

The electricity sector, as the main focus of this study, underwent a significant transformation between the reference case, which is rooted in the PDP-VII-interim-revision, and the low-carbon case. Over the study period (2010–2050), energy-efficiency measures reduced the demand for electricity compared with the reference case, consequently lowering absolute emissions from the electricity sector significantly. On top of this, the abatement potential of cleaner generation technologies is substantial.

This substitution of generation technology results in a total mitigation over 2010–2050 of 2,962 $MtCO_2e$ at an average mitigation cost of –$1.06 per tCO_2e. In 2050, these supply-side measures reduce electricity sector emissions by 348 $MtCO_2e$.

Figure 46 shows the marginal abatement cost curve of these measures. Of the four technologies employed, three exhibit net savings. Only wind has a positive MAC of $1.72/$tCO_2e$.

Figure 46: Marginal Abatement Cost Curve for Supply-Side Measures in Electricity Generation



Code	Sector	Intervention	Mitigation Potential $MtCO_2e$	Abatement Cost $/tCO_2e$
1	Power	Hydro	37	(5)
2	Power	Biomass	1,648	(2)
3	Power	Solar	978	0
4	Power	Wind	299	2

( ) = negative, $MtCO_2e$ = million tons of carbon dioxide equivalent, tCO_2e = tons of carbon dioxide equivalent.
Source: Authors.

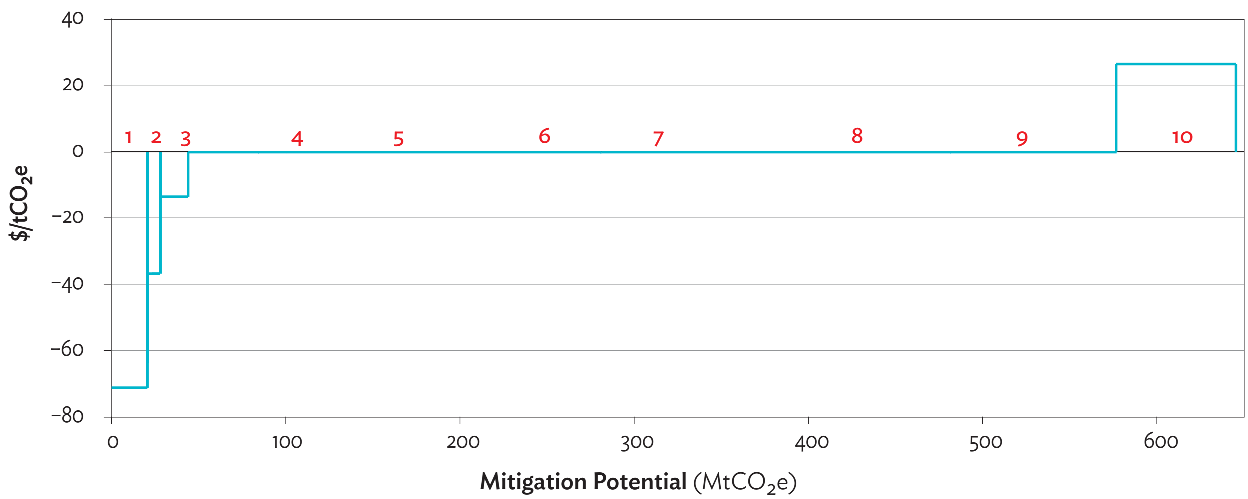
7.4 Transport

The study evaluated 10 measures—for on-road, rail, inland waterway, and coastal transport—which improve transport efficiency or move passenger and freight transport to modes that lower specific emissions.

Figure 47 shows the MACC of these measures. Only one policy has a positive MAC, while the measures for all the others imply a net savings. Improving public transit has mitigation of 96 million tons, and a direct abatement cost of nearly $0. Overall, the transport measures reduce greenhouse gas (GHG) emissions over the modeling period (2010–2050) by 645 million tons at an average cost of –$0.29/$tCO_2e$.

There are strong interdependencies among the transport measures. For example, modal shifts enhance the benefits that can be achieved from better emissions standards, as lower congestion means greater efficiency is possible. Thus, these measures should be seen as a package, rather than in isolation.

Figure 47: Marginal Abatement Cost Curve for Transport



Code	Sector	Intervention	Mitigation Potential $MtCO_2e$	Abatement Cost $/tCO_2e$	Code	Sector	Intervention	Mitigation Potential $MtCO_2e$	Abatement Cost $/tCO_2e$
1	Transport	Fuel switching to CNG for buses	20	(71)	6	Transport	Increase sales of electric two-wheelers	180	0
2	Transport	Passenger modal shift from road to rail	8	(36)	7	Transport	Coastal freight improvement	0	0
3	Transport	Freight modal shift from road to coastal	16	(14)	8	Transport	Technology improvement in private vehicles toward EU efficiency	200	0
4	Transport	Freight modal shift from road to rail	41	0	9	Transport	Increasing the use of biofuel	96	0
5	Transport	Inland waterways improvement	16	0	10	Transport	Passenger modal shift from two-wheelers and cars to buses	68	26

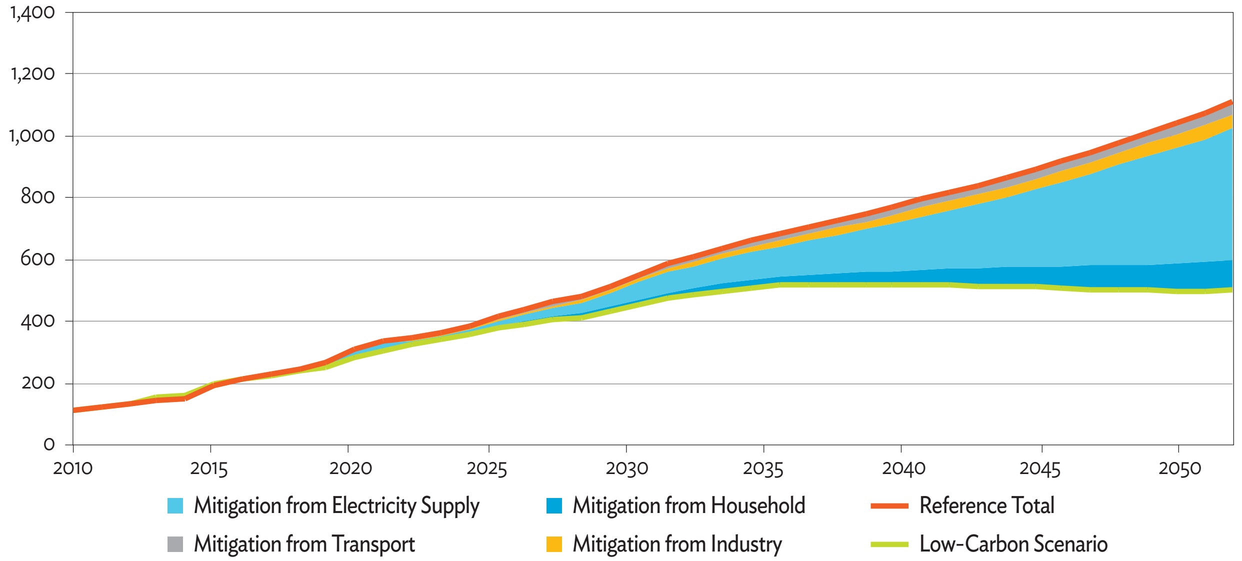
( ) = negative, CNG = compressed natural gas, EU = European Union, $MtCO_2e$ = million tons of carbon dioxide equivalent, tCO_2e = tons of carbon dioxide equivalent.
Source: Authors.

7.5 All Sectors

In total, the study evaluated 63 specific measures to reduce GHG emissions from the power, industry, and transport sectors, achieving a low-carbon scenario that emits 53% less GHG emissions in 2050, having reduced the reference scenario emissions of 1,073 $MtCO_2e$ to 499 $MtCO_2e$ in the low-carbon scenario (see Figure 48). The greatest contribution of 492 $MtCO_2e$ in 2050 comes from the power sector, between efficiency measures that reduce the demand for electricity and a strong move toward low-carbon power generation options.

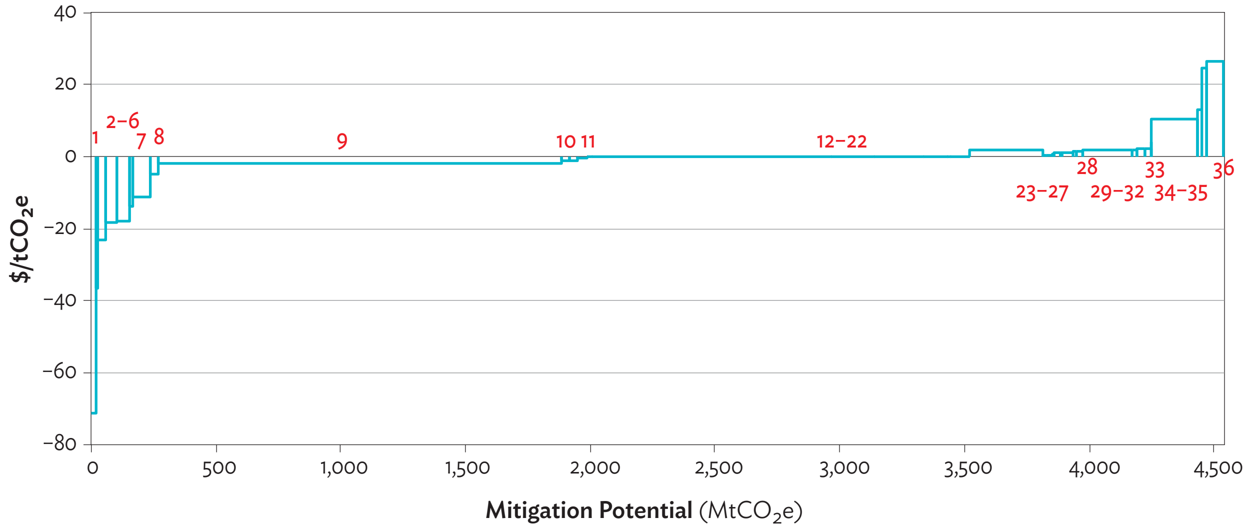
Over 2010–2050, these measures permit a mitigation of 4,638 $MtCO_2e$ with an average mitigation cost of −\$0.68/tCO_2e. They permit emissions from these sectors to level off at around 500 $MtCO_2e$ per year from 2035 onward (Figure 49). It is important to note that 76% of total mitigation savings (4,638 $MtCO_2e$ over this period) can be achieved with a negative or zero mitigation cost.

Figure 48: Total Mitigation from Power, Industry, and Transport Sectors
($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

Figure 49: Overall Marginal Abatement Cost Curve



Code	Sector	Intervention	Mitigation Potential $MtCO_2e$	Abatement Cost $\$/tCO_2e$
1	Transport	Fuel switching to CNG for buses	20	(71)
2	Transport	Passenger modal shifts to rail	8	(36)
3	Household	Efficient refrigerators	31	(23)
4	Household	Other efficient household appliances	45	(18)
5	Household	Efficient air conditioning	49	(18)

continued on next page

Figure 49 continued

Code	Sector	Intervention	Mitigation Potential $MtCO_2e$	Abatement Cost $\$/tCO_2e$
6	Transport	Freight modal shift from road to coastal	16	(14)
7	Household	Efficient lighting	68	(11)
8	Power	Hydro	37	(5)
9	Power	Biomass	1,648	(2)
10	Steel ISP	Natural gas injection in blast furnace	33	(1)
11	Steel ISP	Pulverized coal injection in blast furnace	32	(1)
12	Transport	Freight modal shift from road to rail	41	0
13	Transport	Inland waterways improvement	16	0
14	Power	Solar	978	0
15	Transport	Increase sales of electric two-wheelers	180	0
16	Transport	Technology improvement in private vehicles toward EU efficiency standards	200	0
17	Transport	Increasing the use of biofuel	96	0
18	Fertilizer	Installation of variable speed drives for cooling tower fans of ammonia and power plant	18	0
19	Cement	Combustion system improvements	73	0
20	Power	Wind	299	2
21	Pulp and Paper	Waste heat recovery from paper drying	15	0
22	Steel ISP	Sinter plant heat recovery	25	0
23	Fertilizer	Other efficient technologies	8	1
24	Steel SSP	Other efficient technologies	30	1
25	Steel ISP	Blast furnace and coke oven cogeneration	49	1
26	Pulp and Paper	Other efficient technologies	13	2
27	Pulp and Paper	Increased use of recycled pulp	25	2
28	Steel ISP	Thin slab casting and strip casting	198	2
29	Steel ISP	Hot charging in rolling mills	24	2
30	Steel ISP	BOF gas sensible heat recovery	33	2
31	Steel ISP	Installation of the top pressure recovery turbine	22	2
32	Refinery	Efficient technologies	4	4
33	Household	Low-e windows or shades and high-efficiency ceiling fan	186	10
34	Household	Water heaters	24	13
35	Cement	Other efficient technologies	22	25
36	Transport	Passenger modal shift from two-wheelers and cars to buses	68	26
Total			**4,638**	**(0.68)**

( ) = negative, BOF = basic oxygen furnace, CNG = compressed natural gas, EU = European Union, ISP = integrated steel plant, $MtCO_2e$ = million tons of carbon dioxide equivalent, SSP = small-scale producer, tCO_2e = tons of carbon dioxide equivalent.
Note: Low carbon measures are grouped together to ease visualization in the figure.
Source: Authors.

8. ECONOMY-WIDE CONSEQUENCES OF LOW-CARBON GROWTH

8.1 Background

The previous chapters assess the effects of low-carbon development levers in a partial equilibrium framework, where rebound effects and macroeconomic responses are not represented. However, the changes in demand for fossil fuels and in electricity prices can have general equilibrium effects, based on substitution within and across markets that vary on where and how costs occur. To assess these effects, a different approach is required.

This chapter investigates the economic and social impacts of the low-carbon options package presented in the previous chapters using the computable general equilibrium (CGE) model. By its nature, the model captures the behavior of main entities in the economy (producers and consumers) as well as the main linkages (among production sectors, income, and consumption). Changes in one variable or parameter will trigger changes in the economy in order to reach a new balance. These characteristics make the model relevant by capturing multi-round interaction effects to assess the impact of low-carbon options.

8.2 Model Structure and Data

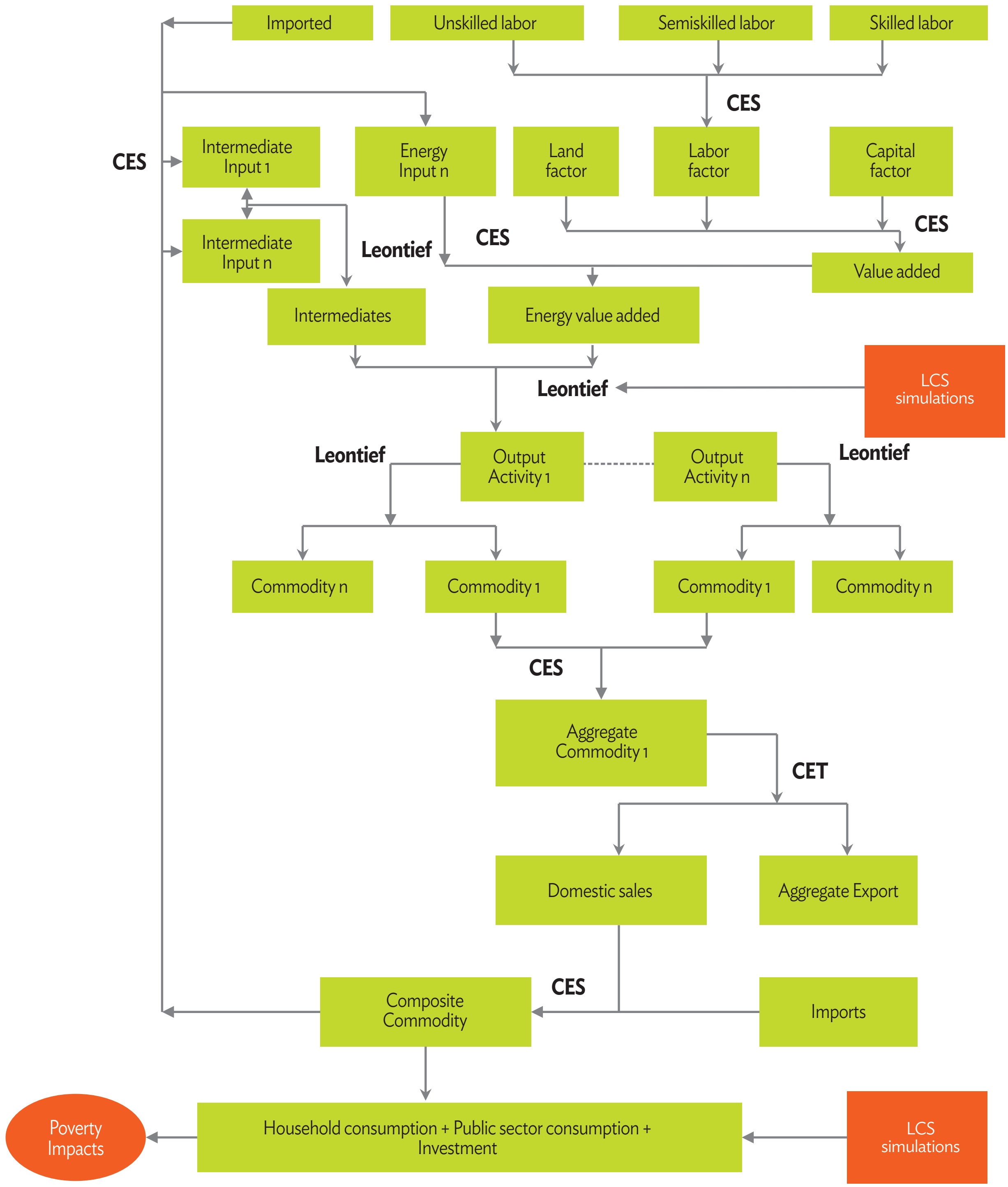
The CGE model developed in this report is a recursive dynamic type with a combined neoclassical-structural feature, extended from an original static CGE model built by the International Food Policy Research Institute and the dynamic model for Viet Nam by James Thurlow (CIEM and University of Copenhagen 2010).[25] In collaboration with the World Institute for Development Economics Research, United Nations University, CIEM constructed the 2011 social accounting matrix (SAM), which underpins the latest version of the model. The main features are briefly presented below.

Overall, the model has 32 production sectors, which include 9 energy sectors (crude oil, natural gas, coal, fuels/refined oil, and coal-based, gas-based, oil-based electricity, hydropower, and renewable electricity); 32 corresponding commodities; 3 labor factors classified by skill level (skilled, semiskilled, and unskilled); and a land factor and a capital factor. The three labor factors are then further disaggregated into location category (rural and urban); and 20 types of representative households in the model are divided by quintile consumption and location (rural and urban). The model also includes the public sector, investment and savings, and the rest of the world.

Producers in the model maximize their profits subject to several types of constraints, which are presented in Figure 50. First, the combinations between energy-production factors composite and other intermediate inputs, among intermediate inputs, and between the commodities produced, follow the Leontief function. This specification implies that combinations are determined by the technology, not by the producers. Second, energy and different production factors are combined in a form of constant elasticity of substitution function. This specification allows the substitution

25 For more on the development of this CGE type model, see Lofgren, Harris, and Robinson (2002) and Dervis, de Melo, and Robinson (1982).

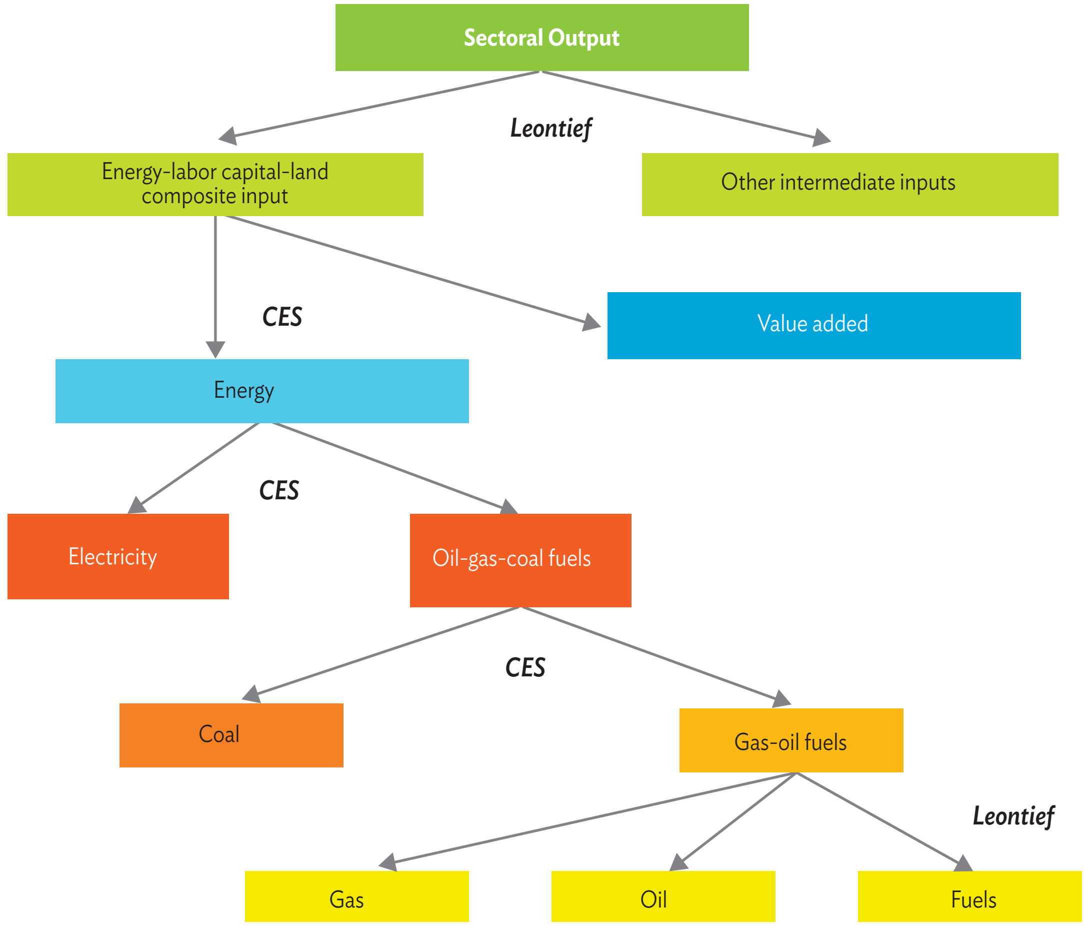
Figure 50: Production Technology and Commodity Flows in Viet Nam under the Low-Carbon CGE Model



CES = constant elasticity of substitution, CET = constant elasticity of transformation, CGE = computable general equilibrium, LCS = low-carbon scenario.
Note: Leontief is a fixed-share function.
Source: Adapted from J. Thurlow. 2004. Working Paper 1-2004: A Dynamic Computable General Equilibrium (CGE) Model for South Africa: Extending the Static IFPRI Model. *Trade and Industrial Policy Strategies*. Johannesburg.

between production factors and energy and the substitution between different types of energy under the change in their relative price. Figure 51 gives specific details on the substitution among energy types. Third, imported and domestic goods are imperfectly substituted under a constant elasticity of substitution Armington specification. Exported and domestic goods are substituted under a constant elasticity of transformation function. In this model, Viet Nam is assumed to be a small country, and therefore faces an infinite elastic world supply at fixed world prices.

Figure 51: Energy Substitution in Low-Carbon CGE Model Production Functions



CES = constant elasticity of substitution, CGE = computable general equilibrium.
Source: Authors.

The household consumption demand follows a linear expenditure system. The public sector gets revenue from direct and indirect taxes, and then spends it on public consumption, investment, and on transfers to households and payments to the rest of the world. All of these payments are fixed in real terms; therefore, the budget deficit is mainly financed by borrowing from the domestic capital market. Public consumption is separated from the production of public services.

The goods and services markets are perfectly competitive, while rigidities in the factor markets reflect the transitional characteristics of Viet Nam's economy as it transforms from a planning to a market economy. Capital and land are fully employed and activity specific. The labor market is segmented in two: semiskilled and unskilled labor, with the latter redundant in Viet Nam up to 2030.

Savings by households and enterprises are collected into a savings pool from which investment is financed. The model adopts closure that investment is savings driven. Closures of current account and the public sector are selected based on current public policies. For the current account, it is assumed that a flexible exchange rate adjusts in order to maintain a fixed level of foreign borrowing. In other words, the external balance is held fixed in foreign currency. In the public account, public sector savings are flexible and direct tax rates are fixed. Finally, the domestic producer price index is chosen as a numéraire such that all prices in the model are relative to the weighted unit price of the initial domestic producers' price. The model is recursive dynamic, which is based on an adaptive rather than a forward-looking expectation.[26] The dynamic part of the model generates new capital stock for the subsequent period while skilled labor supply responds to changes in real wages over time, whereas real wages of unskilled and semiskilled workers adjust across periods.

The model has been extended to be able to assess the impact of low-carbon options on poverty reduction in Viet Nam by adding a poverty module. To do that, 20 representative households in the original CGE model have been mapped via annual expenditures to the 9,393 households in the 2010 Viet Nam Household Living Standard Survey (VHLSS) General Statistics Office of Viet Nam (2010).[27] This poverty module has been developed to allow the impacts of different low-carbon scenarios on poverty reduction to be measured by three poverty indexes (headcount [PO], poverty gap [P1], and poverty severity [P2]). Besides measuring poverty impact through the changes in household expenditure, the poverty module also takes into account the impact through the price change of the goods baskets used to calculate the poverty line in Viet Nam. The poverty line for Viet Nam in 2010 is D653,000 per person per month (equivalent to $2.26 per person per day, 2005 PPP US dollars) (World Bank 2012).

Greenhouse gas (GHG) emissions are modeled based on quantity demand and quantity output of energy from related industry sectors and households and by the emission coefficients of each primary energy source. The quantity demand and production of energy were taken from the energy table for Viet Nam in 2011. The total GHG emission calculated by this way, more or less matched with the carbon emission in the Energy Forecasting Framework and Emissions Consensus Tool (EFFECT) model.

[26] The model can be made dynamic in several ways. According to Ginsburgh and Keyzer (1997), there are finite and infinite horizon dynamics. The model applied in this paper belongs to one of three finite horizontal dynamic models: single-period equilibrium model, T-period competitive equilibrium model, and temporary equilibrium model.

[27] The VHLSS surveyed 9,399 households, which represent Viet Nam's total population in 2010. However, when processing the data, 6 households were dropped for coding reasons, bringing the number of mapping households in the model to 9,393 households.

8.3 Simulations and Assessment Results

8.3.1 Reference Scenario and Low-Carbon Scenario

To assess the low-carbon options assessed within EFFECT, the reference scenario is also made consistent between the models, in gross domestic product (GDP) growth, GDP structure, and power structure and development during 2011–2050. These assumptions were defined on a shared basis between the models to ensure consistency.

The low-carbon scenario (LCS) has been developed based on the low-carbon options identified in the previous chapter. As a result, the LCS consists of the low-carbon interventions on seven industries (five industry sectors, transportation, and power sector) and household, which have been developed by the bottom–up models for Viet Nam. These may be divided into the following four main groups of action regarding energy consumption and production:

(i) **Industrial energy efficiency:** Improve the energy efficiency of five energy-intensive industries: cement, steel, oil refining, fertilizer, and paper, by investing in energy-saving technologies and production rearrangement.

(ii) **Household energy efficiency:** Improve the energy efficiency of households by investing in power-saving equipment.

(iii) **Transportation sector:** Direct the energy consumption patterns of transportation toward electricity from fuels.

(iv) **Power production structure:** Increase the share of gas-based electricity and renewable power while reducing the share of coal-based electricity.

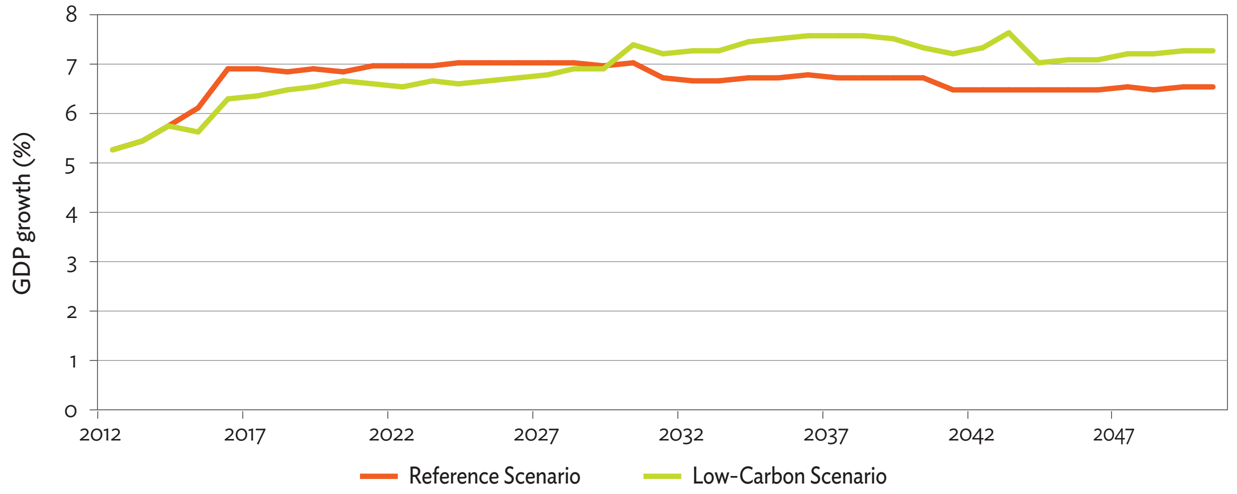
8.3.2 Economic Growth Effects of Low-Carbon Scenario

This analysis finds that low-carbon options will have a short-term initial cost through the 2020s, after which the long-term impact on economic growth is positive (Figure 52). The lower growth rates of GDP during the initial period is mainly a result of the large initial investment to improve energy efficiency of industries, especially for cement and steel, and the investment in changing the power production structure. The new investment in these sectors will withdraw the capital from other sectors of the economy, which may have higher contribution to GDP growth in that year. Over the longer term, efficiency improvements result, and GDP in the low-carbon scenario exceeds that of the reference scenario.

Within specific sectors, the low-carbon scenario initially favors the shares of agriculture and services in the economy (Figure 53). However, after 2040, industry has a higher share of GDP under the low-carbon scenario than under the reference scenario. This is due to initial investment in efficiency that leads to greater long-term productivity, especially in manufacturing.

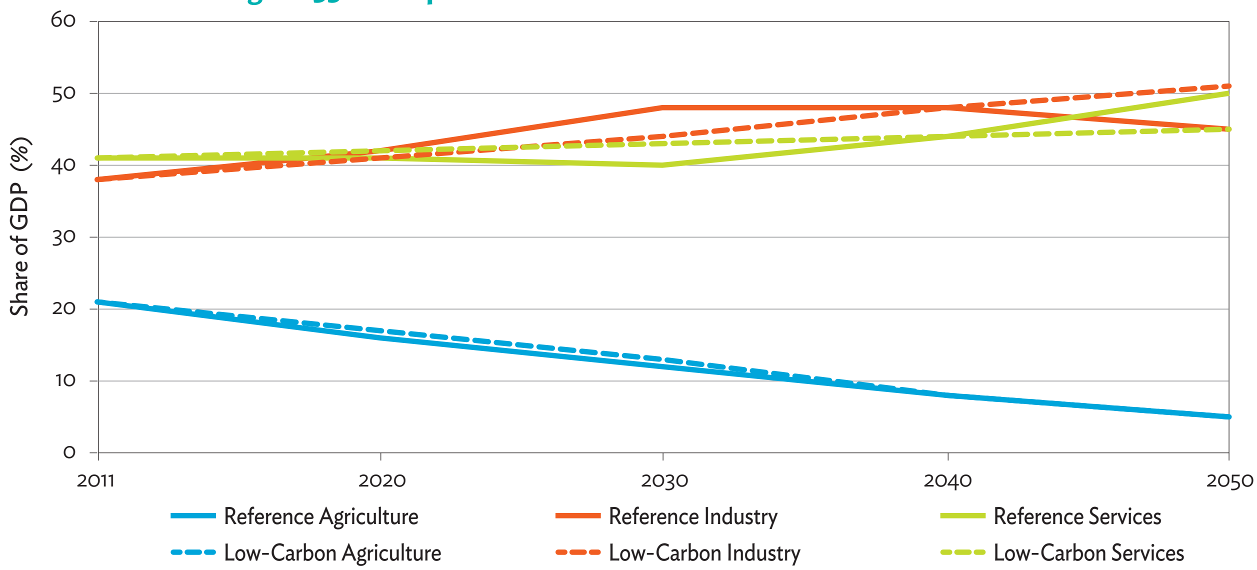
However, the low-carbon scenario results in a lower export value compared with the reference scenario. Low-carbon options also increase private consumption constantly from 2015 as a result of reduced energy expenditure. After 2030, when the impacts on the economy become positive, the gains in private consumption will be larger between the LCS and reference scenario. In addition, low-carbon development may also create the new green industries and services that are not accounted for in this model.

Figure 52: Annual GDP Growth Rate of Reference Scenario and Low-Carbon Scenario, 2011–2050 (%)



GDP = gross domestic product.
Source: Authors.

Figure 53: Composition of GDP under the Modeled Scenarios



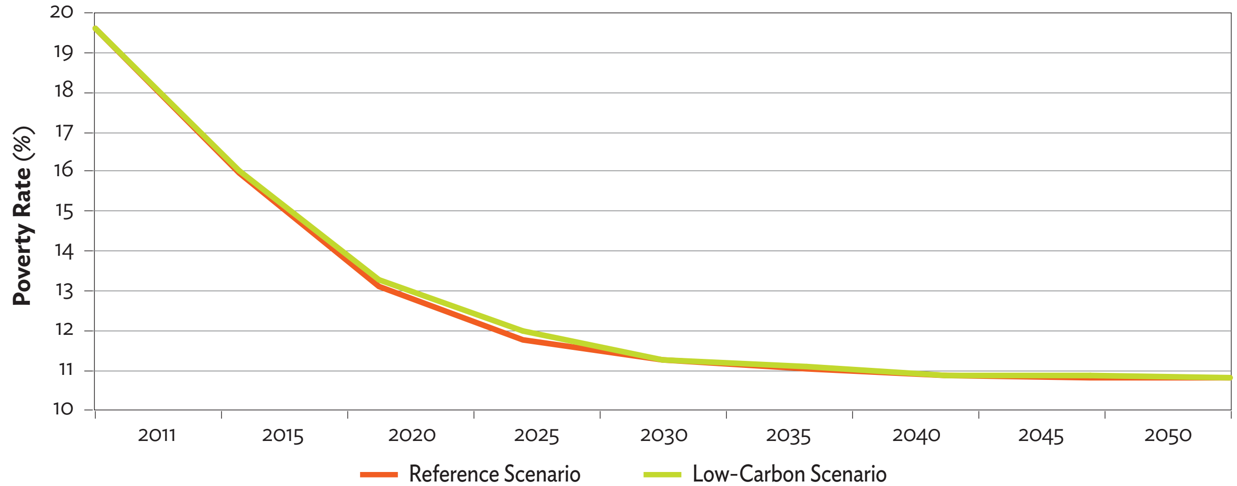
GDP = gross domestic product.
Source: Authors.

8.3.3 Poverty Impacts

The results show that the low-carbon scenario will bring long-term benefits to the economy and will not have regressive distributional implications. According to the model results in Figure 54, poverty reduction is initially very slightly slowed, but is more or less the same in the reference scenario and the low-carbon scenario after 2030.

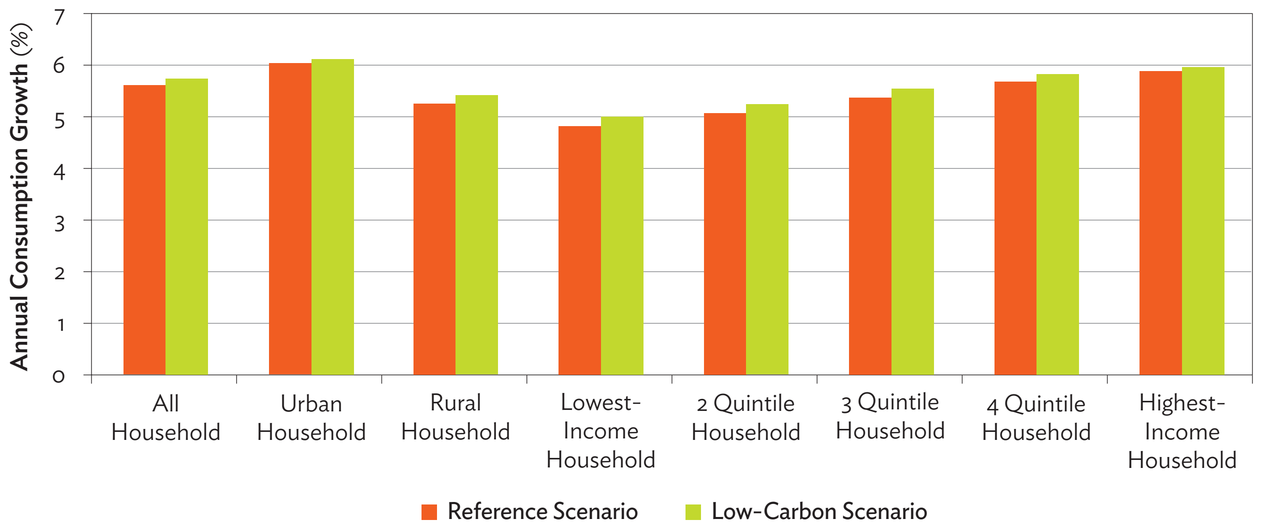
However, the effect on the poverty rate masks the pro-poor nature of the low-carbon scenario. As Figure 55 illustrates, the largest gain in consumption growth under the low-carbon scenario accrues to the groups with the lowest income. This suggests that the poor have more to gain than the higher-income groups from the collective effects of the low-carbon interventions, largely through reduced energy expenditures.

Figure 54: Poverty Headcount Rates of Modeled Scenarios during 2011–2050



Source: Authors.

Figure 55: Average Annual Growth Rate of Household Real Consumption by Scenario

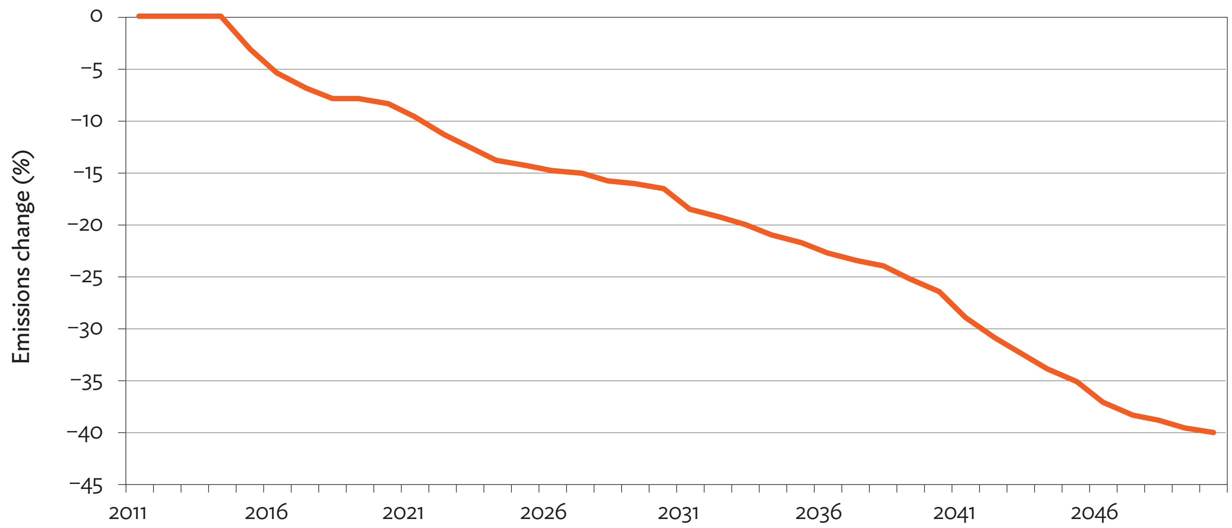


Source: Authors.

8.3.4 Rebound Effects on Emissions

This CGE approach also illustrates that there can be rebound effects conditioning emissions reduction. Figure 56 shows that the low-carbon scenario will reduce GHG emissions by about 40% compared with the reference scenario by 2050, which is smaller than presented earlier. This is a product of two elements. First, the CGE model captures the fact that energy consumption may increase when energy prices fall as a result of reduced demand. Second, the accounting here is against a larger denominator that captures more national emissions, rather than only the sectors subjected to bottom–up analysis.

Figure 56: Change in Greenhouse Gas Emissions of Low-Carbon Scenario Compared with the Reference Scenario



Source: Authors.

9. POLICIES TO REALIZE LOW-CARBON GROWTH POTENTIAL

9.1 Viet Nam's Mitigation Goals Can Be Met or Exceeded

The earlier chapters have demonstrated that Viet Nam can achieve 40% to 53% reduction in greenhouse gas (GHG) emissions by 2050 by using specific enhanced technologies for energy production and consumption. The financial costs of such a transition are found to be modest, while the long-term effect is faster economic growth and a larger economy. Moreover, those benefits are progressively distributed, as poorer populations have larger relative gains than those with more income. These results demonstrate that a low-carbon/green growth development pathway can be economically attractive, requiring lower investment and operating expenses than a "normal" development scenario based on a continuation of current practices.

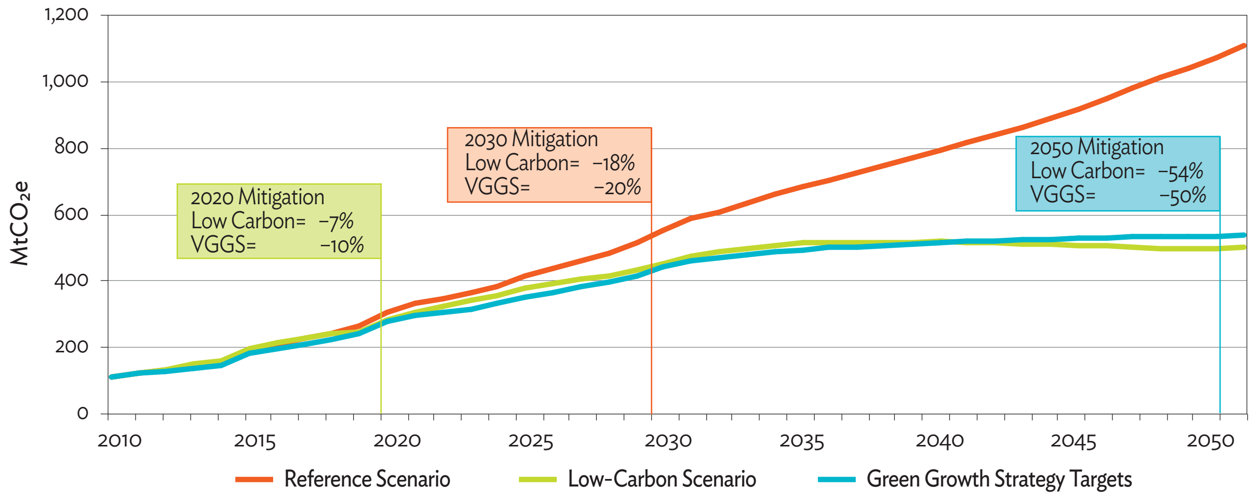
The Viet Nam Green Growth Strategy (VGGS) issued in 2012 and the 2016 Nationally Determined Contribution (NDC) to the Paris Agreement reflect important commitments to emissions reduction. The key targets of the VGGS are to reduce GHG emissions by 1.5%–2% per year by 2030, to reduce GHG in energy activities by 20%–30% compared with business as usual (BAU). The only target set toward 2050 is to reduce GHG emissions by 1.5%–2% per year, which suggests about a 50% reduction. The NDC sets a goal of 8% reduction of all emissions by 2030, which may increase to 25% under international support.

The modeled low-carbon pathway exhibits a direct mitigation of the energy sector of 7.3% in 2020 compared with a VGGS target of 10%. In 2030, the modeled pathway exhibits a mitigation of 18% compared with a VGGS target of 20% and, in 2050, a mitigation of 54% compared with a VGGS target of 50% (Figure 57). The un-modeled sectors mentioned above may also contribute a further mitigation component. The analysis confirms that the long-term targets of the VGGS are achievable. Similarly, the modeled mitigation exceeds the unconditional goal of the NDC, and satisfies most of the relative conditional ambition of the NDC for 2030.

Although relative reduction goals align between the NDC and this study, the study shows that Viet Nam can be on a greener growth trajectory than the NDC envisions. Under the NDC, BAU emissions in 2030 are 787 million tons or a 443% increase from 2010 levels. This study shows reference scenario energy sector emissions of 552 million tons in 2030, or a 393% increase from 2010 levels in those sectors that have the fastest growth in emissions. If grid-supplied electricity emissions are compared, the NDC reflects 404 million tons of carbon dioxide equivalent ($MtCO_2e$) in 2030, while this study finds 325 million tons, reflecting 19% lower-grid emissions without low-carbon options in place. The lower figures in this study are a result of more incorporation of likely efficiency improvements in the reference scenario, such that emissions grow less rapidly.

The 2030 reference emissions level in this study corresponds approximately to 650 million tons if other non-energy emissions are added, which is already 17% below the NDC BAU. In levels, the low-carbon scenario in 2030 represents a 30% reduction from the NDC baseline, without counting any abatement from other sectors. This suggests that a greener growth pathway than is reflected in current goals can be achieved. Given that the low-

Figure 57: Comparison of Reference and Low-Carbon Scenario Emissions with the Viet Nam Green Growth Strategy Targets



$MtCO_2e$ = million tons of carbon dioxide equivalent, VGGS = Viet Nam Green Growth Strategy.
Source: Authors.

carbon scenario leads to faster and more inclusive growth than the reference scenario according to this study, such a greener growth pathway is also in Viet Nam's interest.

9.2 Renewable Power Deployment Can Be Accelerated

Deployment of renewable power is essential to meeting mitigation goals.

Scaling up renewable power is the most important opportunity for mitigation in Viet Nam. Over the modeling period (2010–2050), power generation measures reduced GHG emissions by 64% of the total mitigation potential. The supply-side measures in the power sector—which increase generation from biomass, solar, and to a lesser extent, onshore wind and microhydro—generate a total mitigation of nearly 3,000 $MtCO_2e$ at a negative weighted average marginal abatement cost.

Over the modeling period, investment costs for power sector technology are projected to decrease year-on-year in a manner that is consistent with the international trends adjusted to local conditions. These give new plant investment costs that decrease over time, in real terms, for all plant types with the biggest cost reduction being predicted for utility-scale photovoltaic (PV) and solar thermal plants, followed by wind. At the same time, the analysis forecasts a slight but continual increase in international oil and coal prices in real terms and natural gas prices that tend to stabilize. Consequently, utility-scale PV and biomass become more cost-effective forms of generation than coal from 2020 onward when compared with both national coal and imported coal.

The ability to avoid importing expensive coal in the low-carbon scenario is a major contributor to low abatement costs. A trend of coal imports is already beginning. In 2016, Vinacomin will start to import between 2 million and 3 million tons of coal, with projections to reach nearly 20 million tons by 2020, or 30% of demand. Similarly, this analysis finds that by 2050, almost 3 out of 4 coal-based gigawatt-hours (GWh) come from imported coal. Thus, biofuel and utility-scale PV should displace imported coal. Beyond 2030, there is value to avoiding the creation of new infrastructure around an increased use of imported coal—with inherent energy security issues—and moving as quickly as possible to renewable sources that reduce the cost of generation.

Deployment of renewable power can be accelerated, compared with current plans.

Changing the energy mix requires major changes to power development plans—especially in terms of longer-term development. By 2030, 68% of capacity installed and 71% of electricity generated is expected to be from fossil fuels under PDP-VII. The low-carbon scenario drops this to 59% and 62%, respectively. The difference from the 2050 extrapolation of PDP-VII-interim-revision is more profound, with current plans leading to 57% of capacity and 55% of generation from fossil fuels, while the low-carbon scenario cuts this in half to 26% of capacity and 29% of generation.

The results of this study are largely aligned with the Viet Nam Renewable Energy Development Strategy (VREDS), which shows much more adoption of renewable energy than the PDP-VII-interim-revision (or PDP-VII-Revised). The share of renewables through 2030 in electricity generation is very similar in this study and the VREDS (31%), as is aggregate electricity production of around 1,050 terawatt-hours (TWh) in 2050 (Table 16). Over the period to 2050, this study shows a bit more potential for renewables than currently envisaged, and this additional potential may come from biomass. Even in that sense, this study and the VREDS may show similar messages, as the VREDS portrays biomass utilization for heating and biofuels, while this study uses that biomass potential for power generation. At the same time, this study is actually more conservative about the deployment of wind and solar power than the VREDS, which has large adoption after 2030.

Given the similarity in overall renewable shares for much of the analytical period, this study helps to illustrate a similar level of mitigation as has been envisioned under the VREDS. Many costs will be similar, given that both studies model the displacement of increasing imports of coal-fired power plants with renewable energy technologies that are cheaper over the long term. This study can be taken as evidence that the VREDS approach helps to achieve substantial abatement at minimal cost relative to the existing plans for a power sector that is increasingly dependent on coal.

Viet Nam's PDP-VII-Revised portrays an updated composition of the power sector for 2011–2020 and vision to 2030. Here, generation is much more fossil-fuel dominated, as may be expected under the lower mitigation ambition, compared with this study. Table 17 presents the generation mix under this master plan.

In 2030, coal-fired thermal power is planned to account for 53.2% of total electricity generated in Viet Nam, while the corresponding figure in the low-carbon scenario reflects 38%. In contrast, the hydropower share is much higher in this study at 20% compared with that of PDP-VII-Revised, which comes with only 12% in 2030.

Table 16: Renewable Energy Goals of Viet Nam's Renewable Energy Development Strategy

		2015	2020	2030	2050
Electricity	**Total electricity generation** (TWh)	**160**	**260**	**587**	**1,049**
	Renewable share (%)	35.0	38.4	31.5	43.0
	Hydropower (% of electricity generation)	34.5	33.9	16.5	9.9
	Biomass (% of electricity generation)	0.4	3.0	6.3	8.1
	Wind (% of electricity generation)	0.1	1.0	2.7	5.0
	Solar (% of electricity generation)	0.1	0.5	6.0	20.0
Primary energy	**Total primary energy** (TWh)	**914.3**	**1,388.1**	**2,232.4**	**3,647.6**
	Renewable share (%)	31.8	31.0	32.3	44.0
	Biofuel production (% of primary energy)	0.3	0.7	3.3	6.2
	Solar heating (% of primary energy)	17.4	12.3	10.4	9.2
	Biomass heating (% of primary energy)	0.0	0.9	1.6	1.9

TWh = terawatt-hour.
Source: Authors' interpretation of the Viet Nam Prime Minister's Decision No. 2068/QD-TTg.

Table 17: Power Generation Mix of Viet Nam under PDP-VII-Revised (%)

Source	2020	2025	2030
Hydropower (% of electricity generation)	25.2	17.4	12.4
Coal-fired thermal (% of electricity generation)	49.3	55	53.2
Gas-fired thermal (% of electricity generation), including liquefied petroleum gas	16.6	19.1	16.8
Renewable share	6.5	6.9	10.7 and nuclear share of 5.7
Imported (% of electricity generation)	2.4	1.6	1.2

Source: Decision No. 428/QD-TTg dated 18 March 2016 by the Prime Minister of Viet Nam.

Incentives are important to attract investment in low-carbon energy.

Risk can be a substantial barrier to renewable energy investment, as such investments are dependent on public policies that are subject to change, and may have front-loaded costs with long periods of payoff. Risk-reducing measures, such as loan and risk guarantees, may be important to attract private investment in this context. The Government currently offers loan guarantees, with subsidized interest for projects covered under the Viet Nam Environment Protection Fund to support science and technology development; the National Fund for Technology Innovation; the National Program for High Technology Development; the National Target Program on Energy Efficiency and Conservation; and the Strategy on Cleaner Industrial Production to 2020, among others. However, the actual financial resources for these loans are quite limited. For example, the Viet Nam Environment Protection Fund loans totaled D40.55 billion (around $1.93 million) from 2011 up to 2015 for six projects to construct waste collection and treatment stations for livestock, seafood processing units, and renewable energies (biomass). Other larger projects funded from international funds are the Global Environment Facility and the Viet Nam Environment Protection Fund—such as the Promotion of Non-Fired Brick Production and Utilization in Viet Nam (2014–2018) totaling $38.88 million as well.

Tax incentives for renewable power development currently include exemption or reductions in import tax and corporate income tax on wind power and biomass power projects in Viet Nam. These measures can be expanded to cover solar projects as well. For example, import tax is reduced for the projects that are listed as special prioritized investments including those for developing power from solar, wind, biogas, geothermal, or tidal sources.[28] Exemption and reductions in corporate income tax are applied on biomass power projects, and import exemption is applied on imported goods, which are used for manufacturing fixed assets or materials and semi-products for producing biomass power in accordance with Decision No. 24/2014/QD-TTg dated 24 March 2014. In addition, the Ministry of Industry and Trade (MOIT) is drafting a Decision of the Prime Minister for supporting solar power development in Viet Nam.[29] According to the draft, solar power projects will be supported by investment capital, tax, and land rent concessions.

Feed-in tariffs encourage investment and help to ensure a market for renewable power. At present, Viet Nam has applied a feed-in tariff mechanism for wind and biomass power industries but not yet for other forms of renewable energy. The feed-in tariff offers a price of about $0.078 per kilowatt-hour (kWh) for wind power (average electricity tariff from other energy sources was $0.078/kWh). The Government also subsidizes about $0.01/kWh for electricity purchasers (applied from August 2011) and about $0.058/kWh for biomass power.[30] The grid-connected solar power is also expected to be eligible for feed-in tariffs soon.

28 Decree No. 87/2010/ND-CP dated 13 August 2010 of the Government of Viet Nam, detailing a number of articles of the law on import duty and export duty.

29 Viet Nam Energy Online. http://nangluongvietnam.vn/news/vn/dien-hat-nhan-nang-luong-tai-tao/nang-luong-tai-tao/du-an-dien-mat-troi-se-duoc-huong-nhieu-co-che-uu-dai.html.

30 These are only approximations in US dollars because the feed-in tariff values are stipulated in dong. Anyway, these values are subject to be adjusted according to exchange rate of the US dollar to the dong. Sources: Decision No. 37/2011/QD-TTg dated 29 June 2011 of the Prime Minister, on the mechanism supporting the development of wind power project in Viet Nam; and Decision No. 24/2014/QD-TTg dated 24 March 2014 of the Prime Minister, on support mechanism for development of biomass power projects in Viet Nam.

Net metering promotes small-scale renewable generation investment by facilitating electricity sales back into the grid. This instrument is being considered by the Government to encourage solar energy system owners (including both businesses and households). This electricity billing mechanism helps owners reduce their production costs and is a good leverage for solar energy development in Viet Nam. To realize the large share of solar power reflected in the low-carbon scenario, net metering should be prioritized. This policy is stipulated in VREDS by 2030 (vision to 2050), in which the net metering mechanism is applied to end-user customers who produce renewable electricity.[31]

The application of more **standard producer purchase agreements** especially for renewable energy companies should be promoted. Currently, standard producer purchase agreements are available for small hydropower plants in Viet Nam. These can be more effective if they are available for other renewable energy sources.

Renewable portfolio standards are applied in many countries to require minimum shares of renewable power generation from power-producing companies. In Viet Nam, portfolio standards currently stipulate 3% by 2020, 10% by 2030, and 20% of total power generation by 2050, according to VREDS.

Development of advanced energy technologies ultimately helps to lower the cost of a low-carbon transition. The rising use of biomass over the long term for power generation in the low-carbon scenario could be facilitated by the application of second-generation biofuels, which have only recently become commercially viable.

Piloting advanced energy technologies is essential for new technologies to become viable when they need to be adapted to Viet Nam's conditions. To scale up energy production from biomass, as envisioned both under this study and the VREDS, collection of agricultural residues from broad and geographically dispersed locations needs to be established. To address this challenge—as it involves coordination with many actors, including producers, collectors, processors, and transporters—logistical innovations will be needed, along with appropriate infrastructure for preprocessing and refining. Currently, Viet Nam has few small sugarcane biomass power plants such as those in Tuyen Quang province. These can be expanded to include those using other residues from cash crops, waste, and urban wastewater.

9.3 Energy Efficiency is Essential to Low-Carbon Growth

Energy-efficiency targets can be achieved by carrying out targeted measures. Improving energy-efficiency is found in this study to have a lower economic cost than increasing generation, and thus is important to achieving low cost mitigation potential. Energy-efficiency targets were set in the Viet Nam Green Growth Strategy (VGGS), including a reduction of 2%–3% per year of energy consumption per gross domestic product (GDP) and a reduction of electricity consumption elasticity of GDP from 2 to 1 by 2020. The results of the efficiency measures considered here lead to the electricity elasticity of GDP to fall from 2 to 1 for modeled sectors by the early 2020s, which is consistent with these goals. A large share of these gains can be achieved via a few identified efficiency improvements in households and industries.

Energy subsidy reform can encourage improved efficiency. Energy pricing reform in the reference case is an essential prerequisite for low-carbon/green growth development. Although Viet Nam has recently had substantial fossil fuel subsidies for the power sector (UNDP 2014), getting the prices right on energy by removing direct and indirect subsidies and fully adopting market-based prices is part of the country's current policy framework.[32] As fossil fuel subsidies encourage energy inefficiency, make

31 By Decision No. 2068/QD-TTg dated 25 November 2015 by the Prime Minister, approving the development strategy of renewable energy of Viet Nam by 2030 with a vision to 2050.

32 According to Decision 1855/QD-TTg dated 27 December 2007 of the Prime Minister, approving Viet Nam's national energy development strategy up to 2020, with 2050 vision.

investment in efficient equipment uneconomic and renewable energy uncompetitive, their removal can set the right incentives for the measures assessed here. The Government has basically removed subsidies for all non-electricity fossil fuels. More can be done by completely eliminating subsidies and fully adopting market prices for electricity in Viet Nam.

A range of other regulatory and incentive measures can be an incentive toward greater efficiency. Current tax incentives for investments in energy efficiency are concessions on import taxes, export taxes, corporate income taxes, and land-use tax according to investments in energy-saving products, production chains, or technologies.[33] These can be complemented by measures to improve information availability on efficient practices, particularly in industry, such as quality assured energy audits, energy performance benchmarking, and public reporting on energy efficiency performance. Such reporting can also enhance the transparency and effectiveness of fiscal measures.

Minimum energy performance standards (MEPS) can set ambitious efficiency targets through the application of enhanced mandatory standards that tighten over time. These standards can be applied to household consumer items as well as to industry. In Viet Nam, MEPS were applied from 1 January 2015 in accordance with Decision No. 03/2013/QĐ-TTg.[34] These MEPS cover compact fluorescent lamps, fluorescent lamps (tube type), electronic ballasts in fluorescent lamps, magnetic ballasts in fluorescent lamps, refrigerators, washing machines, rice cookers, electric fans, storage water heaters, TVs, air conditioners, computer screens, printers, photocopiers for the household sector and distribution transformers, electric motors, and boilers used in industrial factories. They are based on Viet Nam's standards (according to Decision No. 78/2013/QĐ-TTg dated 25 December 2013[35] and Dispatch No. 1808/TCNL-KHCN of the General Department of Energy dated 30 December 2014),[36] and are linked to standards of the International Electrotechnical Commission. These standards could be improved by expanding coverage to all other electronic household appliances and industrial equipment. They could also be linked to those of a larger market, so as to reduce regulatory costs and promote trade links through market integration.

Transparent labeling of information on the energy-efficiency performance of energy-demanding equipment and appliances can help reinforce demand for efficient units. Viet Nam currently requires the labeling of appliances and equipment in specific types of products—including household appliances and transportation means (under 7-seater autos) before they are provided to the market.[37] Household appliances include computer monitors, printers, photocopiers, air conditioners with frequency converters, and television receivers. The list could be expanded in the future to include more appliances and equipment.

Green building codes can require energy efficiency. Buildings represent an important and growing share of energy consumption, particularly for heating and/or cooling and lighting, and in this study, cooling is identified as a major source of emissions reduction. In Viet Nam, building codes cover energy-efficiency measures related to mandatory technical standards to achieve energy efficiency in the design, new construction, or retrofit of civil buildings (office buildings, hotels, hospitals, schools, commercial buildings, service buildings, apartment buildings, among others) with a gross floor area of 2,500 square

33 According to Law No. 50/2010/QH12 of 17 June 2010, on the economical and efficient use of energy.

34 Decision No. 03/2013/QĐ-TTg dated 14 January 2013 of the Prime Minister, amending and supplementing a number of articles of the Prime Minister's Decision No. 51/2011/QD-TTG of 12 September 2011, promulgating the list of devices and equipment subject to energy labeling and application of the minimum energy efficiency, and the implementation road map.

35 Decision No. 78/2013/QD-TTg dated 25 December 2013, promulgating the list of energy consumption vehicles, equipment for disposal and ban on construction of low-efficiency power plants.

36 Dispatch No. 1808/TCNL-KHCN dated 30 December 2014 of the Ministry of Industry and Trade, providing guidance on road map of energy labeling and application of the minimum energy efficiency.

37 By Decision No. 03/2013/QĐ-TTg dated 14 January 2013 of the Prime Minister, amending and supplementing a number of articles of the Prime Minister's Decision No. 51/2011/QD-TTG of 12 September 2011, promulgating the list of devices and equipment subject to energy labeling and application of the minimum energy efficiency, and the implementation road map.

meters or more. The requirements of this code apply to the building envelope, except envelopes of non-air-conditioned storage space or warehouses; and equipment and systems in the building, including interior lighting, ventilation and air conditioning, water heating, energy management equipment, and elevators and escalators.[38] Those codes can be improved to promote efficiency through stricter compliance with these standards.

Markets for energy service companies can be improved. Energy service companies (ESCOs) help to provide energy solutions to energy consumers, and are paid on the basis of reductions in energy costs. As a result, they can play a key role in facilitating the adoption of technologies and other energy-efficiency measures such as those assessed in this study. At present, the number of ESCOs in Viet Nam is very limited and legal and policy frameworks are lacking specific regulations for this type of business. The market for ESCOs can be improved by stipulating a clear legal framework in which a market for them could thrive. Bidding for energy solutions should also be widely applied to find the best ESCO for energy consumers. Awareness raising and information distribution on the ESCO markets and services can be enhanced as well.

9.4 Transportation Improvements Reduce Emissions while Generating Important Co-Benefits

Transport is an important area for mitigation attention, not only because mitigation potential is substantial, with 640 $MtCO_2e$ from 2010 to 2050, but because improved transport has many co-benefits. Without mitigation actions, emissions of particulate matter (PM) and nitrogen oxide (NO_x) are projected to escalate rapidly, with negative effects on respiratory ailments and mortality. Although not quantified here in terms of benefits, modal shifts reduce congestion and transport times, while lower emissions technologies generally also lead to reduced pollution and health benefits.

Of the 10 different packages of measures considered, 544 $MtCO_2e$ of mitigation came from the following four measures:

(i) 200 $MtCO_2e$ from technology improvement in private vehicles toward the European Union (EU) efficiency standards;

(ii) 180 $MtCO_2e$ from increased sales of electric two-wheelers;

(iii) 96 $MtCO_2e$ from increasing the use of biofuel; and

(iv) 76 $MtCO_2e$ from passenger modal shift from two-wheelers and cars to public transit.

Vehicle efficiency and emissions standards are an accessible low-cost mitigation policy option. Since private car ownership can be expected to grow from 500,000 in 2010 to 17.8 million in 2050 and as cars can often have a long useful life, it is imperative that those that enter the market are as efficient (and clean) as possible. In developed economies (including those with a high-end-user fuel cost, such as the EU), the efficiency or CO_2 emissions regulations of fleets sold by manufacturers are important to improving average actual fuel efficiency. Emissions standards can be expanded to include clean fuel to be used in urban transportation. About 5%–20% of buses and taxis are targeted to use liquefied petroleum gas (LPG), compressed natural gas (CNG), or solar energy by 2020, strengthened to require checking and controlling technical safety and environmental protection conditions for road vehicles.[39]

Fleet regulations to stipulate large shares of motorcycle sales play a similar role. This is especially important in Viet Nam given the prevalence of motorcycles in the overall vehicle mix. In the process, electric motorcycles are important

38 According to Circular No. 15/2013/TT-BXD dated 26 September 2013 by the Ministry of Construction, promulgating the National Technical Regulation on Energy Efficiency Buildings (QCVN 09:2013/BXD).

39 Decision No. 318/QD-TTg dated 4 March 2014 of the Prime Minister, approving the Strategy for Development of Transportation Services through 2020, and Orientations Toward 2030.

to improving urban air quality and reducing noise pollution. Viet Nam has no target share of electric motorcycles in its strategy for transportation service development by 2020 and direction by 2030. Electric bicycles have been introduced to Viet Nam in recent years although they have not yet been as popular as motorcycles.

Biofuel blending mandates can be expanded in Viet Nam to help reduce emissions. Viet Nam is only introducing a 5% ethanol blending mandate for gasoline and has no mandate for diesel. Expanding this to 10% or more, as is common in other countries, can help to reduce emissions. Emissions reduction can be most meaningful over the fuel life cycle if the ethanol is produced via second generation biofuels that rely on agricultural residues.

Modal shifts are important to reduce emissions from private vehicles, and are likely to have greater effects than captured in this modeling, as not only are emissions avoided directly from passengers using more efficient modes, but congestion is reduced, such that emissions fall from remaining road transport. The study portrays a future in which half of all motorized passenger-kilometers are handled by mass transit, which is a very ambitious goal. To facilitate such a shift, policies are required to actively discourage car ownership and use within cities. This is best accomplished in the context of overall urban planning for efficient public transit, as well as integrated transport development that maximizes the convenience of public facilities. Ensuring shifts to public transit fundamentally depends upon mass transit being an attractive option for commuters, which in turn requires sufficient investment in public transit infrastructure.

9.5 Cross-Sector Planning is Needed to Realize Mitigation Potential

There is a complex array of interlinkages between and among the low-carbon options assessed in this study. For example, changes to the efficiency of electricity use affect the amount of electricity to be generated, and a large share of residential electricity use is shown to be driven by heating and cooling practices that may be conditioned by building codes. Adoption of electric vehicles will also increase demand for electricity at particular times for charging. Modal shifts toward public transport will depend on appropriate urban planning practices. Increased use of biomass and biofuels for energy will require changes to agricultural practices, so that residues are collected. The responsibility for each of these aspects is presently spread among various line ministries in Viet Nam at the national level and among different levels of Government.

The low-carbon scenario of this study requires a closely coordinated approach to maximize intersectoral synergies and avoid tensions. Viet Nam has a long history of economy-wide assessment of green growth potential, although most quantitative assessments have not gone beyond 2030, when mitigation potential can be best realized over a longer period, as many investment decisions have emissions implications for several decades or more. This study helps to pioneer longer-range planning, but it is only a starting point. To execute the low-carbon scenario, intersectoral planning needs to be continued at a greater level of detail, and be continuously updated as new information becomes available.

This study has not modeled scenarios for emissions taxation or regulation of emissions. If such were in place, many of the mitigation responses quantified here would be naturally induced. Low marginal abatement costs for large amounts of mitigation imply that even low-carbon prices may imply large levels of emission reduction. At the same time, reducing investor risks and other barriers to green investment, investing in energy-efficient public infrastructure, ensuring sufficient intersectoral coordination, and facilitating technology deployment will remain important even where economy-wide emissions policies are adopted.

10. CONCLUSIONS

This study finds that specific low-carbon development options can allow Viet Nam's greenhouse gas (GHG) emissions to peak by 2035, rather than continually rise through 2050 and beyond. This leads to a reduction in energy emissions of up to 53% by 2050. In direct financial terms, all assessed options have negative to very low abatement costs. Although, in economic terms, there is some very minor initial cost, over the longer term, Viet Nam's economy is found to benefit from a low-carbon growth scenario. Moreover, the poorest populations are found to benefit most.

Such mitigation meets the goals of the Viet Nam Green Growth Strategy (VGGS), and exceeds those of the Nationally Determined Contribution (NDC). As a result, ambitious mitigation is fully possible at negative to low cost to a greater extent than is reflected in key Government policies.

The power sector accounts for about two-thirds of the mitigation potential assessed. Falling costs for renewable energy allow renewable generation capacity to substitute for increasing reliance on expensive imported coal at negative to low cost. Viet Nam is rich in renewable energy resources, such as wind, solar, and hydro resources, and also has substantial biomass potential that can be exploited. Given that new and modern technologies for producing renewable energies have not yet been developed in Viet Nam on a large scale, renewable power expansion is possible at low cost. These results generally support the Viet Nam Renewable Energy Development Strategy (VREDS) approved in 2015, which has similar renewable energy shares for much of the analytical period to this study. However, realizing the potential of renewable energy requires policies that can better leverage private sector investment.

Energy security is an important consideration, to which energy efficiency can make important contributions. The study shows a range of possible energy-efficiency measures that could be promoted through appropriate regulations, as well as measures such as labeling support to energy service companies and energy pricing, which create incentives for efficiency.

Measures for transportation contribute about 15% of mitigation, but may be much more socially important than this share suggests due to large co-benefits, especially for health. A number of transport options can be achieved through relatively simple regulatory changes, such as fleet sales requirements and blending mandates. Others, such as modal shifts, can be best implemented in the context of sound urban planning.

There are interaction effects between these low-carbon interventions and among the sectors in which they are implemented. For example, changes to energy demand from energy efficiency and transport measures affect the optimal power generation mix. Urban planning will condition the effectiveness of energy-efficiency measures related to building and transportation. This means that low-carbon development may be most effective if low-carbon and green growth considerations are included in all planning processes across sectors and ministries.

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* ADB recognizes "China" as the People's Republic of China, "Vietnam" as Viet Nam, and "Hanoi" as Ha Noi.

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APPENDIX: DETAILS ON TECHNICAL POTENTIAL TO IMPROVE DEMAND-SIDE ENERGY EFFICIENCY

The following section outlines details and specific means by which the mitigation potential described in Chapters 3 and 4 is achieved. For residential electricity, it outlines the effects of improved standards by appliance on electricity consumption, while for industry it outlines the technical options employed in each industry subsector in terms of investment requirements, adoption over time, effects on variable costs, and mitigation outcomes.

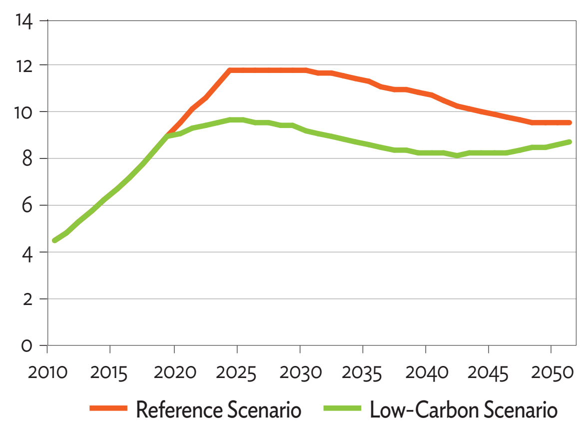
1. Residential Electricity

Three sets of more efficient appliances, cooling and/or heating, and lighting have been assessed, within which multiple subcategories of technologies are individually appraised. The technical options employed and potential effects on energy consumption are as follows:

1.1 Home Appliances

Refrigerators consume much additional power in the medium term, but growth in power consumption can be curbed by applying energy-efficiency standards on more efficient technologies such as magnetic refrigeration. The area between the two curves on Figure A1 represents the energy savings of having enacted this policy.

Figure A1: Total Electricity Consumption from Refrigerators in the Reference and Low-Carbon Scenarios
(TWh/yr)

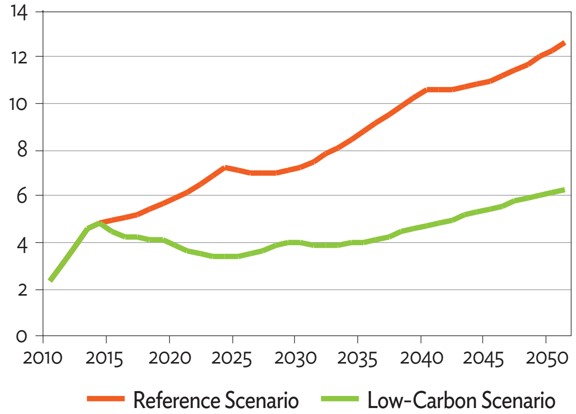


TWh = terawatt-hour.
Source: Authors.

1.2 Lighting

Short-term measures for lighting in the low-carbon and reference scenarios include eliminating incandescent lamps and magnetic ballasts in fluorescent lighting in 2016. Over the longer term, standards are extended to require LED and other similar lighting sources, with 120 lumens per watt in 2020 and 150 lumens per watt in 2030. Figure A2 shows the effectiveness of these measures when compared with the reference scenario.

Figure A2: Total Electricity Consumption from Lighting in the Reference and Low-Carbon Scenarios
(TWh/yr)



TWh = terawatt-hour.
Source: Authors.

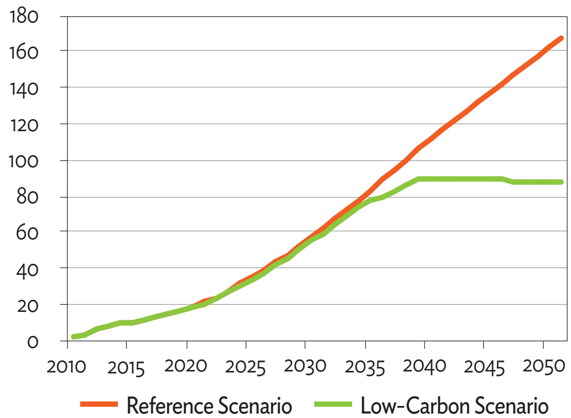
1.3 Heating and Cooling

Under the Viet Nam Household Living Standards Survey, households were analyzed by household disposable income. As households become predominantly urban, with fast-rising income over the modeling period, their demand for air conditioning (AC) will increase and become their fastest-growing energy need. In later years, the expected growth of the resultant energy demand cannot be offset by improved energy efficiency of the AC units themselves. Even with an accelerated adoption of the highest efficiency AC units, their electricity demand would continue to rise sharply.

To offset this growth, the International Finance Corporation's EDGE Buildings Model was used to evaluate other measures that could be more cost-effective in limiting electricity demanded for AC than further tightening AC efficiency standards.[1] For Viet Nam, the analysis showed two measures that would be possible to retrofit into existing buildings and have significant impact on their energy requirement: (i) the incorporation of low-e coated glass or external shading devices on windows to reduce the amount of heat entering the building;[2] and (ii) the use of ceiling fans in combination with AC units, which can give the same level of comfort with lower power consumption than using AC units by themselves.

The low-carbon scenario assesses the impacts of incorporating both measures into households at the same rate as new air conditioners are bought, which over a couple of decades would be incorporated into most urban households. It also assesses requiring from 2035 onward the installation of low-e coated glass that meets Energy Star standards in habitable rooms that have new AC units installed. From 2040 onward, the scenario assumes that any habitable room that has a new AC installed would also have a ceiling fan. Figure A3 compares the impact of these measures against the reference scenario.

Figure A3: Total Electricity Consumption from Air Conditioning in the Reference and Low-Carbon Scenarios
(TWh/yr)



TWh= terawatt-hour.
Source: Authors.

The impact of these two measures is significant. According to the International Finance Corporation's EDGE Buildings Model for a typical 75-square-meter (m^2) apartment (considering a weighted average annual climate between Ha Noi and

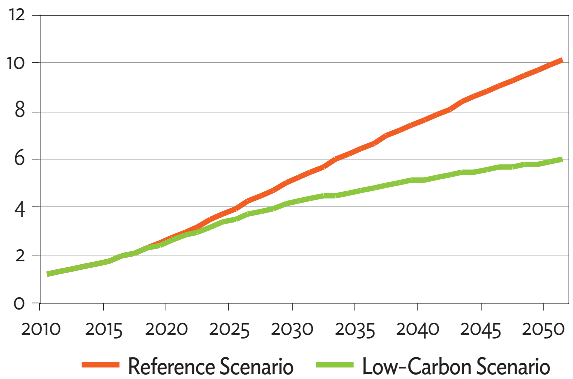
1 International Finance Corporation. Excellence in Design for Greater Efficiencies. http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/edge.

2 ENERGY.GOV Energy Saver. Energy-Efficient Windows. http://energy.gov/energysaver/energy-efficient-windows.

Ho Chi Minh City), the first measure shall reduce the AC energy consumption by 24.2% while the two measures together (low-e glass and ceiling fan) can reduce energy consumption by 55.2%.

The low-carbon scenario for household water heating also assumes a concerted policy to introduce solar water heaters with electric backup, such that they account for 50% of all new water heater sales by 2030 and 70% by 2050. The scenario considers that initially this could be a requirement for all new construction and later extended into the replacement market. As can be seen in Figure A4, the impact is substantial.

Figure A4: Total Electricity Consumption from Water Heating in the Reference and Low-Carbon Scenarios
(TWh/yr)



TWh = terawatt-hour
Source: Authors.

2. Industry

A total of 41 technical options for reducing energy use and emissions have been appraised in the iron and steel, cement, fertilizer, and petroleum refining industries. Detailed parameters on investment and variable expenditure requirements, plausible adoption rates over time, effects on energy use, and process emissions are presented below.

2.1 Iron and Steel

2.1.1 Iron and Steel Small-Scale Producers

The energy intensity for existing plants is approximately 6.7 gigajoules per ton (GJ/t) and the scenario does not consider any major changes to this industry subsector.[3] These plants are dependent on grid-based electricity and therefore the abatement options for the small steel sector of Viet Nam have been selected with a view to reduce their electricity consumption (Table A1). Figure A5 shows the adoption rate that has been used for each measure. Figure A6 shows the resultant carbon dioxide equivalent (CO_2e) emissions from the plants over 2010–2050.

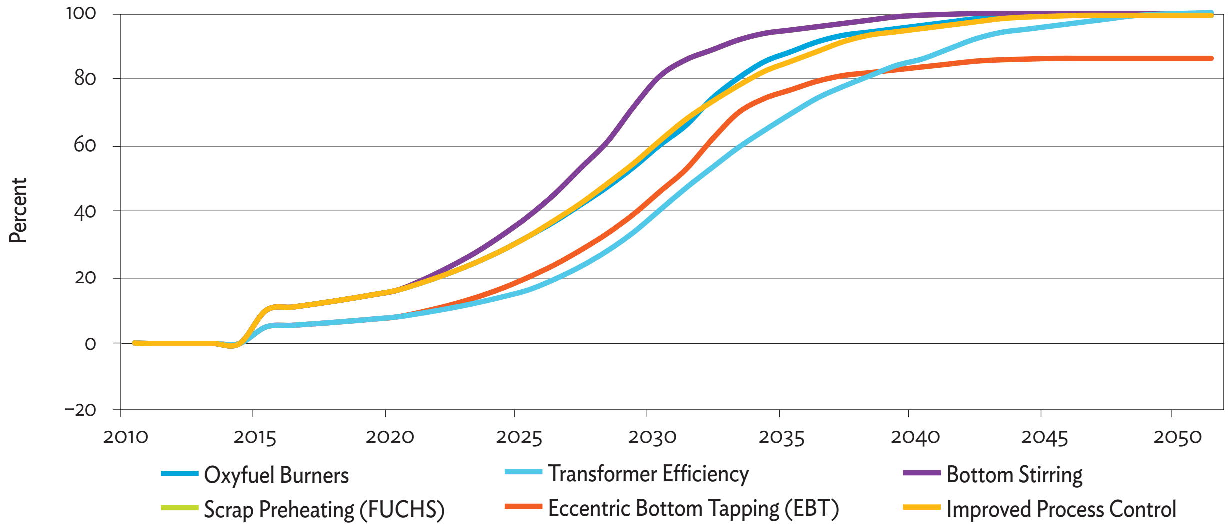
Table A1: Small-Scale Steel Producer Abatement Options

Abatement Option	Capital Expenditure ($/ton)	O&M Expense ($/ton)	Energy Savings (GJ/ton)
Oxyfuel burners	7.5	(0.17)	0.14
Eccentric bottom tapping	5	0	0.05
Scrap preheating (FUCHS)[a]	9.4	(0.8)	0.43
Bottom stirring	0.94	0.08	0.07
Transformer efficiency improvement	2.75	0	0.19
Improved process control	0.95	0	0.33

( ) = negative, GJ = gigajoule, O&M = operation and maintenance.
[a] The FUCHS shaft furnace is a batch-feed system. Within the shaft, scrap is preheated by low-velocity gases from the electric arc furnaces (EAF) and then dropped into the EAF (Intergovernmental Panel on Climate Change. 2001. *Climate Change 2001: The Scientific Basis.* Cambridge, UK).
Source: Authors.

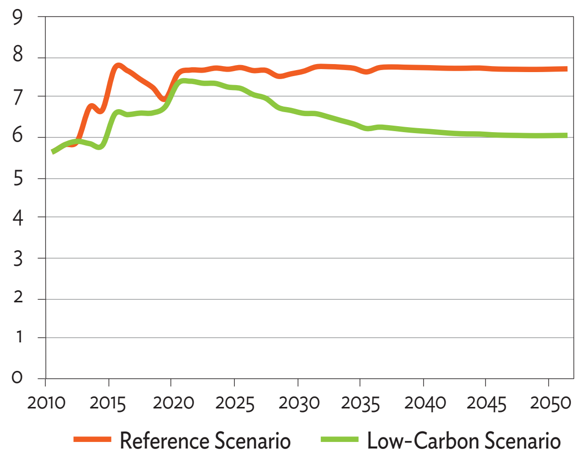
[3] Institute of Energy.

Figure A5: Adoption Rate of Energy Intensity Measures for Small-Scale Steel Producers



Source: Authors.

Figure A6: Total Emissions from Energy and Processes in Small-Scale Steel Plants ($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

2.1.2 Iron and Steel Integrated Steel Plants

The energy intensity of existing integrated steel plants (ISPs) is estimated as 29.5 GJ/t.[4] Most of the future capacity is expected to come from the blast furnace to basic oxygen furnace production route, and the energy intensity of new plants is assumed to be 25.1 GJ/t by 2030 from 29.1 GJ/t in 2012.[5]

Table A2 illustrates that efficiency measures have substantial differences in initial capital expenditure, although little effect on variable costs. Figure A7 illustrates that all technologies follow a similar sigmoidal diffusion curve, although the slowest adoption occurs for the most expensive investments on casting technology. Figure A8 illustrates how technology improvements allow emissions to stabilize after 2020, rather than grow at a linear rate through 2050, with substantial effects.

The current energy intensity of ISPs is well above the global benchmark of 12.5 GJ/ton (UNIDO 2010). However, this can be expected to improve in the

4 Discussions with Institute of Energy (IEVN) experts.
5 Discussions with IEVN experts.

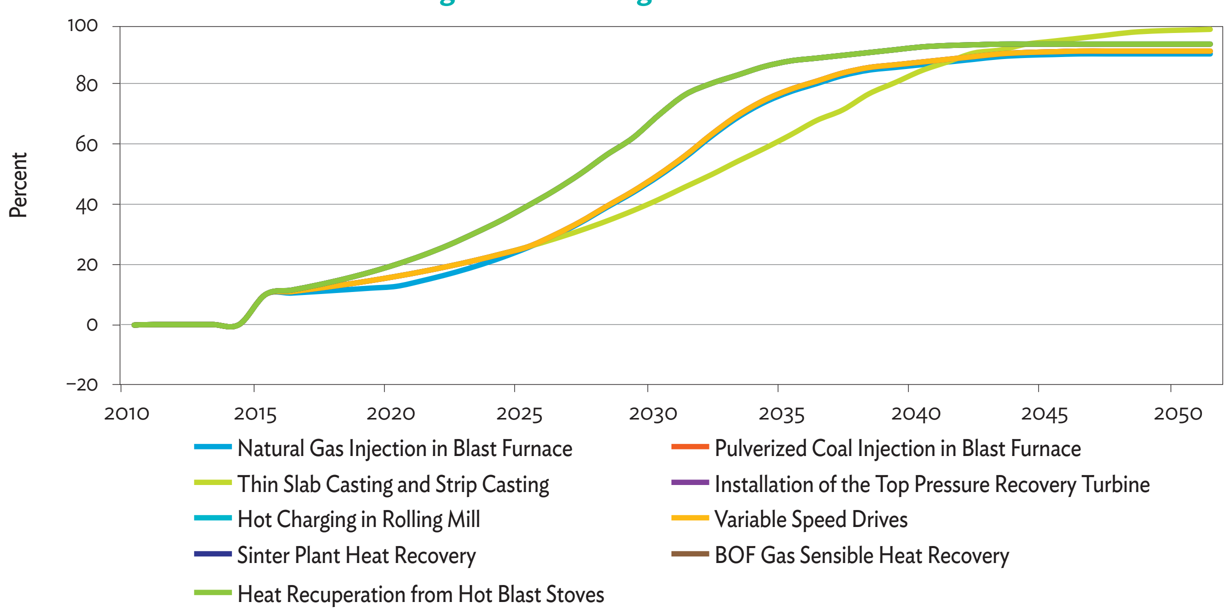
reference scenario as a result of inherent technology improvement. In the low-carbon scenario, significant gains can be made by incorporating technologies, such as continuous casting, pulverized coal injection, and heat recovery for the process and for electricity generation. With full-scale utilization of the waste gas for generation, some ISPs would be in a position to supply electricity to the grid, assuming cogeneration is actively promoted in future development plans.

Table A2: Abatement Options for Integrated Steel Plants

Abatement Option	Capital Expenditure ($/ton)	O&M Expense ($/ton)	Energy Savings (GJ/ton)
Coke dry quenching	85	3.4	1.41 (energy generation)
BFG, COG-based power generation	20	0.8	Computed from calorific values of the gases
Heat recuperation from hot blast stoves	2	0	0.08 GJ/ton of hot metal
Sinter plant heat recovery	5	0	0.55
BOF gas sensible heat recovery	35	0	0.73
Natural gas injection in blast furnace	5	0	0.80
Pulverized coal injection in blast furnace	11	0	0.77
Thin slab casting and strip casting (two main types of near net shape casting)	235	0	4.89
Hot charging in rolling mill	24	0	0.52
Installation of the top pressure recovery turbine	18	0.84	0.40
Variable speed drives in steel making	0	0	0.01

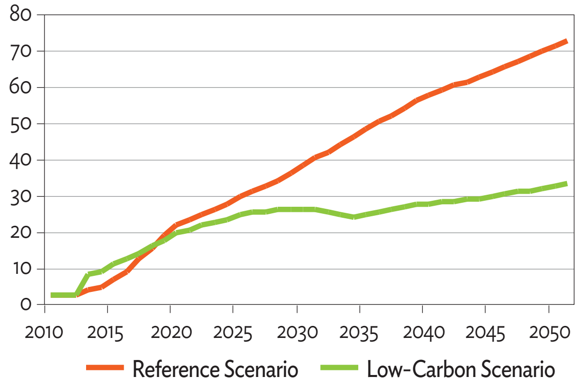
BFG = blast furnace gas, BOF = basic oygen furnace, COG = coke oven gas, GJ = gigajoule, O&M = operation and maintenance.
Source: Authors.

Figure A7: Adoption Rate for Energy Intensity Measures for Existing Plants of Integrated Steel Producers



BOF = basic oxygen furnace.
Source: Authors.

Figure A8: Total Emissions from Energy and Processes in Integrated Steel Plants ($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

2.2 Cement

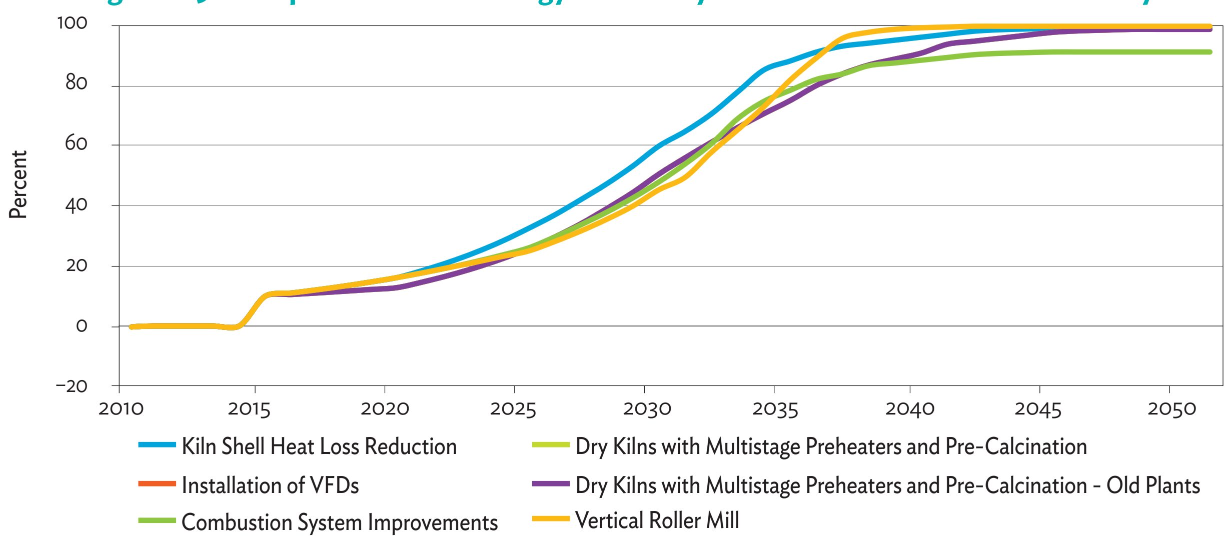
Table A3 shows that the capital expenditure is minor for most technologies other than waste heat recovery, with variable frequency drive installation and combustion optimization having the lowest cost, and vertical roller mills offering moderate cost but high energy savings. Kiln shell heat loss reduction has slightly faster adoption than the other technologies, but all are similar in trajectory with minor differences in peak adoption (Figure A9). Emissions reduction becomes important after about 2030 (Figure A10).

Table A3: Cement Sector Abatement Options

Abatement Option	Capital Expenditure ($/ton)	O&M Expense ($/ton)	Energy Savings (GJ/ton)
Waste heat recovery from cement	2,000 ($/kW)	80 ($/kW)	35 kWh/ton of clinker
Dry kilns with multistage preheaters and pre-calcination	65	0	0.2
Vertical roller mill	18.89	0	20 kWh/ton
Kiln shell heat loss reduction	0.25	0	0.12
Variable frequency drive installation	0.2	0	0.01
Combustion optimization	1	0.04	2% intensity of clinkerization

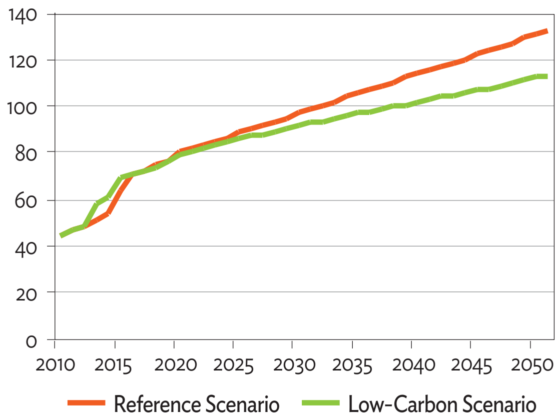
GJ = gigajoule, kW = kilowatt, kWh = kilowatt-hour, O&M = operation and maintenance.
Source: Authors.

Figure A9: Adoption Rate for Energy-Efficiency Measures in the Cement Industry



VFD = variable frequency drives.
Source: Authors.

Figure A10: Cement–Total Emissions from Energy and Processes
($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

2.3 Fertilizer

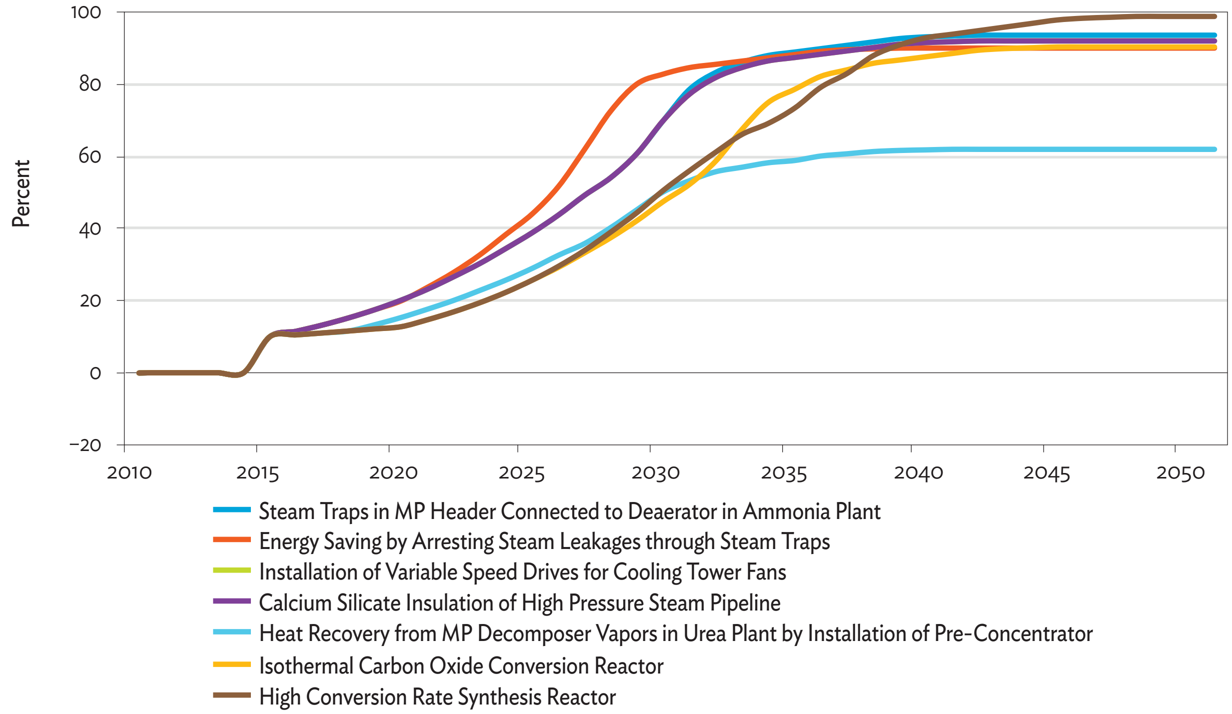
Table A4 illustrates that all the abatement options for fertilizer production entail relatively low capital expenditure and variable cost, but that the energy savings are relatively small as well, compared with other sectors. Initial adoption trajectories are similar for most technologies, but the use of pre-concentrators for heat recovery is projected to have much lower peak adoption than the other technologies (Figure A11). Figure A12 illustrates that fertilizer industry emissions are projected to increase linearly over the period and that the low-carbon options assessed make a relatively small difference to these emissions.

Table A4: Abatement Options for Fertilizer Plants

Abatement Option	Capital Expenditure ($/ton)	O&M Expense ($/ton)	Energy Savings (GJ/ton)
Calcium silicate insulation of high pressure steam pipeline	0.33	0	0.78
Heat recovery from medium pressure decomposer vapors in urea plant by installation of pre-concentrator	2.14	–	0.66
Isothermal carbon oxide conversion reactor	15.9	0.04	0.418
High conversion rate synthesis reactor	4.77	0.008	0.007
Installation of variable speed drives for cooling tower fans in fertilizer	0.20	0.00	2.77 kWh/ton
Steam trap management	0.017	0	0.0003
Arresting steam leakages	0.07	–	0.0006 ton of gas/ton of product

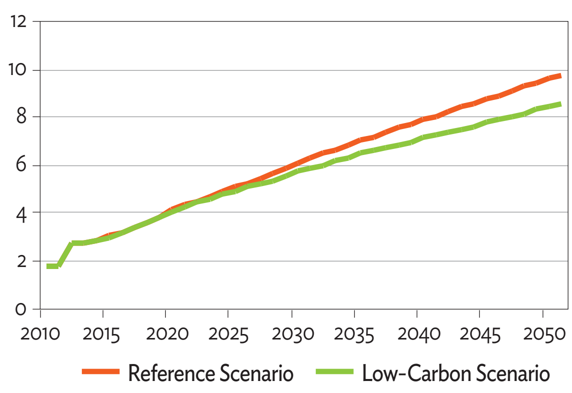
– = data not available, kWh = kilowatt-hour, GJ = gigajoule, O&M = operation and maintenance.
Source: Authors.

Figure A11: Adoption Rate for Efficiency Options for the Fertilizer Industry



BOF = basic oxygen furnace.
Source: Authors.

Figure A12: Fertilizer-Emissions from Energy and Processes ($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

2.4 Petroleum Refining

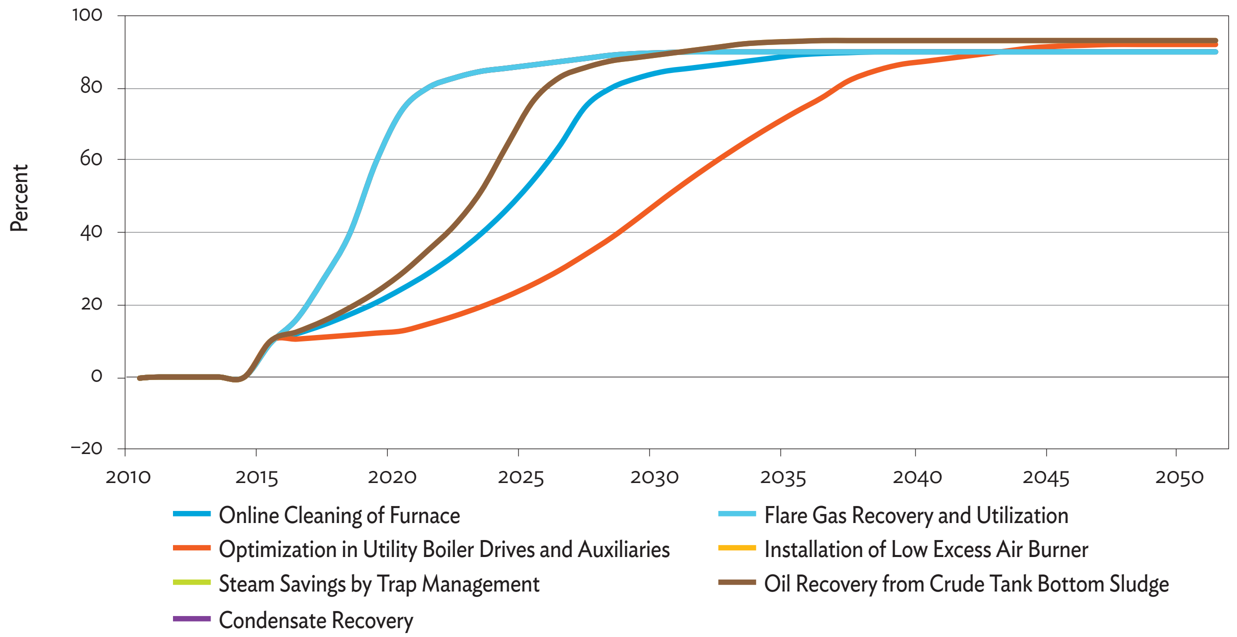
Table A5 shows that all options to reduce energy use in refining have low capital expenditures (ranging from \$0.0066–\$0.14 per ton) and variable costs (\$0–\$0.1 per ton), but that the energy savings are rather minor as well. The adoption rates used (Figure A13) are relatively differentiated for the different options, with flare gas recovery projected to have the most rapid adoption, and optimization of boiler drives having the slowest adoption. However, given the minor energy savings, the overall effects on emissions are minor (Figure A14).

Table A5: Abatement Options for Refineries

Abatement Option	Capital Expenditure ($/ton)	O&M Expense ($/ton)	Energy Savings (ton of oil/ton of product)
Online furnace cleaning	0.13	0.08	0.00003
Optimization of power consumption in utility boiler drives and auxiliaries	–	0.01	0.00018
Steam savings by trap management	0.0066	–	0.0004
Condensate recovery	0.04	–	0.00004
Flare gas recovery and utilization for process heating requirements	0.14	0.10	0.0006
Installation of low excess air burner	0.07	0	0.000045
Oil recovery from crude tank bottom sludge by chemical treatment	0.07	–	0.0006 ton of gas/ ton of product

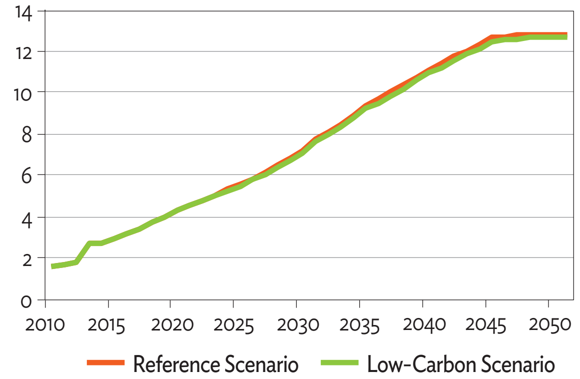
– = data not available, O&M = operation and maintenance.
Source: Authors.

Figure A13: Adoption Rate of Energy-Efficiency Measures for Refinery Production



Source: Authors.

Figure A14: Refining–Total Emissions from Energy and Processes ($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

2.5 Pulp and Paper

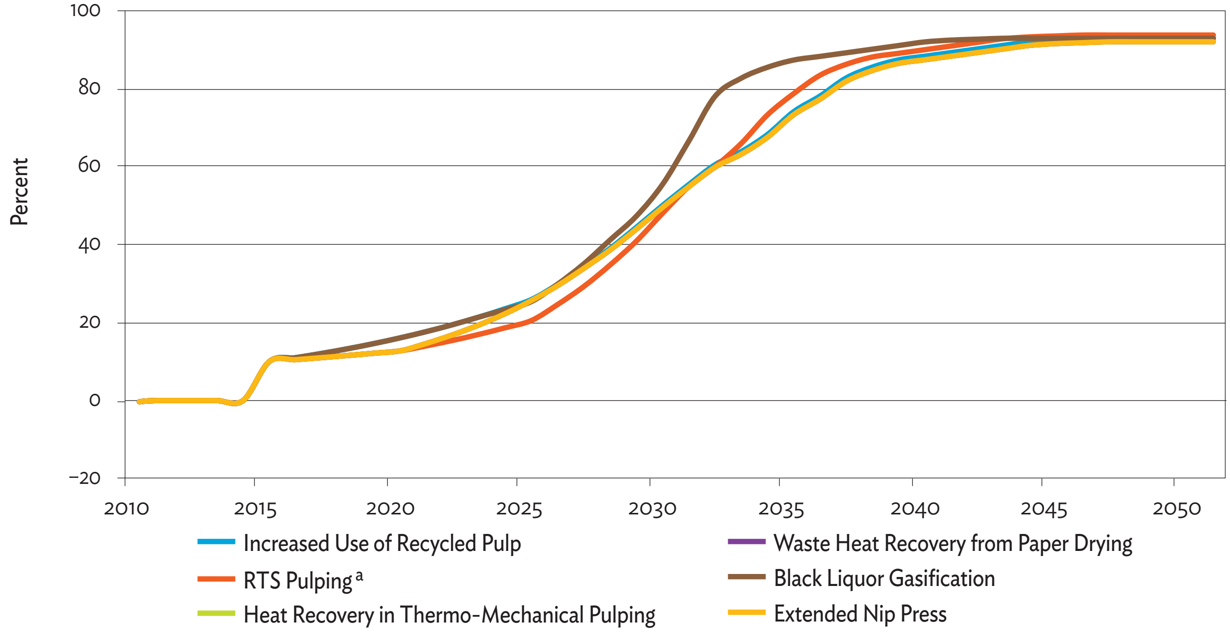
Table A6 illustrates substantial variability in the capital expenditures required for the different abatement options, with increased use of recycled pulp ($485/ton) facing the highest costs and waste heat recovery facing the lowest ($18/ton). The projected adoption rates for the technologies are broadly similar, although black liquor gasification proceeds faster in the 2030s (Figure A15). Effects on emissions are relatively small, especially before the mid-2030s (Figure A16).

Table A6: Pulp and Paper Sector Abatement Options

Abatement Option	Capital Expenditure ($/ton)	O&M Expense ($/ton)	Energy Savings (GJ/ton)
Heat recovery in thermo-mechanical pulping	21	0	7.52
Waste heat recovery from paper drying	18	0	5
Increased use of recycled pulp	485	0	22.4
RTS pulping	50	0	306 kWh/ton
Black liquor gasification	82	3.28	1.6
Extended nip press	38	2.28	1.6

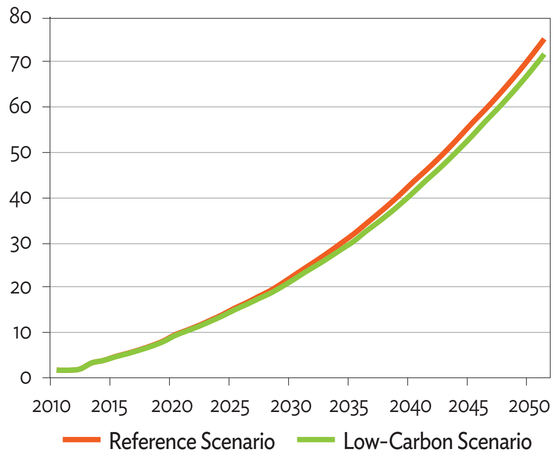
GJ = gigajoule, kWh = kilowatt-hour, O&M = operation and maintenance, RTS = low retention/high temperature/high speed.
Source: E. Worrell, N. Martin, and L. Price. 1999. *Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Iron and Steel Sector*. Berkeley, CA.

Figure A15: Adoption Rate of Energy-Efficiency Measures for Pulp and Paper



[a] RTS is a thermo-mechanical pulping process performed at lower retention time, higher temperature, and higher refiner speed.
Source: Authors.

Figure A16: Pulp and Paper–Total Emissions from Energy and Processes
($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Source: Authors.

ANNEX A

1. Viet Nam Policy Matrix–Basis for the Reference Scenario

1.1 Low-Carbon Targets

- **Targets 2011–2020:**
  - Reduce the intensity of greenhouse gas (GHG) emissions by 8%–10% as compared with the 2010 base
  - Reduce energy consumption per unit of gross domestic product by 1%–1.5% per year
  - Reduce GHG emissions in the energy sector by 10%–20% compared with business as usual (BAU)
- **Orientation toward 2030:**
  - Reduce GHG emissions by 1.5%–2% per year at least
  - Reduce GHG emissions in the energy sector by 20%–30% in comparison with BAU
- **Orientation toward 2050: Reduce GHG emission by 1.5%–2% per year**

1.2 Legal and Policy Framework Considered in the Reference Scenario

Law/Decree	Year	Brief Description
Energy Efficiency and Conservation	2011	The law specifies the responsibility of energy-consuming units in coordinating and reporting current use of energy, developing, and implementing energy efficiency and conservation plans at the units. It encourages the formation of services and organization networks to implement energy-saving programs and projects in the localities. Source: The National Assembly of the Socialist Republic of Viet Nam. Resolution No. 51/2001/QH10. Law on Economical and Efficient Use of Energy Passed on 17 June 2010. http://www.moj.gov.vn/vbpq/en/lists/vn%20bn%20php%20lut/view_detail.aspx?itemid=10481
Environmental Protection	2005	This law provides for activities of environmental protection; policies, measures, and resources for environmental protection; and rights and obligations of organizations, households, and individuals in environmental protection. Source: National Assembly of the Socialist Republic of Viet Nam. Resolution No. 52/2005-QH11. Law on Protection of the Environment Passed on 29 November 2005. https://haiduong.eregulations.org/media/Law%20on%20Enviroment.pdf

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Annex A1.2. continued

Law/Decree	Year	Brief Description
Electricity Law	2004	The law aims to stimulate development and diversify forms of investment in the electricity sector, encourage economical use of electricity, protect the country's electricity infrastructure, and develop a competitive electricity market. Source: The National Assembly of the Socialist Republic of Viet Nam. Resolution No. 28/2004/QH11. Electricity Law Passed on 3 December 2004. http://moj.gov.vn/vbpq/en/lists/vn%20bn%20php%20lut/view_detail.aspx?itemid=7325
Forest Protection and Development	2004, and amended 2012	The law provides for the management, development, and use of forests; and forest owners' rights and obligations. This includes state rights over forests, owners' rights, and prohibited acts. It also states that forest protection and development activities must ensure sustainable economic, social, environmental, defense, and security development; and be in line with the socioeconomic development strategy and forestry development strategy. Source: National Assembly of the Socialist Republic of Viet Nam. Resolution No. 29/2004/QH11. Law on Forest Protection and Development Passed on 3 December 2004. http://theredddesk.org/sites/default/files/law_on_forest_protection_and_development_-_vietnam_2.pdf
Petroleum Law	Amended 2000	This law makes provisions for petroleum exploration and production activities carried out within the territory, the exclusive economic zone, and the continental shelf of Viet Nam. Source: National Assembly of the Socialist Republic of Vietnam. Resolution No. Law 19-2000-QH10. Amendment of and Addition to a Number of Articles of the Law on Petroleum Passed on 9 June 2000. http://vietnamembassy-usa.org/vi/node/2077

1.3 Policy Arrangements and Instruments Underpinning the Reference Scenario

Policy/Strategy	Year	Brief Description
National Green Growth Strategy 2011–2020, with Vision to 2050	2012	The strategy sets out three targets, including restructuring and improving economic institutions toward greening existing industries, and encouraging industries that use energy and resources efficiently and produce high value-added products. It aims to improve research and the application of advanced technology in using natural resources, reducing greenhouse gas emissions, and effectively responding to climate change. Source: Prime Minister of the Socialist Republic of Viet Nam. Approval of the National Green Growth Strategy on 25 September 2012. Ha Noi. https://www.giz.de/en/downloads/VietNam-GreenGrowth-Strategy.pdf
National Climate Change Strategy	2011	The strategy comprises 6 components with 10 strategic tasks to deal with climate change. It outlines overall objectives, priority projects to be implemented in 2011–2015, and plans for 2016–2025 as well as objectives for 2050, with a vision to 2100. It also identifies strategic tasks to cope with global climate change. Source: London School of Economics and Political Science and Grantham Research Institute on Climate Change and the Environment. The National Climate Change Strategy and the No. 2139/QD-TTg Decision on 1 December 2011, approving the National Climate Change Strategy. http://www.lse.ac.uk/GranthamInstitute/law/the-national-climate-change-strategy-and-the-no-2139qd-ttg-decision-on-approval-of-the-national-climate-change-strategy/

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Annex A1.3. continued

Policy/Strategy	Year	Brief Description
National Energy Development Strategy for the Period up to 2020 and Vision to 2050	2012	Overall, the strategy aims to assure national energy security, contributing to firmly maintaining security and defense and developing an independent and self-reliant economy; supply adequate high-quality energy for socioeconomic development; exploit and use domestic energy resources in a rational and efficient manner; diversify forms of investment and business in the energy domain and develop an energy market conducive to fair competition; boost the development of new and renewable energies, bio-energy, and nuclear power to meet the requirements of socioeconomic development, especially in deep-lying, remote, and border areas and offshore islands; and develop the energy sector quickly, efficiently, and sustainably in association with environmental protection. Source: The Prime Minister of the Socialist Republic of Viet Nam. Decision No. 1855/QD-TTg of 27 December 2007, Approving Viet Nam's National Energy Development Strategy up to 2020, with 2050 Vision. http://www.asialeds.org/sites/default/files/resource/file/2007_LEG1855_PM_National%20Energy%20Development%20Strategy.pdf
National Strategy for Environmental Protection until 2010 and Vision toward 2020	2004	The strategy goals are to halt the acceleration of pollution, remedy degraded areas, and improve the environment quality and ensure sustainable development of the country; and guarantee that all people are entitled to live in the environment, landscapes, and other environmental components with the good quality of air, land, and water measuring up to standards stipulated by the State. Source: Socialist Republic of Viet Nam Government Portal. Decision No. 1216/QĐ-TTg of the Prime Minister on 5 September 2012 to approve the National Strategy on Environment Protection to 2020, with Visions to 2030. http://www.chinhphu.vn/portal/page/portal/English/strategies/strategiesdetails?categoryId=30&articleId=10051159
National Strategy for Development of Electricity Sector, 2004–2010, and Vision toward 2020	2007	The strategy provides the main orientation for the development of electricity in 2004–2010, which includes hydro, atomic, and thermal electricity. It ensures that electricity quality is increased and prices are made competitive, focusing especially on electricity savings from transmission, distribution, and use phase; and promotes the development research of new and renewable energy to meet demand of electricity use, especially for islands and remote areas. Source: Ministry of Justice. Decision No. 176/2004/QD-TTg of the Prime Minister of the Socialist Republic of Viet Nam on 5 October 2004 approving the Strategy on Development of Vietnam Electricity Industry in the 2004–2010 Period, with Orientations Towards 2020. http://moj.gov.vn/vbpq/en/lists/vn%20bn%20php%20lut/view_detail.aspx?itemid=7523
National Target Program on Efficient Use and Saving Energy (EUSE), 2006	2006	The program aims to save 3%–5% of total national energy consumption in 2006–2010 and 5%–8% of total national energy consumption in 2011–2015. Source: London School of Economics and Political Science and Grantham Research Institute on Climate Change and the Environment. National Target Program on Efficient Use and Saving Energy (EUSE), approved by Decision No. 79/2006/QĐ-TTg of the Prime Minister of the Socialist Republic of Viet Nam. http://www.lse.ac.uk/GranthamInstitute/law/national-target-program-on-efficient-use-and-saving-energy-euse-approved-by-decision-792006qd-ttg/
National Forest Development Strategy (NFDS) 2006–2020	2007	The NFDS 2006–2020 seeks to modernize forestry so that it plays its part in industrializing and modernizing rural agriculture, eradicating hunger, reducing poverty for people in mountainous areas, and protecting the environment. In relation to reducing emissions from deforestation and forest degradation, it is strongest on the need for clear ownership conditions for land and forest use so that they can receive the benefits from that transaction. It also discusses the enforcement of land laws, providing guidance on the responsibilities involved in this activity. Source: Prime Minister of the Socialist Republic of Viet Nam. Decision No. 18/2007 / QĐ-TTg TTg dated 5 February 2007, approving the Viet Nam Forestry Development Strategy 2006–2020. http://theredddesk.org/sites/default/files/viet_nam_forestry_development_strategy_2.pdf

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Annex A1.3. continued

Policy/Strategy	Year	Brief Description
National Target Program (NTP) in Response to Climate Change, 2008	2008	The NTP's strategic objectives are to assess climate change impacts on sectors and regions in specific periods; develop feasible action plans to effectively respond to climate change in the short term and long term to ensure sustainable development of Viet Nam; take opportunities to develop toward a low-carbon economy; and join the international community's efforts in mitigating the effects of climate change. The NTP also sets targets on what should be achieved by 2010 and 2015, which include assessing the impact of climate change on Viet Nam, identifying measures to combat climate change, and strengthening the capacity of organizations involved in responding to climate change. Source: Prime Minister of the Socialist Republic of Viet Nam. Decision No. 158/2008 /QD-TTg dated 2 December 2008, approving the National Target Program to respond to climate change. http://www.noccop.org.vn/Data/vbpq/Airvariable_ldoc_49enDecision%20158%20on%20approval%20of%20NTP.pdf
National Master Plan for Power Development in 2011–2020, with considerations to the 2030 (Power Development Plan-VII) Viet Nam Agenda 21	2011	The Power Development Plan-VII puts strong emphasis on energy security, energy efficiency, renewable energy development, and power market liberalization. It sets out high-level strategies for the national power development in four main areas: (i) development of power sources; (ii) development of the power transmission grid; (iii) interconnection of power networks with other regional countries; and (iv) electricity supply to rural, mountainous, and island areas. Source: Prime Minister of the Socialist Republic of Viet Nam. Decision No. 1208/QD-TTg dated 21 July 2011, approving the National Master Plan for Power Development for the 2011–2020 Period with the Vision to 2030. http://www.nti.org/media/pdfs/VietnamPowerDevelopmentPlan2030.pdf?_=1333146022

1.4 Policy Matrix Underpinning the Reference Scenario

Sector	Current Scenario/Targets	Medium-Term Policy Targets (2020/2030 Scenario)	Long-Term Policy Targets (2050 Scenario)
A. Transport *Revised National Strategy for Transportation until 2020, with vision to 2030. Decision of Prime Minister No. 335/QD-TTg dated 25 Feb. 2013*	By 2020, the country's transport system will meet diversified domestic demands for transportation with rapid growth, improved quality, and reasonable costs to control and reduce traffic accidents and limit environmental pollution. Overall, a national transport system will be formed, with different modes of transportation and principal transportation corridors for major and mass commodities. By 2030, the national transport network and external traffic corridors will be improved. Transportation quality will reach international standards in smoothness, speed, safety, and rational connection among different modes of transportation, especially points for connecting long-distance passenger transit with passenger transportation in urban centers.	Produce 5 billion liters per year of gasohol E10 and 500 million liters per year of biodiesel B10 by 2020 *(this measure is included in the low-carbon scenario)*. • By 2020, the transportation system to meet the societal needs. By 2050, complete the modernization of the domestic transportation network as well as the international transportation network. • Accelerate the transformation to using compressed natural gas and liquefied gas in buses and taxis, with 20% of buses and taxis. • Reduce 30% of carbon dioxide equivalent (CO_2e) compared with 2005. • Reduce air pollutant emissions (sulfur dioxide [SO_2], nitrogen oxide [NO_x], particulate matter [PM], and volatile organic carbon [VOC]): i) reducing 80% of PM compared with 2005 in Ho Chi Minh City and Ha Noi; and ii) reducing 50% of SO_2, NO_x, and VOC compared with 2005 in Ha Noi and Ho Chi Minh City. • Apply the standard of emission from vehicles according to the following road map: • EURO 2: 2007; EURO 3: 2009; and EURO 4: 2012. • Reduce 20% of the noise volume from transport in urban areas to 65 dB compared with 2005.	Accelerate the transformation to using compressed natural gas and liquefied gas in buses and taxis, with 80% of buses and taxis by 2050.

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Annex A1.4 continued

Sector	Current Scenario/Targets	**Medium-Term Policy Targets** (2020/2030 Scenario)	**Long-Term Policy Targets** (2050 Scenario)
B. Energy/ Power			
B.1 PDP-VII Decision No. 1208/QD-TTg (2011) Gradually increase the rate of access to clean energy and electricity sources by local people in rural, mountainous, remote, and border areas as well as islands. Most of households shall have electricity in 2020 and access to modern, sustainable, and reliable energy services with reasonable electricity selling and/or energy prices in 2030.	Provide adequate electricity for the domestic demand; electricity production and import will range from 194 billion to 210 billion kWh in 2015. Prioritize the development of renewable energy sources for electricity production, increasing the percentage of electricity produced from these energy sources from 3.5% of total electricity production in 2010. Accelerate the program of electrification in rural and mountainous areas to ensure that in 2020 most of the rural households have access to electricity. Reduce the electricity elasticity coefficient and GDP from the current average of 2.0 to 1.5 by 2015 and 1.0 by 2020. Electricity price will be incrementally adjusted to achieve the long-term marginal cost of the electricity system by 2020, equivalent to $0.80–$0.90/kWh. To widely implement, and increase the effectiveness of, the national target program on electricity conservation for saving 5%–8% of electricity by 2015 and 8%–10% of total electricity consumption by 2020.	Electricity production and import will range from 330 billion to 362 billion kWh in 2020; and from 695 billion to 834 billion kWh in 2030. **In 2020:** ● Total capacity of power plants will be about 75,000 MW, of which hydropower accounts for 23.1%, energy storage hydropower 2.4%, coal 48.0%, gas burn power 16.5% (of which LNG power accounts for 2.6%), renewable energy 5.6%, nuclear power 1.3%, and imported power for 3.1%. ● Produced and imported electricity will be about 330 billion kWh in 2020 (hydropower 19.6%, coal 46.8%, natural gas thermal power 24.0% [including LNG 4.0 %]; renewable energy 4.5%, nuclear 2.1%, and imported power 3.0%). **Orientation to 2030:** ● The total power plant capacity will be about 146,800 MW (hydropower 11.8%, energy storage hydropower 3.9%, coal thermal power 51.6%, gas-fired power 11.8% of which LNG is 4.1%, renewable energy 9.4%, nuclear power 6.6%, and imported power 4.9%). ● Electricity output in 2030 will be 695 billion kWh; hydropower accounts for 9.3%, coal thermal 56.4%, natural gas thermal power 14.4% (including the use of LNG 3.9%), renewable energy 6.0%, nuclear power 10.1%; and imported power 3.8%.	

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Annex A1.4 continued

Sector	Current Scenario/Targets	Medium-Term Policy Targets (2020/2030 Scenario)	Long-Term Policy Targets (2050 Scenario)
B.2 Revised National Power Development Master Plan Alternative Decision No. 428/QD-TTg (2016)	Prioritized development of hydropower sources, especially multipurpose projects (for flood control, water supply, and electricity production); carrying out research studies on putting pumped-storage hydropower plants into operation in conformity with the development of the national electricity system, aiming to improve the operational efficiency of the system. Total capacity of hydropower sources (including small and medium-sized, and pumped-storage hydropower) estimated to be at less than 17,000 MW. Total wind power capacity from current 140 MW. Development of biomass power sources: applying cogeneration method in sugar mills and food/foodstuff processing plants; co-combustion of biomass and coal in coal-fired power plants; electricity generation from solid wastes, etc. Accelerated development of solar power, including large ground-mounted and small rooftop systems, bringing the total solar power capacity from the current negligible level.	Electricity to be produced and imported: approximately 265 billion–278 billion kWh in 2020; approximately 400 billion–431 billion kWh in 2025, and approximately 572 billion–632 billion kWh in 2030. **In 2020:** • The total capacity of power plants shall be approximately 60,000 MW, of which approximately 30.1% is for large, medium-sized, and pumped-storage hydropower; approximately 42.7% for coal-fired thermal power; 14.9% for gas-fired thermal power (including LNG); 9.9% for renewable sources (including small hydropower, wind power, solar power, and biomass power); and 2.4% for imported power. **Orientation to 2030:** • The total capacity of power plants shall be approximately 129,500 MW, of which approximately 16.9% is for large, medium-sized, and pumped storage hydropower; approximately 42.6% for coal-fired thermal power; 14.7% for gas-fired thermal power (including LNG); 21% for renewable sources (including small hydropower, wind power, solar power, and biomass power); 3.6% for nuclear power; and 1.2% for imported power. • The electricity to be produced and imported shall be about 572 billion kWh, of which approximately 12.4% is for large, medium-sized, and pumped storage hydropower; approximately 53.2% for coal-fired thermal power; 16.8% for gas-fired thermal power (including LNG); 10.7% for renewable sources (including small hydropower, wind power, solar power, and biomass power); 5.7% for nuclear power; and 1.2% for imported power.	

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Annex A1.4 continued

Sector	**Current Scenario/Targets**	**Medium-Term Policy Targets** (2020/2030 Scenario)	**Long-Term Policy Targets** (2050 Scenario)
PDP-VII Interim Revision from the Institute of Energy (2014)		Gross generation of 264 billion kWh in 2020; 394 billion kWh in 2025; and 560 billion kWh in 2030. Electricity to be supplied to end users: 231 billion kWh in 2020, 346 billion kWh in 2025, and 495 billion kWh in 2030. **2020:** ● Identified power plant capacity is 61,700 MW (hydropower 33.6%, coal thermal power 45.0%, gas-fired power 12.3%, renewables 1.5%, and captive and imports 5.3%). **2030:** ● Identified power plant capacity is 125,000 MW (hydropower 20.6%, coal thermal power 47.5%, gas-fired power 16.8%, renewables 5.9%, nuclear 3.7%, and captive and imports 4.9%).	
B.3 Viet Nam's Renewable Energy (RE) Development Strategy *Decision No. 2068/QĐ-TTg (2015)*	Increase the total production and use of RE sources from approximately 25 million tons of oil equivalent (TOE) in 2015; the RE share in total primary energy consumption in 2015 is approximately 31.8%.	Increase to 37 million TOE in 2020; and approximately 62 million TOE in 2030.	Increase total production and use of RE sources by 138 million TOE in 2050. Bring resources together, and exploit and maximize RE potentials in the country by applying advanced types of technology that are suitable for actual conditions of each region, thus bringing high economic, social, and environmental efficiencies.
	Increase the total electricity production from RE sources from approximately 58 billion kWh in 2015.	101 billion kWh in 2020, and approximately 186 billion kWh in 2030.	Strongly develop RE technology market, machinery and/or equipment manufacturing industry, and supply of domestic RE services. Strengthen potential for research, development, transfer, and application of new types of renewable energy.
	The share of RE-based electricity in the total national production shall rise from 35% in 2015.	RE share in total primary energy consumption will be 31% in 2020; and 32.3% in 2030.	RE share in total primary energy consumption will be 44% in 2050.
	Total hydropower production shall be increased from 56 billion kWh in 2015.	Increase to nearly 90 billion kWh in 2020, and approximately 96 billion kWh in 2030.	452 billion kWh in 2050.

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Annex A1.4 continued

Sector	Current Scenario/Targets	Medium-Term Policy Targets (2020/2030 Scenario)	Long-Term Policy Targets (2050 Scenario)
	Total electricity generated from wind sources shall increase from approximately 180 million kWh in 2015.	2.5 billion kWh in 2020, and approximately 16 billion kWh in 2030.	43% in 2050.
		The share of wind power in total electricity production shall increase from a negligible level at present to about 1% in 2020, and 2.7% in 2030	The share of wind power in total electricity production shall increase by 5% in 2050.
	Total solar power production shall increase from about 10 million kWh in 2015.	1.4 billion kWh in 2020, and approximately 35.4 billion kWh in 2030.	Increase to 53 billion kWh in 2050.
		The share of solar power in total electricity production shall increase from a negligible level at present to around 0.5% in 2020, and about 6% in 2030.	210 billion kWh in 2050. The share of solar power in total electricity production shall increase by 20% in 2050.
	Increase the utilization rate of wastes generated from industrial/ agricultural plants for energy purposes from 45% in 2015.	Increase to 50% in 2020, and approximately 60% in 2030.	Further increase to 70% in 2050.
		Total biomass energy for electricity increase to 1.8 million TOE in 2020, and approximately 9 million TOE in 2030.	Total biomass energy for electricity increase to 20 million TOE in 2050.
	Total biomass energy for electricity generation shall go up from 0.3 million TOE in 2015.	7.8 billion kWh in 2020, and approximately 37 billion kWh in 2030.	85 billion kWh in 2050.
	Accordingly, the electricity generated shall increase from 0.6 billion kWh in 2015.		
	Share of biomass power in total electricity production is approximately 1.0% in 2015.		

Sources: Revised National Strategy for Transportation until 2020, with vision to 2030. Decision of Prime Minister No. 335/QD-TTg dated 25 February 2013; Prime Minister of the Socialist Republic of Viet Nam. Decision No. 1208/QD-TTg Dated 21 July 2011, Approving the National Master Plan for Power Development for the 2011–2020 Period with the Vision to 2030; Prime Minister of the Socialist Republic of Viet Nam. Decision No. 1855/QD-TTg dated 27 December 2007, Approving Viet Nam's National Energy Development Strategy up to 2020, with 2050 Vision.

2. Viet Nam's Mitigation Options Underpinning the Low-Carbon Scenario

Policy/Strategy	Year	Brief Description
National Green Growth Strategy 2011–2020, with Vision to 2050	2012	The strategy sets out three targets, including restructuring and improving economic institutions toward greening existing industries and encouraging industries that use energy and resources efficiently and produce high value-added products. It aims to improve research and the application of advanced technology in using natural resources, reducing greenhouse gas emissions, and effectively responding to climate change.

Sector	Policy Options
Energy Production	(1) Production of renewable energy, including geothermal, solar and wind energy, hydroelectricity, biogas, and biomass (2) Replacement of low efficiency coal-fired boilers by higher efficiency ones or gas-fired plants
Industrial, Public, and Domestic Energy Use	(1) Improvement of energy use efficiency in lighting, production processes, and buildings, including replacement of low efficiency industrial oil-fired boilers and demand-side management programs, e.g., through pricing structures (2) Use of high-efficiency equipment and appliances such as high-efficiency refrigerators, air conditioners, and electric motors (3) Improvement of energy efficiency in transportation: promoting public transport, improving infrastructure, controlling vehicle emissions, and switching from diesel oil to compressed natural gases (4) Efficiency improvement in coal-fired and other household cooking stoves through replacement of stoves of liquefied gas (5) Using innovative brick kilns (6) Using high-press sodium lamps in public lighting
Forestry Sector	(1) Full implementation of the program to plant 5 million hectares of forest (2) To conserve and restore the existing forest through payment for environmental services and other schemes (3) Prevent forest fires through improved fire risk management
Agriculture Sector	(1) Biogas replacing cooking coal for households with livestock (2) Development and application of sustainable agricultural farming techniques to enhance agricultural production, and increase soil organic material content such as zero tillage, use of cover crops, balanced fertilization, and use of waste (3) Improvement of irrigation-drainage management in rice fields to reduce methane emissions based on alternate wetting and drying (4) Provision of improved feed (e.g., molasses urea block) to domestic animals to reduce methane emissions (5) Strengthening the capacity of agriculture research institutions
Methane Recovery in Energy Production and Transportation	(1) From surface and underground coal mining and gas exploitation: potential Clean Development Mechanism projects (2) From large landfills in big cities: potential Clean Development Mechanism projects

Source: Ministry of Natural Resources and Environment. 2010. Viet Nam's Second National Communication to the United Nations Framework Convention on Climate Change. Ha Noi. http://unfccc.int/resource/docs/natc/vnmnc02.pdf.

2.1 Priorities in the Viet Nam Transport Development Strategy up to 2020 with a Vision Toward 2030 Underpinning the Low-Carbon Scenario

Transport Category	Goal by 2020

Road	• 2.8 million–3 million automobiles of all kinds nationwide
	  • 0.5 million passenger cars
	  • 0.8 million trucks

Railways	• Complete renovation and upgrading of existing railway with a speed of 120 kilometers per hour (km/h) • Prioritize building of the North–South express railway with a speed of 350 km/h • Attach importance to development of high-speed trains • 1,000–1,200 locomotives • 50,000–53,000 carriages of all kinds • 4,000–5,000 passenger carriages **2030 Vision** • Complete the North–South express railway
Seaways	Reduce the age of the seagoing ship fleet to 12 years on average National fleet will have a total tonnage of 12 million–14 million deadweight tonnage (DWT)

Inland Waterways	• In the Red River Delta, use
	  • towing and pushing ships of 1,200–1,600 tons
	  • self-propelled ships of up to 500 tons
	  • passenger ships of 50–120 seats
	• In the Mekong River Delta, use
	  • towing and pushing ships of 600–1,200 tons
	  • self-propelled ships of up to 500 tons
	  • passenger ships of 30–100 seats
	• Short-distance routes along the coastline, use
	  • self-propelled ships of 500–1,200 tons
	  • special-use vessels (transporting containers, loose cement, gasoline, and oil)
	• Inland waterway ship fleet will have a total tonnage of 10 million–12 million tons with a total towing power of 12 million–13 million horsepower and total loading power of 0.8 million–1 million passenger seats

Shipbuilding Industry	• Build new ships up to 300,000 DWT • Repair ships of up to 400,000 DWT • Increase localization rate of up to 70%
Urban Transport	• Develop urban transport infrastructure and mass transit systems • Reserve 16%–26% of the land for urban transport • Strongly develop bus system in big cities • Reach mass transit ratio of 35%–35% in Ha Noi and Ho Chi Minh cities by rapidly investing in building mass transit routes (e.g., sky trains and metros) **2030 Vision** • Build mass transit routes in grade-1 urban centers • Develop overhead and underground mass transit in Ha Noi capital and Ho Chi Minh City • Increase mass transit ratio in Ha Noi and Ho Chi Minh City to 50%–55%
Rural Transport	• Rate of solid and asphalted roads will reach 60%–80%
Automobile and Vehicle and Machine Construction Industry	• Increase localization rate to over 60%

2.2 Prorities in Transport Infrastructure Development up to 2020 with a Vision Toward 2030 Underpinning the Low-Carbon Scenario

Transport Category	Goal by 2020

Road	• North–South Axis
	  • Upgrade and expand national highway 1A from Huu Nghi Quan to Nam Can
	  • Connect and upgrade the entire Ho Chi Minh road from Cao Bang to Dat Mui
	  • Build North–South expressway and coastal roads
	• Northern Region
	  • Build new expressways in the two corridors and one economic belt between Viet Nam and the People's Republic of China and sections of the North–South expressway, radial routes with large transportation volumes, and belt routes in the Ha Noi capital region
	  • Connect and upgrade all national highways in the northern belt system and coastal roads
	  • Complete the building of border belt routes and flood diversion sections
	• Central Viet Nam and Central Highlands Region
	  • Upgrade and build roads in the East–West economic corridor and transverse roads linking the coastal region with Central Highlands provinces and Vietnamese seaports with neighboring countries such as the Lao People's Democratic Republic, Thailand, and Cambodia
	  • Build border corridors and roads west of Central Viet Nam provinces from Thanh Hoa to Quang Nam
	  • Build eastern Truong Son road from Da Nang to Lam Dong
	• Southern Region
	  • Build sections of the North–South expressway and express routes from Ho Chi Minh City to provinces and cities, and belt roads in Ho Chi Minh City
	  • Upgrade and build main axes and connect and upgrade coastal roads

Rail	• North–South Axis
	  • Complete upgrading of Thong Nhat railways
	  • Build the North–South railway
	• Northern Region
	  • Build Ha Noi–Vinh section of the North–South express railway
	  • Build new high-speed railways in the two corridors and one economic belt between Viet Nam and the People's Republic of China and routes linking with seaports and large economic zones
	• Central Viet Nam and Central Highlands Region
	  • Build the section of the North–South express railway, Vung Ang–Cha Lo (Mu Gia) railway, and a railway linking the Central Highlands provinces
	  • Build a railway for alumina–aluminum exploitation and production in Central Highlands provinces and linking the Central Highlands to seaports
	• Southern Region
	  • Build Ho Chi Minh City–Nha Trang express railway (of the North–South express railway) and Bien Hoa–Vung Tau railway
	  • Build Di An–Loc Ninh railway for linking with trans-Asian railways
	  • Build Ho Chi Minh City–My Tho–Can Tho railway

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Annex A2.2 continued

Transport Category	Goal by 2020
Seaway	● North–South Axis • Develop the North–South passenger transportation route at sea ● Northern Region • Complete the expansion of seaports in Hai Phong and Quang Ninh • Build Lach Huyen international gateway port for accommodating ships of up to 80,000 DWT • Prioritize the development of container wharves and special-use harbors • Build passenger ports in Hai Phong and Quang Ninh ● Central Viet Nam and Central Highlands Region • To complete the construction of, and put into operation, two departure wharves for Van Phong international transit port to build an international transit port of regional and international level • To further build, upgrade, and expand Nghi Son, Cua Lo, Vung Ang, Da Nang, Dung Quat, and Quy Nhon ports • To build special-use ports for thermo-power plants and alumina export • To select and build an international passenger harbor in the Hue–Da Nang–Nha Trang region ● Southern Region • Renovate, upgrade, and build four seaport clusters in the southeastern region ◦ Cai Mep, Ben Dinh Sao Mai–Vung Tau port cluster will function as an international gateway port in the southern key economic region ◦ Ho Chi Minh City port cluster will embrace Hiep Phuoc port area for accommodating ships of up to 50,000 DWT; Cat Lai port area for accommodating ships of up to 30,000 DWT; and Sai Gon–Nha Be port area for accommodating ships of up to 20,000 DWT; to complete the relocation of ports in inner cities to Cat Lai, Hiep Phuoc, and Cai Mep; Thi Vai areas; and to transform the functions of Sai Gon port to suit the city's planning ◦ Dong Nai port cluster will embrace Dong Nai, Phu Huu–Nhon Trach, and Phuoc An–Go Dau port areas ◦ Ba Ria–Vung Tau port cluster will embrace My Xuan–Phu My and Dinh river–Vung Tau areas • Build new fairways into Hau river through Quan Chanh Bo canal for fully-loaded ships of 10,000 DWT and empty ships of 20,000 DWT, in association with the expansion and upgrading of the Can Tho–Cai Cui port cluster into a major port cluster in the southwestern region
Inland Waterways	● Northern Region • Upgrade and expand main ports, such as Ninh Binh–Ninh Phuc, Da Phuc, Viet Tri, and Hoa Binh • Build Phu Dong container port • Build major passenger ports in Ha Noi, Hai Phong, and Quang Ninh ● Central Viet Nam and Central Highlands Region • Adjust and upgrade important river sections • Increase the length of river sections under management and operation ● Southern Region • Complete main waterways from Ho Chi Minh City to southwestern provinces up to prescribed technical standards, ensuring round-the-clock ship operation • Upgrade the Ho Chi Minh City–Ben Tre–Tra Vinh–Soc Trang–Ca Mau coastal waterway • Build and upgrade inland waterway ports for cargo and passenger transportation

Source: Authors.

ANNEX B

1. Model Development under the ADB Regional Technical Assistance, Enabling Climate Change Responses in Asia and the Pacific

Under the Asian Development Bank regional technical assistance, Enabling Climate Change Responses in Asia and the Pacific – Strengthening Planning Capacity for Low Carbon Growth in Developing Asia, major extensions were made to the Energy Forecasting Framework and Emissions Consensus Tool (EFFECT).

1.1 General Module

The modeling period was extended from 25 to 41 years (for example, to 2050 from a 2010 base year). A new marginal abatement cost (MAC) curve drawing utility and extended summary of the results were added. All carbon dioxide equivalent (CO_2e) emissions factors and net calorific values were completely overhauled in line with the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories.

1.2 Power Module

The original EFFECT power module contained 27 grid-based generating technologies. An additional 40 generating technologies were added, covering other grid and off-grid generation to better cover and represent the technologies in use in Asia and proposed for future use. These included smaller power-generating units that are mainly used in off-grid generation and electrical storage solutions. User-selectable cost data for each of these technologies were included from low-, middle-, and high-income countries. The load–dispatch calculation was modified to improve the model's handling of off-grid and microgrid generators together with the grid-connected units. The user was also given the choice to include local pollution emissions controls (sulfur dioxide [SO_2], nitrogen oxide [NO_x], particulate matter [PM]), process, and project contingencies. A new plant and equipment investment learning curve effect was added to allow the cost of different generating technologies to be changed over the modeling period.[6]

[6] Although the analysis is normally performed at constant values, the improved model allows the impact of rising fossil fuel prices and diminishing renewable technologies—such as concentrated solar—to be evaluated.

1.3 Household Module

Additional appliances were added to EFFECT, and a new more detailed treatment was used to calculate energy used in lighting. A range of regression functions (Gompertz/Logistic, 3- or 4-factor, free/forced) now allows more options for linking income to appliance ownership.

1.4 Transport Module

New modules were developed to incorporate rail and waterborne transport (inland waterway and coastal shipping for both passengers and freight). A new Asian cross-country analysis was added to estimate the baseline growth in passenger-kilometers for mass transit (waterborne, rail, urban buses, and coaches) based on the relationship between passenger-kilometers per capita and gross domestic product per capita. Changes were also made to how historic fuel consumption data for on-road vehicles are used to adjust the calculated COPERT results and adjust the annual mileage per vehicle so that the calculated total automotive gasoline (petrol) fuel consumed in the base year matches an exogenous value for retail gasoline sales to on-road vehicles.

ANNEX C

1. Reference Scenario Results

Summary–Reference Scenario										
		2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Macroeconomics										
GDP annual growth	%	0.00%	6.20%	6.90%	7.00%	7.00%	6.60%	6.60%	6.40%	6.40%
Population annual growth	%		1.01%	0.85%	0.65%	0.41%	0.26%	0.09%	0.04%	0.14%
GDP	D (trillion)	1,981	2,622	3,661	5,134	7,201	9,912	13,645	18,607	25,373
GDP	$ (billion)	106	141	197	276	387	533	733	1,000	1,363
Population	Persons (million)	85.2	89.7	94.1	97.9	100.7	102.8	104.3	105.4	105.9
CO_2e Emissions										
Grid supply electricity	Gg	33,171	82,172	155,013	226,457	325,408	414,542	482,549	565,107	672,167
Captive generation[a]	Gg	3,645	6,275	12,358	18,952	24,285	28,607	28,896	28,896	28,896
Industry (energy and process)	Gg	51,993	77,926	110,208	130,757	154,062	180,792	209,905	236,248	263,784
Nonresidential	Gg	163	253	314	336	349	361	372	382	390
Road and rail transport	Gg	22,740	23,838	29,477	38,786	48,081	59,017	72,983	88,983	107,621
Total	**Gg**	**111,711**	**190,463**	**307,370**	**415,288**	**552,184**	**683,319**	**794,705**	**919,615**	**1,072,858**
CO_2e Emissions Intensity										
CO_2e emissions per $1,000 GDP	CO_2e tons/$1,000 GDP	1.05	1.35	1.56	1.51	1.43	1.28	1.08	0.92	0.79
CO_2e emissions per capita	CO_2e tons/capita	1.31	2.12	3.27	4.24	5.48	6.64	7.62	8.73	10.13

CO_2e = carbon dioxide equivalent, GDP = gross domestic product, Gg = gigagram.

[a] Excludes captive generation in industry that is accounted for in other fuel use.

Summary–Reference Scenario		2010	2015	2020	2025	2030	2035	2040	2045	2050
Power Sector										
Installed Capacity										
Hydro	MW	9,402	18,063	21,898	25,128	28,943	36,806	41,431	46,485	51,525
Thermal	MW	13,531	22,414	38,504	60,762	86,722	109,437	134,207	160,846	193,455
Nuclear	MW	0	0	0	0	4,600	10,600	22,600	34,600	46,600
Renew	MW	25	245	895	3,550	7,340	11,524	20,214	31,159	44,869
Total	**MW**	**22,958**	**40,721**	**61,296**	**89,439**	**127,604**	**168,367**	**218,452**	**273,090**	**336,449**
Generation										
Hydro	GWh	34,417	66,296	80,498	84,835	90,831	104,657	109,237	113,940	116,965
Thermal	GWh	58,155	91,050	161,009	256,664	361,824	449,606	523,683	617,051	737,666
Nuclear	GWh	0	0	0	0	30,661	70,596	150,250	229,774	309,281
Renew	GWh	100	693	2,887	11,085	21,933	37,638	71,677	114,282	167,365
Total grid	**GWh**	**92,672**	**158,039**	**244,394**	**352,584**	**505,249**	**662,497**	**854,847**	**1,075,047**	**1,331,276**
Captive/Off Grid[a]	GWh	3,406	5,863	11,548	17,709	22,692	26,730	27,000	27,000	27,000
Total	**GWh**	**96,077**	**163,902**	**255,942**	**370,293**	**527,940**	**689,227**	**881,847**	**1,102,047**	**1,358,276**
CO_2e Emissions										
Hydro	Gg	0	0	0	0	0	0	0	0	0
Thermal	Gg	33,171	82,172	155,013	226,457	325,408	414,542	482,549	565,107	672,167
Nuclear	Gg	0	0	0	0	0	0	0	0	0
Renew	Gg	0	0	0	0	0	0	0	0	0
Total	**Gg**	**33,171**	**82,172**	**155,013**	**226,457**	**325,408**	**414,542**	**482,549**	**565,107**	**672,167**
Captive/Off Grid[a]	Gg	3,645	6,275	12,358	18,952	24,285	28,607	28,896	28,896	28,896
Total	**Gg**	**36,816**	**88,447**	**167,371**	**245,409**	**349,693**	**443,149**	**511,444**	**594,002**	**701,063**
Specific CO_2e Emissions										
Grid electricity	g/kWh	358	520	634	642	644	626	564	526	505
Captive/Off-grid electricity	g/kWh	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Average	**g/kWh**	**383**	**540**	**654**	**663**	**662**	**643**	**580**	**539**	**516**

Gg = gigagram, g/kWh = gram per kilowatt-hour, GWh = gigawatt-hour, MW = megawatt.
Note: In this table, "hydro" includes large hydro, small hydro (which is classified in PDP-VII as renewable), and pumped storage. "Thermal" includes coal, oil, gas, and diesel. "Renew" includes solar, wind, and biofuel generation.
[a] Excludes captive generation in industry that is accounted for in other fuel use.

Summary–Reference Scenario										
		2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household Electricity Consumption										
Electricity Consumed by Households (Grid and Captive)										
Lighting	GWh	2,354	4,936	5,916	7,149	7,236	8,792	10,548	10,930	12,284
Entertainment	GWh	5,888	8,467	7,969	7,341	6,484	6,161	6,219	6,055	6,175
Kitchen Appliances	GWh	16,491	20,813	27,535	32,622	34,897	36,544	37,968	37,509	37,928
Heating/Cooling	GWh	5,404	14,616	24,159	42,473	66,545	93,801	123,724	150,538	176,372
Total	**GWh**	**30,137**	**48,832**	**65,580**	**89,586**	**115,162**	**145,298**	**178,459**	**205,033**	**232,759**
Operating	GWh	27,098	45,837	62,753	86,890	112,667	142,928	176,116	202,861	230,653
Standby	GWh	3,039	2,994	2,826	2,696	2,495	2,370	2,343	2,172	2,107
Total		**30,137**	**48,832**	**65,580**	**89,586**	**115,162**	**145,298**	**178,459**	**205,033**	**232,759**
CO_2e Emissions from Household Electricity Consumption										
Total	**Gg**	**11,548**	**26,351**	**42,885**	**59,372**	**76,280**	**93,422**	**103,501**	**110,513**	**120,137**

CO_2e = carbon dioxide equivalent, Gg = gigagram, GWh = gigawatt-hour.

Summary–Reference Scenario										
		2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Industry (6 Sectors)										
Electricity Consumed by Sector (Grid Only)										
Iron and steel, ISP plants	GWh	510	1,441	4,377	5,889	7,590	9,623	11,735	13,111	14,602
Iron and steel, small plants	GWh	6,602	7,435	6,452	6,452	6,452	6,452	6,452	6,452	6,452
Aluminium	GWh	0	0	0	0	0	0	0	0	0
Cement	GWh	5,764	7,476	10,141	11,138	12,100	13,069	14,149	15,129	16,203
Fertilizer	GWh	319	526	704	858	1,018	1,172	1,316	1,458	1,590
Refining	GWh	0	0	0	0	0	0	0	0	0
Pulp and paper	GWh	604	1,652	3,187	5,115	7,578	10,634	14,414	18,819	23,817
Total	**GWh**	**13,800**	**18,529**	**24,861**	**29,453**	**34,738**	**40,951**	**48,065**	**54,969**	**62,664**
Total Energy Consumption by Sector (Including Grid)										
Iron and steel, ISP plants	PJ	25	69	211	284	366	464	565	632	703
Iron and steel, small plants	PJ	57	64	55	55	55	55	55	55	55
Aluminium	PJ	0	0	0	0	0	0	0	0	0
Cement	PJ	222	303	411	452	491	530	574	614	657
Fertilizer	PJ	29	47	63	77	93	108	122	137	151
Refining	PJ	21	39	57	73	94	123	146	166	169
Pulp and paper	PJ	16	45	87	139	206	289	392	512	648
Total	**PJ**	**369**	**568**	**885**	**1,081**	**1,305**	**1,569**	**1,855**	**2,116**	**2,384**
CO_2e Emissions from Energy Consumption (Including Grid)										
Iron and steel, ISP plants	Gg	2,412	7,070	22,010	29,648	38,205	48,245	58,048	64,299	71,283
Iron and steel, small plants	Gg	5,604	7,630	7,418	7,457	7,452	7,323	6,892	6,618	6,472
Aluminium	Gg	0	0	0	0	0	0	0	0	0
Cement	Gg	21,636	30,858	43,108	47,416	51,502	55,365	58,991	62,439	66,503
Fertilizer	Gg	1,784	3,029	4,160	5,101	6,094	7,052	7,895	8,768	9,620

continued

Industry (6 Sectors) continued

Summary–Reference Scenario		2010	2015	2020	2025	2030	2035	2040	2045	2050
Refining	Gg	1,610	2,979	4,350	5,576	7,165	9,348	11,137	12,653	12,849
Pulp and paper	Gg	1,610	4,696	9,453	15,204	22,519	31,387	41,579	53,490	67,157
Total	**Gg**	**34,656**	**56,262**	**90,498**	**110,401**	**132,937**	**158,721**	**184,542**	**208,268**	**233,884**
CO_2e Emissions from Industry Process Emissions										
Iron and steel, ISP plants	Gg	0	0	0	0	0	0	0	0	0
Iron and steel, small plants	Gg	0	0	0	0	0	0	0	0	0
Aluminium	Gg	0	0	0	0	0	0	0	0	0
Cement	Gg	22,813	32,307	37,058	41,085	45,550	50,045	54,984	59,525	64,442
Fertilizer	Gg	0	0	0	0	0	0	0	0	0
Refining	Gg	0	0	0	0	0	0	0	0	0
Pulp and paper	Gg	0	0	0	0	0	0	0	0	0
Total	**Gg**	**22,813**	**32,307**	**37,058**	**41,085**	**45,550**	**50,045**	**54,984**	**59,525**	**64,442**
Total energy and process	**Gg**	**57,468**	**88,569**	**127,556**	**151,486**	**178,487**	**208,766**	**239,525**	**267,793**	**298,326**

CO_2e = carbon dioxide equivalent, Gg = gigagram, GWh = gigawatt-hour, ISP = integrated steel plant, PJ = petajoule.

Summary–Reference Scenario		2010	2015	2020	2025	2030	2035	2040	2045	2050
Land Transport										
Electricity Consumed by Sector										
2W	GWh	977	2,270	2,850	3,714	4,510	5,283	6,270	7,059	7,685
3W	GWh	0	0	0	0	0	0	0	0	0
PC	GWh	0	0	0	0	0	0	0	0	0
LCV	GWh	0	0	0	0	0	0	0	0	0
HCV	GWh	0	0	0	0	0	7	30	54	80
Total on-road	**GWh**	**977**	**2,270**	**2,850**	**3,714**	**4,510**	**5,290**	**6,300**	**7,113**	**7,765**
Mainline and commuter passenger	GWh	0	0	0	0	0	0	0	0	0
Mainline goods rail	GWh	0	0	0	0	0	0	0	0	0
Total rail	**GWh**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total	**GWh**	**977**	**2,270**	**2,850**	**3,714**	**4,510**	**5,290**	**6,300**	**7,113**	**7,765**
Total Energy Consumption by Sector (Including Grid)										
2W	PJ	180	168	183	198	203	214	228	240	252
3W	PJ	0	0	0	0	0	0	0	0	0
PC	PJ	10	16	32	72	128	184	249	313	370
LCV	PJ	12	15	21	29	40	54	73	97	131
HCV	PJ	69	81	87	117	123	147	184	230	291
Total on-road	**PJ**	**271**	**280**	**323**	**416**	**494**	**599**	**733**	**881**	**1,044**

Continued on next page

Land Transport continued

Summary–Reference Scenario										
		2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Inland and coastal passenger service	PJ	7	9	12	15	20	25	32	40	50
Inland waterway freight	PJ	14	17	21	28	36	46	58	73	93
Coastal freight	PJ	3	3	4	5	7	9	11	14	17
Total waterway	**PJ**	**24**	**29**	**37**	**48**	**62**	**79**	**101**	**127**	**161**
Mainline and commuter passenger	PJ	1	1	7	9	12	15	17	20	23
Mainline goods rail	PJ	20	26	48	73	107	137	174	220	278
Total rail	**PJ**	**21**	**27**	**55**	**82**	**119**	**151**	**191**	**240**	**301**
Total	**PJ**	**317**	**336**	**415**	**546**	**676**	**829**	**1,025**	**1,248**	**1,506**
CO_2e Emissions from Energy Consumption (Including Grid)										
2W	Gg	13,037	12,677	14,255	15,722	16,431	17,410	18,373	19,244	20,110
3W	Gg	0	0	0	0	0	0	0	0	0
PC	Gg	742	1,139	2,305	5,193	9,198	13,242	17,928	22,511	26,664
LCV	Gg	896	1,106	1,504	2,088	2,889	3,900	5,266	7,050	9,451
HCV	Gg	5,041	5,937	6,371	8,516	8,977	10,669	13,291	16,634	20,976
Total on-road	**Gg**	**19,716**	**20,859**	**24,435**	**31,520**	**37,495**	**45,221**	**54,859**	**65,438**	**77,201**
Inland and coastal passenger service		558	694	896	1,157	1,491	1,890	2,393	3,004	3,767
Inland waterway freight		1,076	1,250	1,608	2,077	2,683	3,416	4,349	5,498	6,951
Coastal freight		197	244	314	405	524	667	849	1,073	1,356
Total waterway		**1,832**	**2,188**	**2,818**	**3,640**	**4,697**	**5,973**	**7,591**	**9,575**	**12,075**
Mainline and commuter passenger	Gg	60	97	502	686	906	1,078	1,268	1,471	1,706
Mainline goods rail	Gg	1,506	1,919	3,586	5,401	7,969	10,147	12,919	16,332	20,647
Total rail	**Gg**	**1,566**	**2,016**	**4,088**	**6,087**	**8,876**	**11,225**	**14,188**	**17,804**	**22,353**
Total	**Gg**	**23,114**	**25,063**	**31,341**	**41,247**	**51,068**	**62,418**	**76,637**	**92,817**	**111,629**

2W = two-wheeler, 3W = three-wheeler, CO_2e = carbon dioxide equivalent, Gg = gigagram, HCV = heavy commercial vehicle, LCV = light commercial vehicle, PC = passenger car.

2. Low-Carbon Scenario Results

Summary – Low-Carbon Scenario										
		2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Macroeconomics										
GDP annual growth	%	0.00%	6.20%	6.90%	7.00%	7.00%	6.60%	6.60%	6.40%	6.40%
Population annual growth	%		1.01%	0.85%	0.65%	0.41%	0.26%	0.09%	0.04%	0.14%
GDP	D (trillion)	1,981	2,622	3,661	5,134	7,201	9,912	13,645	18,607	25,373
GDP	$ (billion)	106	141	197	276	387	533	733	1,000	1,363
Population	Persons (million)	85.2	89.7	94.1	97.9	100.7	102.8	104.3	105.4	105.9
CO_2e Emissions										
Grid supply electricity	Gg	33,151	82,142	137,642	202,740	252,671	287,190	261,665	222,230	180,414
Captive generation[a]	Gg	3,645	6,275	12,358	18,952	24,285	28,607	28,896	28,896	28,896
Industry (energy and process)	Gg	51,993	86,331	108,166	125,864	143,433	161,304	180,915	199,800	220,088
Nonresidential	Gg	163	252	313	335	348	360	370	380	387
Road and rail transport	Gg	22,612	23,213	26,448	29,699	33,464	38,444	46,709	56,823	69,116
Total	Gg	111,564	198,213	284,927	377,589	454,201	515,904	518,555	508,129	498,901
CO_2e Emissions Intensity										
CO_2e emissions per $1,000 GDP	CO_2e tons/$1,000 GDP	1.05	1.41	1.45	1.37	1.17	0.97	0.71	0.51	0.37
CO_2e emissions per capita	CO_2e tons/capita	1.31	2.21	3.03	3.86	4.51	5.02	4.97	4.82	4.71

CO_2e = carbon dioxide equivalent, GDP = gross domestic product, Gg = gigagram.

[a] Excludes captive generation in industry that is accounted for in other fuel use.

Summary – Low-Carbon Scenario										
		2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Power Sector										
Installed Capacity										
Hydro	MW	9,402	18,063	21,898	25,128	28,943	36,806	41,431	49,295	56,450
Thermal	MW	13,531	22,414	33,844	54,587	69,947	92,062	91,032	85,621	83,805
Nuclear	MW	0	0	0	0	4,600	10,600	22,600	34,600	46,600
Renew	MW	25	245	895	5,760	15,580	29,009	65,169	103,454	142,974
Total	**MW**	**22,958**	**40,721**	**56,636**	**85,474**	**119,069**	**168,477**	**220,232**	**272,970**	**329,829**
Generation										
Hydro	GWh	34,417	66,295	80,447	84,800	90,780	104,596	109,174	116,825	123,258
Thermal	GWh	58,114	90,916	145,363	228,132	281,053	318,767	277,747	229,151	183,561
Nuclear	GWh	0	0	0	0	30,499	70,083	148,368	225,918	303,106
Renew	GWh	99	693	2,884	19,342	51,522	91,989	198,213	314,181	436,495
Total Grid	**GWh**	**92,630**	**157,904**	**228,694**	**332,274**	**453,853**	**585,435**	**733,501**	**886,075**	**1,046,421**
Captive/Off Grid[a]	GWh	3,406	5,863	11,548	17,709	22,692	26,730	27,000	27,000	27,000
Total	**GWh**	**96,036**	**163,768**	**240,241**	**349,983**	**476,545**	**612,165**	**760,501**	**913,075**	**1,073,421**

Continued on next page

Power Sector continued

Summary – Low-Carbon Scenario		2010	2015	2020	2025	2030	2035	2040	2045	2050
CO_2e Emissions										
Hydro	Gg	0	0	0	0	0	0	0	0	0
Thermal	Gg	33,151	82,142	137,642	202,740	252,671	287,190	261,665	222,230	180,414
Nuclear	Gg	0	0	0	0	0	0	0	0	0
Renew	Gg	0	0	0	0	0	0	0	0	0
Total	**Gg**	**33,151**	**82,142**	**137,642**	**202,740**	**252,671**	**287,190**	**261,665**	**222,230**	**180,414**
Captive/Off Grid[a]	Gg	3,645	6,275	12,358	18,952	24,285	28,607	28,896	28,896	28,896
Total	**Gg**	**36,796**	**88,417**	**150,000**	**221,692**	**276,955**	**315,796**	**290,561**	**251,126**	**209,310**
Specific CO_2e Emissions										
Grid electricity	g/kWh	358	520	602	610	557	491	357	251	172
Captive/Off-grid electricity	g/kWh	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Average	**g/kWh**	**383**	**540**	**624**	**633**	**581**	**516**	**382**	**275**	**195**

CO_2e = carbon dioxide equivalent, Gg = gigagram, g/kWh = gram per kilowatt-hour, GWh = gigawatt-hour, MW = megawatt.
Note: In this table, "hydro" includes large hydro, small hydro (which is classified in PDP-VII as renewable), and pumped storage. "Thermal" includes coal, oil, gas, and diesel. "Renew" includes solar, wind, and biofuel generation.
[a] Excludes captive generation in industry that is accounted for in other fuel use.

Summary – Low-Carbon Scenario		2010	2015	2020	2025	2030	2035	2040	2045	2050
Household Electricity Consumption										
Electricity Consumed by Households (Grid and Captive)										
Lighting	GWh	2,354	4,506	3,890	3,451	3,958	4,050	4,741	5,471	6,178
Entertainment	GWh	5,888	8,467	7,851	6,729	5,659	5,066	5,121	5,421	5,842
Kitchen Appliances	GWh	16,491	20,813	27,072	29,971	30,871	30,669	31,281	32,696	35,010
Heating/Cooling	GWh	5,404	14,612	23,785	40,265	62,811	85,421	98,947	98,980	98,946
Total	**GWh**	**30,137**	**48,397**	**62,598**	**80,416**	**103,298**	**125,206**	**140,089**	**142,568**	**145,975**
Operating	GWh	27,098	45,403	59,803	77,915	101,176	123,402	138,384	140,843	144,135
Standby	GWh	3,039	2,994	2,795	2,501	2,123	1,804	1,706	1,725	1,841
Total		**30,137**	**48,397**	**62,598**	**80,416**	**103,298**	**125,206**	**140,089**	**142,568**	**145,975**
CO_2e Emissions from Household Electricity Consumption										
Total	Gg	11,547	26,129	39,085	50,938	60,034	64,590	53,523	39,211	28,464

CO_2e = carbon dioxide equivalent, Gg = gigagram, GWh = gigawatt-hour.

Summary – Low-Carbon Scenario		2010	2015	2020	2025	2030	2035	2040	2045	2050
Industry (5 Sectors)										
Electricity Consumed by Sector (Grid Only)										
Iron and steel, ISP plants	GWh	510	1,878	2,923	2,599	(1,165)	(9,393)	(12,134)	(14,163)	(16,383)
Iron and steel, small plants	GWh	6,602	6,291	6,193	5,900	5,327	4,900	4,718	4,639	4,621
Aluminium	GWh	0	0	0	0	0	0	0	0	0
Cement	GWh	5,764	8,020	9,842	10,463	10,767	10,712	10,935	11,297	11,683
Fertilizer	GWh	319	525	703	855	1,012	1,164	1,306	1,447	1,578
Refining	GWh	0	0	0	0	0	0	0	0	0
Pulp and paper	GWh	604	1,647	3,177	5,096	7,521	10,520	14,254	18,629	23,603
Total	GWh	13,800	18,361	22,838	24,914	23,462	17,903	19,079	21,847	25,101
Total Energy Consumption by Sector (Including Grid)										
Iron and steel, ISP plants	PJ	25	108	195	245	274	276	293	298	309
Iron and steel, small plants	PJ	57	55	54	52	49	47	46	46	46
Aluminium	PJ	0	0	0	0	0	0	0	0	0
Cement	PJ	222	328	404	432	452	466	485	501	519
Fertilizer	PJ	29	47	62	76	89	103	116	130	143
Refining	PJ	21	39	57	72	93	121	144	164	166
Pulp and paper	PJ	16	44	85	135	197	273	368	483	615
Total	**PJ**	**369**	**620**	**856**	**1,014**	**1,154**	**1,284**	**1,451**	**1,620**	**1,798**
CO_2e Emissions from Energy Consumption (Including Grid)										
Iron and steel, ISP plants	Gg	2,412	10,893	19,811	24,647	26,290	24,956	27,843	29,931	32,799
Iron and steel, small plants	Gg	5,604	6,500	6,969	6,750	5,928	5,241	4,433	3,836	3,391
Aluminium	Gg	0	0	0	0	0	0	0	0	0
Cement	Gg	21,636	33,317	41,887	44,919	46,221	46,736	47,025	47,214	47,768
Fertilizer	Gg	1,784	3,007	4,083	4,946	5,733	6,484	7,123	7,789	8,432
Refining	Gg	1,610	2,975	4,309	5,506	7,062	9,210	10,968	12,462	12,663
Pulp and paper	Gg	1,610	4,621	9,167	14,651	20,890	28,133	35,852	44,761	54,775
Total	**Gg**	**34,656**	**61,312**	**86,225**	**101,421**	**112,125**	**120,759**	**133,243**	**145,993**	**159,829**
CO_2e Emissions from Industry Process Emissions										
Iron and steel, ISP plants	Gg	0	0	0	0	0	0	0	0	0
Iron and steel, small plants	Gg	0	0	0	0	0	0	0	0	0
Aluminium	Gg	0	0	0	0	0	0	0	0	0
Cement	Gg	22,813	35,562	37,058	41,085	45,550	50,045	54,984	59,525	64,442
Fertilizer	Gg	0	0	0	0	0	0	0	0	0
Refining	Gg	0	0	0	0	0	0	0	0	0
Pulp and paper	Gg	0	0	0	0	0	0	0	0	0
Total	**Gg**	**22,813**	**35,562**	**37,058**	**41,085**	**45,550**	**50,045**	**54,984**	**59,525**	**64,442**
Total energy and process	**Gg**	**57,469**	**96,875**	**123,283**	**142,506**	**157,675**	**170,804**	**188,227**	**205,518**	**224,271**

CO_2e = carbon dioxide equivalent, Gg = gigagram, ISP = integrated steel plant.

Summary – Low-Carbon Scenario										
		2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Land Transport										
Electricity Consumed by Sector										
2W	GWh	474	1,829	3,419	5,230	6,877	7,770	8,299	8,703	9,101
3W	GWh	0	0	0	0	0	0	0	0	0
PC	GWh	0	0	0	0	0	0	0	0	0
LCV	GWh	0	0	0	0	0	0	0	0	0
HCV	GWh	0	0	0	0	0	12	27	54	77
Total on-road	**GWh**	**474**	**1,829**	**3,419**	**5,230**	**6,877**	**7,782**	**8,326**	**8,757**	**9,178**
Mainline and commuter passenger	GWh	0	0	0	0	0	0	0	0	0
Mainline goods rail	GWh	0	0	0	0	0	0	0	0	0
Total rail	**GWh**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total	**GWh**	**474**	**1,829**	**3,419**	**5,230**	**6,877**	**7,782**	**8,326**	**8,757**	**9,178**
Total Energy Consumption by Sector (Including Grid)										
2W	PJ	172	150	136	112	77	58	57	59	62
3W	PJ	0	0	0	0	0	0	0	0	0
PC	PJ	10	16	31	58	79	96	120	148	174
LCV	PJ	10	13	17	23	29	35	44	57	76
HCV	PJ	75	90	100	115	135	163	191	219	253
Total on-road	**PJ**	**268**	**269**	**283**	**308**	**320**	**352**	**411**	**483**	**566**
Inland and coastal passenger service	PJ	7	9	12	15	19	24	31	38	48
Inland waterway freight	PJ	14	16	20	25	32	40	50	63	80
Coastal freight	PJ	3	3	4	5	7	8	11	13	17
Total waterway	**PJ**	**24**	**29**	**36**	**45**	**58**	**73**	**92**	**115**	**144**
Mainline and commuter passenger	PJ	1	1	7	11	15	18	21	25	28
Mainline goods rail	PJ	20	27	49	78	114	145	185	233	295
Total rail	**PJ**	**21**	**29**	**57**	**89**	**129**	**163**	**206**	**258**	**324**
Total	**PJ**	**313**	**326**	**375**	**442**	**507**	**588**	**709**	**856**	**1,034**
CO_2e Emissions from Energy Consumption (Including Grid)										
2W	Gg	12,420	11,307	10,988	9,622	7,420	5,949	4,882	4,174	3,636
3W	Gg	0	0	0	0	0	0	0	0	0
PC	Gg	750	1,149	2,241	3,937	5,239	6,145	7,705	9,477	11,193
LCV	Gg	738	910	1,235	1,567	1,936	2,300	2,865	3,706	4,942
HCV	Gg	5,488	6,555	7,234	7,887	8,919	10,461	12,218	14,031	16,231
Total on-road	**Gg**	**19,396**	**19,921**	**21,698**	**23,013**	**23,514**	**24,855**	**27,670**	**31,388**	**36,002**

continued on next page

Land Transport continued

Summary – Low-Carbon Scenario										
		2010	2015	2020	2025	2030	2035	2040	2045	2050
Inland and coastal passenger service		558	690	884	1,135	1,452	1,829	2,300	2,870	3,577
Inland waterway freight		1,076	1,215	1,488	1,869	2,374	2,990	3,775	4,741	5,958
Coastal freight		197	243	312	401	517	656	833	1,050	1,323
Total waterway		**1,832**	**2,148**	**2,683**	**3,405**	**4,343**	**5,475**	**6,908**	**8,660**	**10,859**
Mainline and commuter passenger	Gg	60	97	541	808	1,138	1,350	1,587	1,833	2,111
Mainline goods rail	Gg	1,506	2,034	3,661	5,785	8,466	10,779	13,725	17,350	21,933
Total rail	**Gg**	**1,566**	**2,131**	**4,201**	**6,594**	**9,604**	**12,129**	**15,311**	**19,183**	**24,044**
Total	**Gg**	**22,794**	**24,200**	**28,583**	**33,012**	**37,461**	**42,458**	**49,890**	**59,232**	**70,905**

2W = two-wheeler, 3W = three-wheeler, CO_2e = carbon dioxide equivalent, Gg = gigagram, HCV = heavy commercial vehicle, LCV = light commercial vehicle, PC = passenger car.

Pathways to Low-Carbon Development for Viet Nam

Viet Nam has had rapid economic growth in recent years, but this growth has been energy dependent, even as the energy system has become more carbon intensive. This study uses a bottom-up model to evaluate 63 measures to reduce greenhouse gas emissions from household electricity, industry, power generation, and transport. It finds potential for emissions reduction by 53% in 2050, and that much of this reduction can occur at low or negative financial costs. Moreover, these measures are found to ultimately lead to faster and more inclusive economy-wide growth. Policy measures are identified to help realize the modeled potential.

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ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to a large share of the world's poor. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

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