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Green growth opportunities for the decarbonization goal for Chile

Report on the macroeconomic effects of implementing climate change mitigation policies in Chile 2020

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Green growth opportunities for the decarbonization goal for Chile

Report on the macroeconomic effects of implementing climate change mitigation policies in Chile 2020

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ABSTRACT

The study presents the results of model simulations showing the macroeconomic effects of the implementation of key climate change mitigation policies in Chile, aimed to reduce CO2eq emissions in accordance with Chilean latest NDC and a target of zero net CO2eq emissions by 2050. By using a multi-sector macroeconomic general equilibrium model, the study shows that the implementation of the proposed policy package could have an overall positive impact on the economy both in the short and long run, as measured by the effect on economic indicators such as GDP, and ensures decoupling of growth from fossil fuel use. Per the analysis, the expected level of GDP by 2050 could increase up to 4,4% when compared to the baseline scenario, which corresponds to a higher rate of growth of 0.13 p.p. Main contribution to GDP is expected from increased private consumption and investment, with an estimated 2.4% and 1.7% respectively. Since positive economic and financial implications could arise from the implementation of the proposed mitigation package, the unsolicited participation of the private sector could be expected and enhanced. Remaining questions and discussions from the study relate to limitations for the uptake of mitigation measures sooner than long term scenarios. Lack of enabling conditions and current restrictions to public-private sector engagement could prevent a smooth and spontaneous transition, including the risk of various market and government failures. Future analysis is needed on how to ensure financing of proposed mitigation measures, how to reduce political economy constrains and investment risks, and the evaluation of instruments needed for the implementation of the climate targets and related work plan.

The study evaluated the macroeconomic impact of implementing a mitigation package aligned with the achievement of the recent updated Chilean NDC and committed zero net CO2eq emissions by 2050. The study assessed the impact on value added for the economy, the sectoral activity, the demand side of the economy, and the implications of delaying implementation and varying the costs of the mitigation package. The results for main macroeconomic indicators are positive, showing that the decoupling of economic activity and emissions is possible. The proposed mitigation package could yield a reduction in the use of fossil fuels and the corresponding emissions in main sectors for Chile.

The sensitivity analysis shows that a lag in the introduction of measures puts the achievement of net-zero emissions in 2050 at risk, highlighting the importance of acting now. The study also shows that overestimation of OPEX savings values could have a higher impact on emissions and GDP level than the underestimation of the necessary capital expenditures. It is important to also highlight assumptions and biases behind the modelling exercise. As input to the economic model, mitigation measures are simulated independently, losing the possible interactions and their effects. Results may change depending on the type of financing, budget closure and CAPEX – OPEX information. In addition, the baseline data for the model was built prior to the social unrest that began in October 2019, and more recently, the impacts of the COVID-19 pandemic. Therefore, the simulations in the study should be considered as a reference tool for understanding the impacts of climate mitigation policies on macroeconomic variables. The study acknowledges a degree of uncertainty on capital costs associated with each measure and would require periodic updates to be able to be used as a systematic tool in the selection of mitigation measures.

Keywords:

climate change mitigation, DSGE modeling, environmental economics, low-carbon transition
JEL: Q43, Q58, D58

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Foreword Former Minister, Ministry of Finance

Felipe Larraín

PROFESSOR AT THE PONTIFICAL CATHOLIC UNIVERSITY OF CHILE, MEMBER OF THE EXECUTIVE COMMITTEE OF THE LATIN AMERICAN CENTER FOR ECONOMIC AND SOCIAL POLICIES UC (CLAPES UC).

Chile is aware of the need for a transition to a low carbon economy focused in the social and economic recovery and wellbeing, which is resilient to the impacts of climate change, as part of Government's efforts to achieve sustainable development with greater efficiency, competitiveness, equity and economic growth.

A failure of take quick and effective action shall have significant economic and financial impacts and will leave our society exposed to different risks. Nevertheless, new opportunities will, at the same time, arise with the transformation and transition towards a low carbon economy accompanied by an efficient use of resources, the adoption of clean energy sources, the development of innovative products and services, the growth of environmentally friendly markets and entities' adaptation to climate change.

The Government of President Sebastián Piñera is taking on the responsibility of this challenge, and is working facing the presents demands, like the economic consequences of the COVID-19, but also looking forward a better environment and society.

This document titled "Report on the macroeconomic effects of implementing climate change mitigation policies in Chile" is a specific contribution in the understanding of the climate change and economics in Chile and the region. The applicable of this methodological approach would help the update of the Long-term Climate Strategy toward the neutrality, the National Determine Contribution under the Paris Agreement and the green budgeting process. This contribution is part of several policies that we are promoting in the same line like: i) The Financial Strategy on Climate Change, ii) The Green Agreement subscribed by the financial sector, regulators and the government, iii) The joint statement with the regulators on Climate Change and the relation with financial stability and iv) the two issuance of Green sovereign bonds for the benefit and care of the environment and society, in addition to incredibly competitive rates, which shows that facing climate change and taking advantage of adaptation opportunities can also be a good measure from a financial point of view. The announcement of the goal to reach net emission neutrality as soon as possible is a clear reflection of the commitment as regards climate action.

This year, Chile is playing a particularly significant role as regards this phenomenon, leading the most important worldwide initiative on this matter: our country has been honoured with the presidency of the 25th Conference of the Parties (COP), which offers the opportunity to speed up the progress concerning the reduction of greenhouse gas emissions.

In addition, the Chilean Ministry of Finance is co-chairing, together with Finland, the Coalition of Finance Ministers for Climate Action, an unprecedented initiative where we are working together with over 50 countries to encourage best practices and experiences to mitigate and adapt our economies to the challenges posed by climate change. All of the above requires us to continue strengthening the institutions that drive investment, innovation and the development of technologies towards sectors which will help us to meet Chile's goals on climate while increasing our competitiveness. To this end, the Ministry of Finance, as the entity responsible for governmental policies and public finance, plays a key role by generating the conditions allowing the channelling of public and private capital flows towards sustainable, equitable and fair development for individuals and the environment.

In this sense, this macroeconomic report constitutes a landmark in the economic management of climate change, one of Chile's commitments after the Paris Agreement, defines the axes and measures that shall lead the efforts as regards climate financing to achieve the transition towards a low carbon economy, resilient to the effects of climate change.

Foreword Minister, Ministry of Environment

Carolina Schmidt

The challenges of climate change compel us to take a long-term perspective to the way we think and act in the pursuit of present-day priorities – particularly given the challenges the world is currently facing as a result of the Coronavirus pandemic. It is vital that the actions that we undertake today enable a profound transformation of our economy, setting us on the path to major reductions of Greenhouse Gases (GHG) emissions and increased socioeconomic resilience in order to ensure a sustainable and strong recovery from the Covid-19 crisis.

In order to realize such changes, quantitative and qualitative data that enables robust analyses of future scenarios is crucial, allowing us to make the best decisions for diverse social, political and economic actors by illustrating the potential alternatives and advantages of a low-carbon and climate-resilient economy.

This study is the result of close collaboration between the World Bank and the Chilean Government as presidency of COP25, through the Ministry of Finance and the Ministry of the Environment, which has allowed us to bring together a range of key datasets and policy-makers in order to support the objective of emissions neutrality by 2050. Not only does the study demonstrate the feasibility of achieving this emissions reduction target, but it also highlights the economic, social and environmental benefits of doing so, estimating up to a 4.4% increase in GDP by 2050 and clearly illustrating the potential to decouple economic growth from GHG emissions.

Chile is firmly committed to climate action, as reflected by its pledge to reach carbon neutrality by 2050. The country will be the first in Latin America to have this target enshrined in law, with the relevant legislation currently under discussion in our Parliament. In the midst of the Covid-19 crisis, we have also presented a significantly enhanced Nationally Determined Contribution (NDC) to the UNFCCC, which has been recognized by a number of international organizations as a strong commitment to increased climate ambition.

Chile's new NDC sets out our intermediate goals on the road to carbon neutrality by the middle of the century, presenting important contributions in the areas of adaptation, oceans, peatlands, forests, circular economy and implementation measures. Importantly, it also takes a novel approach by establishing – for the first time in a NDC – a social pillar that aligns our commitments with the United Nations' Sustainable Development Goals to ensure that the implementation of climate measures is consistent with protecting people and livelihoods. For example, this social pillar sets out plans for the development of a Just Transition Strategy for the decarbonization of our energy system.

The present study reaffirms the need to continue building an integrated vision linking social, environmental and economic priorities to ensure equitable and sustainable development, restoring the necessary balances of our planet, in order to promote better standards of living for present and future generations.

As the report reveals, Chile is a prime example of a country which can benefit significantly from the transition to a sustainable, low-carbon economy.

Foreword Minister, Ministry of Energy

Juan Carlos Jobet

The Intergovernmental Panel on Climate Change has made our situation clear: in order to limit the global temperature increase to 1.5 degrees Celsius, global emissions must reach net zero by 2050. Our sector has been a significant part of the problem, yet now it can become an essential piece of the solution given the substantial mitigation opportunities that it holds.

Aware of this, Chile has committed to become carbon-neutral by 2050, a goal in which the energy sector is the main protagonist; not only because it represents 80% of the GHG emissions in the country, but because it channels the leading measures for reducing emissions, hence becoming the principal engine of green economic reactivation and mitigation of climate change.

The Ministry of Energy, along with the Ministry for the Environment and other public institutions, have fostered and designed a plan for reaching carbon neutrality. The plan is ambitious, but its essence is simple: we will clean our electricity generation capacity, to then replace fossil fuels with electricity across different sectors of the economy: mining, industry, transportation and buildings. Additionally, green hydrogen will play an important role in achieving this goal, complementing the replacement of fossil fuels where electricity is not competitive. Chile is one of the countries best suited to produce this fuel, due to its huge, low cost renewable energy potential. This allows Chile to produce green hydrogen for use in transport and industry, as well as for export needs.

The ambitious phase-out plan for all coal-fired plants by 2040 is a big component of our national energy transition. It will be combined with both the development of renewable energy generation and new transmission lines. Therefore, carbon neutrality creates an opportunity for electricity to become one of the main energy sources to reduce global emissions and local pollution, with significant environmental and human health benefits.

In order to understand how the different variables of the country's macroeconomic environment interact with the path towards carbon neutrality, the Ministry of Finance carried out in-depth research. This shows the positive effect that the adoption of mitigation measures has on our economy, evaluated through the growth of the Gross Domestic Product (GDP), and the decoupling between economic growth and the use of fossil fuels.

In other words, facing climate change is not only necessary but advantageous for the country and society. This analysis also shows that it is possible to establish an economic growth path in compliance with environmental and social responsibility. The latter through adoption of cost-efficient policies that promote the energy transition towards a green economy and reduce the negative impacts of climate change.

The study also reinforces Chile's position as a leader in climate and environmental responsibility in the region, evidencing the need for establishing a continuous collaboration between sectors. In awareness of this need for wide collaboration, the Ministry of Energy will continue to provide knowledge, human capital and technical resources for initiatives as important as this report on public policy and climate change.

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ACKNOWLEDGEMENTS

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The report was prepared by Marek Antosiewicz and Piotr Lewandowski from IBS (Poland), under the leadership of Luis Gonzales, Head of Climate Change, Energy, Environment and Economics at Clapes UC y former Chief of Studies, Ministry of Finance.

The report's preparation and launch was overseen by a World Bank Group team led by Ana Elisa Bucher (Sr Climate Change Specialist, Climate Change Group) and Francisco Javier Winter Donoso (Operations Officer, Chile Country Office).

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Green growth opportunities for the decarbonization goal for Chile

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1. INTRODUCTION

The Chilean government has shown significant political will to implement climate change mitigation actions, which will enable the country to fulfil its commitments regarding reductions in greenhouse gas (GHG) emissions. These obligations are set in different initiatives, like the Financial Strategy on Climate Change and the revised Chilean Nationally Determined Contribution (NDC), which aims to reach a target of zero net emissions by 2050. The government has developed and updated a set of intervention measures which encourage emission reductions across the entire economy (Ministry of Environment, 2020). Implementing such policies requires a thorough economic analysis and understanding of their costs and consequences (Krogstrup & Oman, 2019). Since these policies are significant from the point of view of the economy, their full cost goes beyond the simple sum of the expenditures. Required policies usually involve fundamental changes in the structure of the economy, and therefore should be assessed strategically with tools that consider multiple interlinkages between various actors of the economy: government, consumers, firms in different sectors and trade with the rest of the world. Conducting such an assessment can shed light on the possible positive or negative macroeconomic consequences of these actions, while helping identify the winning and potentially losing sectors, and thus; helping ensure public support and enabling conditions for their implementation (IMF, 2019).

During the last decade, the Chilean government, universities and research centers have engaged in assessments of mitigation measures related to climate change (Palma et. al, 2020). The Mitigation Action Plans and Scenarios (MAPS) Chile project began in 2012, to study and deliver the best options the country had for mitigating GHG emissions. The output included the 2013-2030 GHG emissions baseline, mitigation measures and scenarios, together with an analysis of the macroeconomic effects associated with the different scenarios. A description of this process, the implications for the energy sector and the revised National Determined Contribution (NDC), are analyzed in Palma et. al (2019). The purpose of this report is to update the macroeconomic analysis of the new set of mitigation measures[1] . The study aimed to assess the measures considered for the revised NDC and the carbon neutrality commitment along with the updated economic circumstances and projections that were in place by the newly revamped Chile NDC.

This study is based on similar work done for Mexico in 2016. Veysey et al. (2016) estimated that the mitigation costs for the country to implement measures to reduce emissions by 50% in 2050 with respect to 2000, could range from 2% to 4% of GDP in 2030, and from 7% to 15% of GDP in 2050. Similar studies by Tober et al. (2016), estimate that using carbon tax as a mitigation measure could have either negative and positive effects on GDP for Latin American countries, depending on the macroeconomic models used. Lefèvre et al (2018), suggest that Brazil could maintain oil production levels with a deeper decarbonization according to its NDC, and aligned with a 2°C emission pathway, with a small loss in GDP by 2030. The higher cost implications here in comparison with our results may be due to several factors, such as the evaluation of impacts in countries with different energy matrices (Mexico is an oil-producing country, for example) and different sets of mitigation measures, among others.

The study is structured as follows: Section 2 details the Chilean GHG emissions by sector and proposed mitigation measures; Section 3 presents the MEMO model and simulation setup; Section 4 presents plausible results, and Section 5 presents a discussion and suggestions on potential next steps.

[1] *Similar to a MAPS project undertaken previously in Chile by the Ministry of Environment*

2. CHILEAN GHG EMISSIONS AND MITIGATION MEASURES

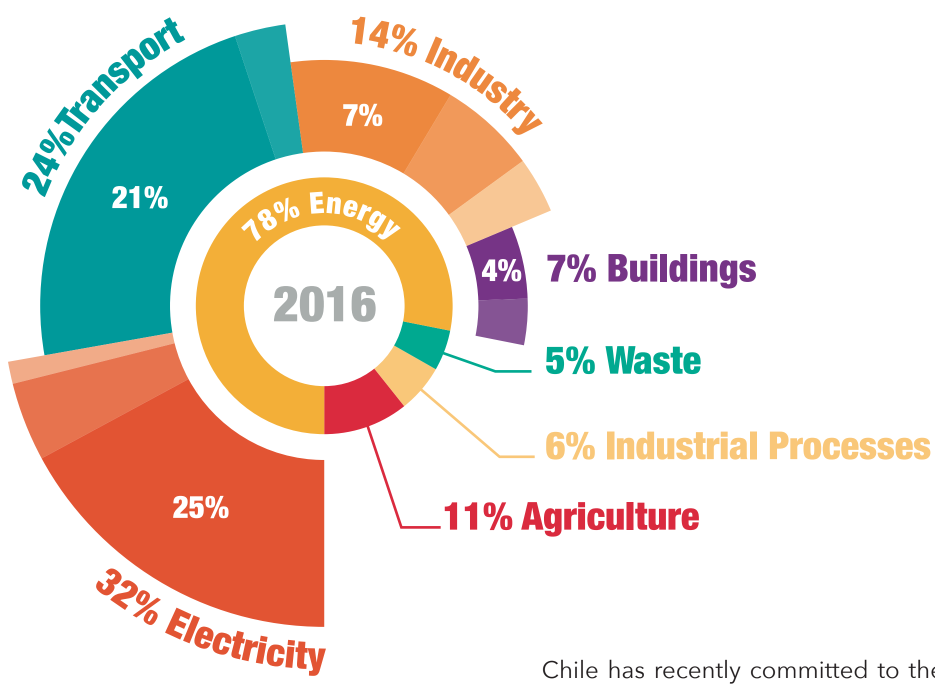
2.1. GHG emissions

Chile recently submitted NDC[2] provides a set of mitigation actions that seek to reduce CO_{2eq} emissions from a wide range of economic activities. According to the 2016 GHG inventory from the country, the main CO_{2eq} source sectors are Electricity and Transport, mostly due to the use of fossil fuels, as shown in Figure 2.1.

Figure 2.1.

Share of GHG emissions by sector (2016 estimates)

Source: Ministry of Energy



Chile has recently committed to the bold action of reaching carbon neutrality by 2050, with an ambitious NDC for 2030 as a step in the process to reduce 45% of net emissions, as stated in the recent revamped NDC. To achieve this neutrality, the ministries of Energy, Environment and Agriculture, have proposed several measures that aim to reduce CO_{2eq} emissions and to increase its capture. These measures are aggregated by category in Figure 2.2, which illustrates their projected contribution. Sustainable Industry, the inclusion of Hydrogen into the energy matrix, Electromobility, Sustainable Building and the phase-out of coal-powered electric plants will play a major role, accounting for 93% of the projected CO_{2eq} reductions.

[2] *Chile submitted its updated NDC to the UNFCCC on April the 8th, 2020. The quantitative goals presented in this NDC are part of a wider analysis, in which Chile will seek to reach GHG neutrality by 2050, as established in the Draft Framework Law on Climate Change that is currently under discussion in the National Congress. As such, this contribution and its consecutive iterations will be intermediate milestones to achieve the 2050 neutrality goal, conforming in design with the necessary measures to reach this. This update presents an increase in the ambition of Chile's commitment to reach the Paris Agreement objective, in line with a path towards GHG neutrality by 2050. This increase in ambition is consistent with what was promoted and highlighted by the country during COP25, which is reflected in the decision 1/CP.25 by all Parties.*

Figure 2.3 shows the projected contributions of the most relevant measures and their share on the levels of CO_{2eq} to be reduced in order to achieve neutrality, given the level of CO_{2eq} captures. The Phase-out of coal plants, the introduction of solar thermal systems and hydrogen for machine drives in the Industry Sector, replacing diesel with hydrogen in freight transport, and the electrification of residential heating are the five interventions with the highest projected contributions towards reducing emissions, accounting for 51% of the reductions.

Figure 2.2.

Measure contributions towards carbon neutrality

Source: Ministry of Energy

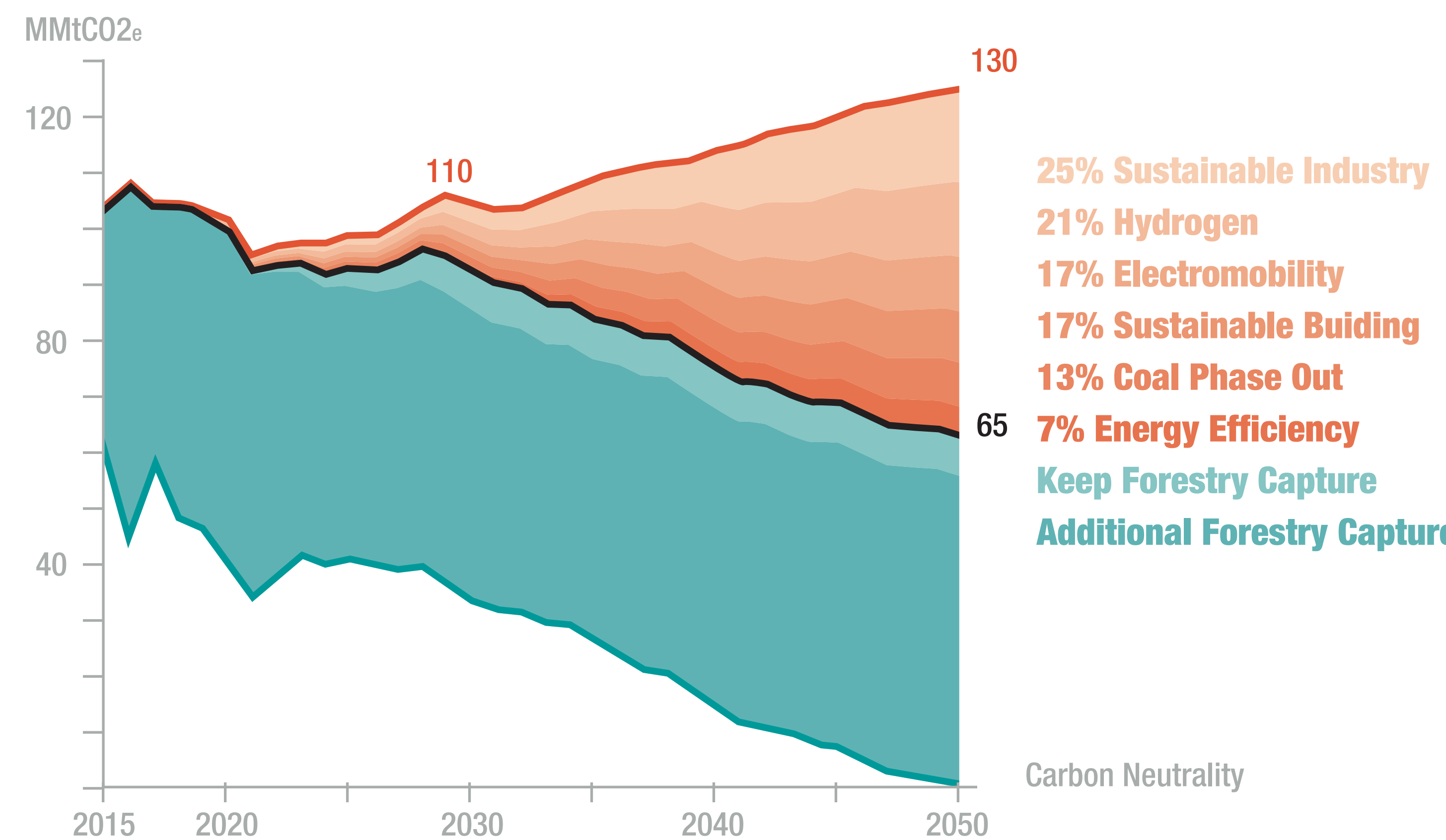


Figure 2.4 shows the abatement costs curve, illustrating that some measures will imply savings, while in order to achieve neutrality it is needed to include measures that will have a high cost per ton of CO2eq reduced. From the previous five identified measures only coal phase-out is projected to have positive abatement costs.

2.2. Mitigation measures

The ministries of Energy, Environment and Agriculture have estimated that the net present value of the investment required to carry out these measures is around US$48.600 million. However, their estimates about the operational and maintenance expenditures represents savings of about US$80.100 million, giving a direct net gain of US$31.500 million. The details aggregated by category of measure are shown in Table 2.1. On the one hand, there are three categories that yield a negative net present value: Phase-out of coal-powered plants, Electromobility and Keeping Forestry Captures. On the other hand, Sustainable Building, Hydrogen and Sustainable Industry policies are projected to have a net present value of over US$9.000 million. Yet, the total CAPEX of the mitigation package adds up to an average 1.1% of the projected GDP and 5.3% of the projected Gross Fixed Capital Formation (GFCF), as summarized in Table 2.2, which sheds light on the relevance of a macroeconomic evaluation of their effects and how it is going to be financed. Indeed, a hypothetical and extreme scenario in which there is no private investment, shows that this package implies an additional 31,3% of public investment. However, according to the Ministry of Energy, electromobility measures and others consider a significant amount of private investment that reduces the public share required to finance the measures. Thus, according to the Ministry of Energy estimates, public investment will need to account for around 26% of all CAPEX (in present value).

Despite this assessment of the measures, there is huge uncertainty around the effectiveness and opportunity of the measures. The package of measures has not considered ex-ante fiscal tools, or regulatory actions to enforce neutrality. However, a climate change bill targeting and mandating neutrality is currently under discussion in the National Congress

The policies identified as the most cost-effective to reach carbon neutrality in 2050 will introduce changes in the energy, transport, industry and residential sectors mainly. These changes will have, among others, macroeconomic effects that we aim to analyze through this report.

Table 2.1

NPV by measures sector, period 2020 – 2050

Source: Ministry of Energy

Sector	CAPEX (Millions USD)	OPEX (Millions USD)	Net value (Millions USD)
Coal Phase Out	-2,100	1,200	-900
Sustainable Industry	-4,800	14,400	9,600
Electromobility	-23,100	20,200	-2,900
Hydrogen	-9,200	18,800	9,600
Sustainable Building	-5,900	16,900	11,100
Energy Efficiency	-2,800	8,900	6,100
Keep Forestry Capture	-700	-300	-1,000
Total	**-48,600**	**80,100**	**31,500**

Note: Discount rate: 6%

Table 2.2

CAPEX of mitigation package (2020-2050) as percentage of macroeconomic indicators

Source: Ministry of Finance with data from the Ministry of Energy and the Budgeting Office

CAPEX as % of:	GDP	GFCF	Public Expenditures	Public Investment
Annual Average (2020-2050)	1.1	5.3	5.3	31.3
Present Value (Discount rate of 6%)	1.0	5.0	4.9	29.2

Figure 2.3

Cumulative reduction of 2050 emissions by sector as a function of mitigation policies, share of reduction of main measures

Source: Ministry of Energ

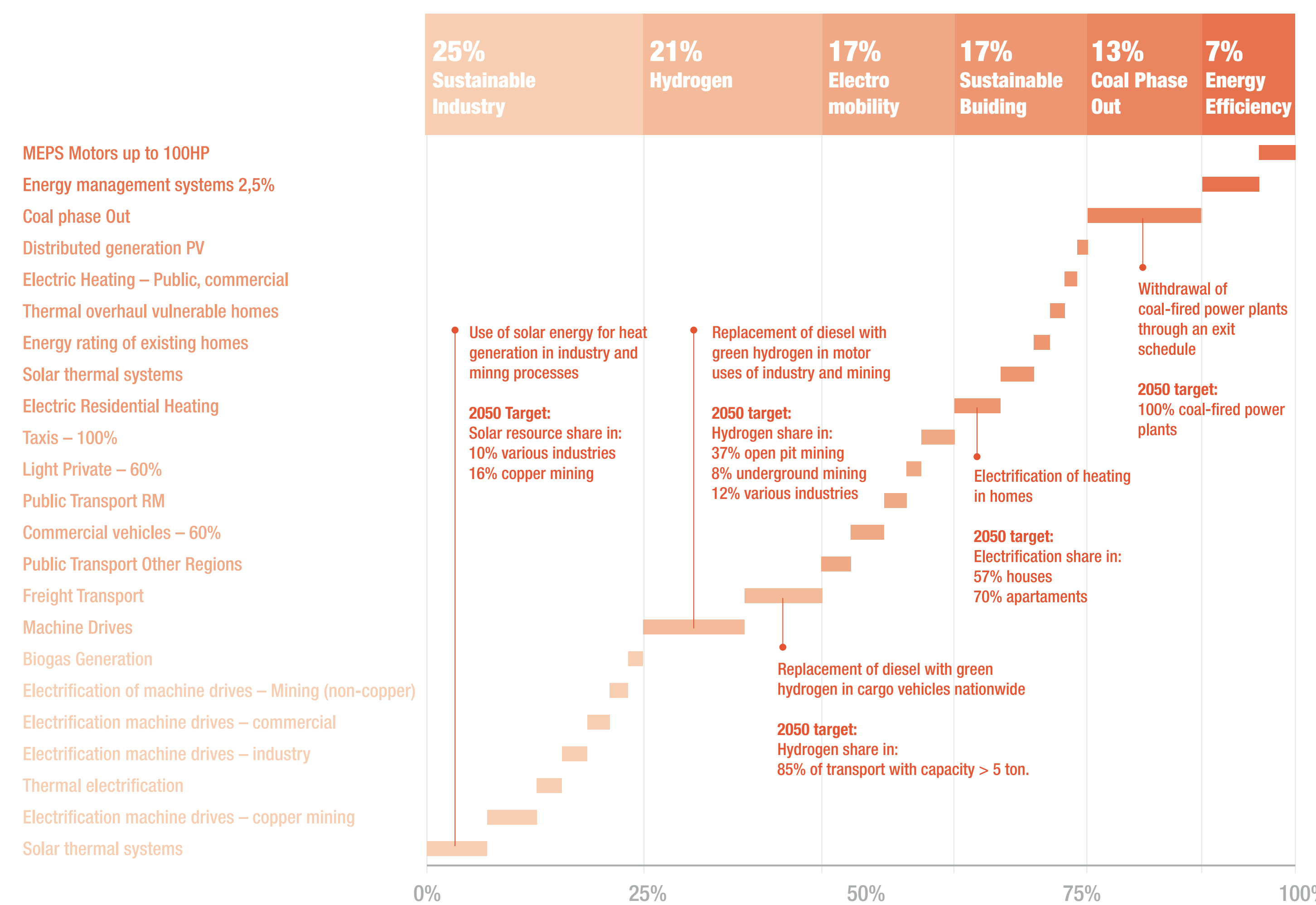
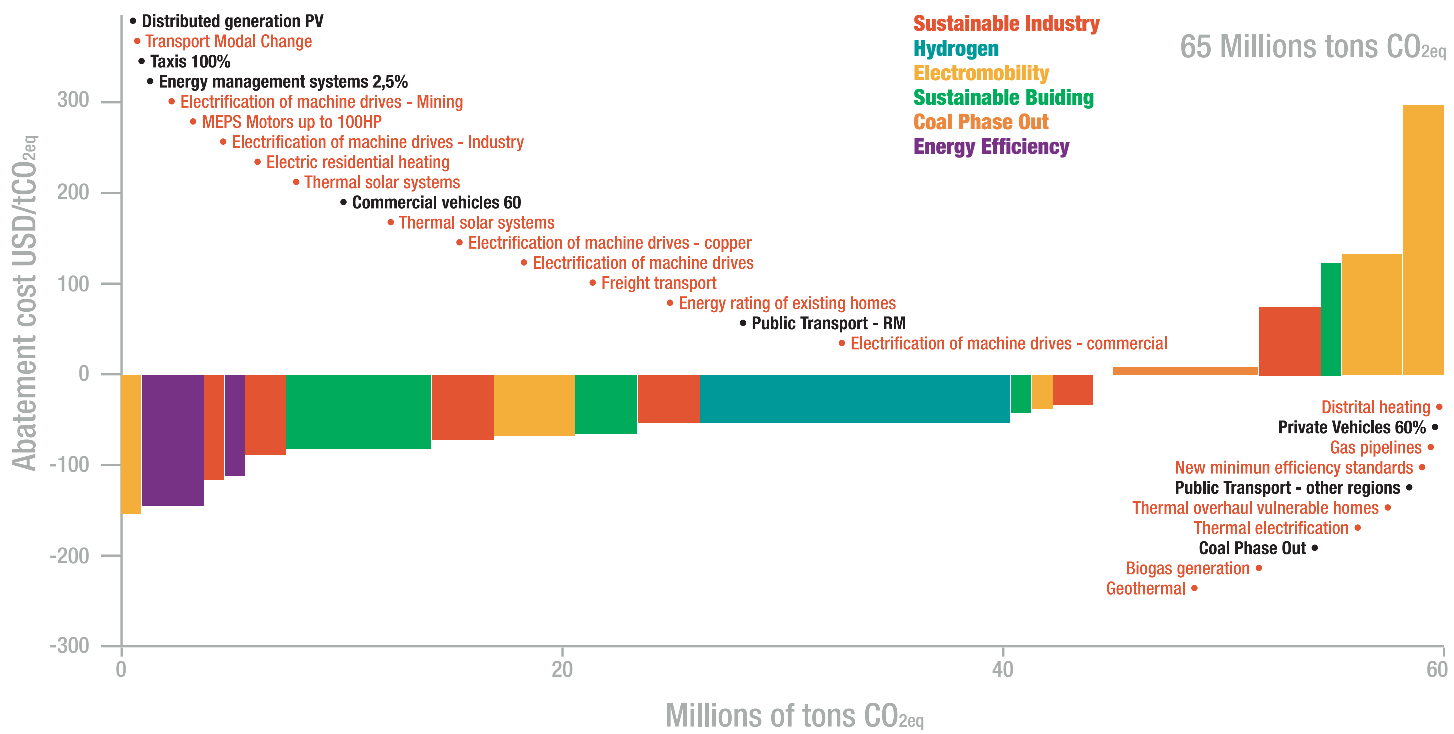


Figure 2.4

Marginal abatement cost curve for mitigation options considered for NDC in public consultation

Source: Ministry of Energ



3. MODELS AND METHODS

The purpose of this work is to model the impact of the CO_{2eq} mitigation intervention package on the economy, particularly for aggregate macroeconomic indicators. Furthermore, it is important to understand how the interventions affect the different economic sectors, especially in the context of ambitious and novel decarbonization goals. The model used is a purely economic model which takes into account CO_{2eq} emissions. One of the main advantages and value added is the soft link with sector models which were used to generate data on the total capital and operational expenditures related to sector interventions. This feature differentiates this exercise from other integrated models, taking advantage of the exogenous information on investment and operational decisions year by year, analyzed by the dynamic general equilibrium approach.

There are several methods used for analyzing the effects of climate change mitigation policies from a macroeconomic perspective. One of the leading approaches is to use the Integrated Assessment Modelling, in which both the economic and environmental spheres and their interlinkages are explicitly modeled, see NGFS (2019) or Krogstrup & Oman (2019). Such models are usually developed from the global perspective, and using such a model for a small open economy such as Chile would not be appropriate, since the country's impact on the environment is rather negligible. The objective here is different with respect to such models and it aims to estimate the impact of the mitigation measures on the Chilean economy. The model does not incorporate a climate damage function, so we do not account for physical climate change negative impacts in both the baseline and the mitigation scenarios. Thus, this work shows how the mitigation package affects the main macroeconomic variables in terms of their deviation from the business-as-usual path[3] . Such exercises are usually conducted by the use of computable general equilibrium (CGE) models or dynamic stochastic general equilibrium (DSGE) models. The former type usually follows a 'one size fits all' approach and encompasses at least several or dozens of regions (countries), which are divided into many sectors. Such a large number of variables requires limiting the complexity of the model in other areas. On the other hand, the latter DSGE approach, which we follow here, sacrifices the number of regions and sectors that are distinguished for enriching the economic structure of the model. A DSGE model usually covers one or two economic areas with the number of sectors limited to approximately 20. However, the DSGE approach allows for the incorporation of various frictions related to the labor market, adoption of technology, open economy, finance, investment process and others. Therefore, when conducting an analysis tailored for only a single country, the advantages of using a DSGE outweigh the advantages of the CGE framework.

3.1. MEMO – Macroeconomic mitigations options model

For the assessment of the policy package we use the dynamic stochastic general equilibrium model MEMO, developed at the Institute for Structural Research. The model combines two strands of research – input-output and general equilibrium modeling. The main agents of the model and their interrelations are depicted in Figure 3.1. The model consists of the household sector, which maximizes utility from consumption and leisure, the firm sector which maximizes profits, the government sector which collects various taxes and finances public consumption, and a foreign sector responsible for trade with the rest of the world. The main features of the model include division of the firm into sectors calibrated to an input-output matrix, searching and matching on the labor market to model the transition of workers between sectors, and endogenous adaptation of technology related to energy use. The sector structure of the model is calibrated using the Chilean 2015 industry by industry input-output matrix from the OECD statistics database[4] . In the model, we distinguish the following sectors and products: Agriculture and Forestry; Mining of Coal; Mining of Crude Oil; Mining of Gas; Mining of Copper and Other; Manufacturing Industry, Manufacturing of Refined Petroleum Products; Fossil Fuel Electricity; Renewable Electricity; Distribution of Gas; Construction; Transport; Market Services; Public Services. The technical details such as exact equations, calibration and solution methods of the MEMO model can be found in the research report by Antosiewicz and Kowal (2016). The exact specification of the model used in this study slightly differs from the model described in the aforementioned research report, as we tailored it to the needs of the current assessment.

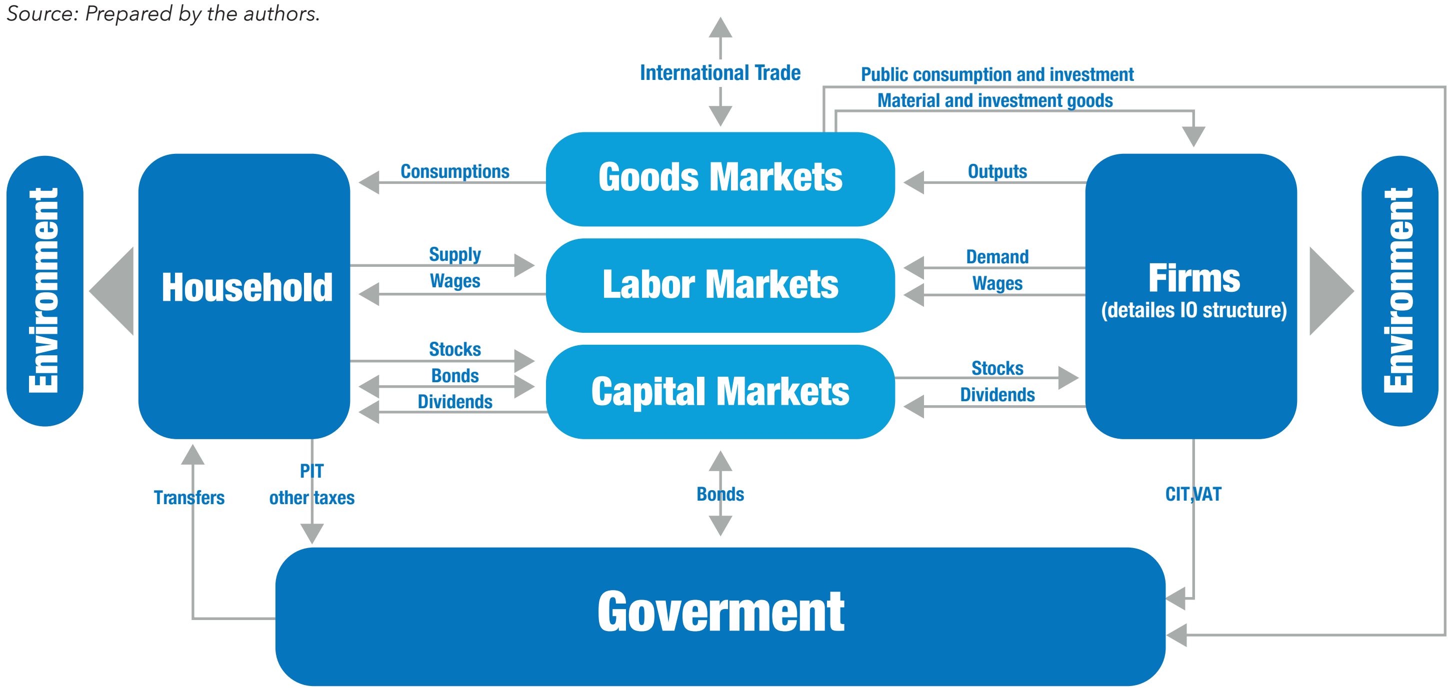
[3] *The baseline or business-as-usual scenario is defined as the one which considers only the measures implemented until June 2019.*

[4] *Calibrating the MEMO model requires the use of a symmetric IO matrix which distinguishes domestic and imported final and intermediate use. The symmetric IO matrix provided by the Chilean Central Bank (BCC) does not distinguish domestic and imported use. On the other hand, the asymmetric IO matrix from the BCC does distinguish domestic and imported use, but it is provided in a product by activity format. Therefore, it is not possible to calibrate the entire production structure of the model to this matrix directly. However, it was used to disaggregate the use of some sectors where the OECD matrix disaggregation was not sufficient.*

Figure 3.1

Main model agents

Source: Prepared by the authors.



3.2. Input-Output sector structure and emissions

There are several distinct sets of parameters whose values need to be calculated. The main set contains the parameters governing the production side of the model. These parameters can be further specified as those which govern the value-added[5] structure of the sectors, investment and compensation of employees in each sector, the intermediate use structure which considers domestically produced and imported goods, and final-use structure which also takes into account domestically produced and imported goods. A scheme of the production structure is shown in Figure 3.2. Each firm operates a production function which utilizes a nested CES (constant elasticity of substitution) specification to combine the factors of production. In the first stage the firm combines capital and energy, the second stage consists of adding labor, whereas in the final stage this bundle is combined with materials (intermediate use). The material bundle is composed of products of each sector, which are further disaggregated into the imported and domestically produced part. On the use side, the goods produced by each sector are purchased by the household as private consumption, by the government as public consumption, by firms as investment and intermediate use, or they can be exported.

In order to calibrate the firm side of the model we use the input-output (IO) matrix from the OECD statistics database. This is a 36 activity by 36 activity matrix which uses the International Standard Industrial Classification of All Economic Activities (ISIC), Rev.4. However, for the purpose of this study we disaggregate some sectors and products which are collapsed into a single activity in the OECD matrix. To conduct this disaggregation, such as the disaggregation of specific fossil fuels, we supplement the data with a highly disaggregated input-output matrix from the Chilean Central Bank. This additional matrix is provided in a 181 product by 111 activities format.

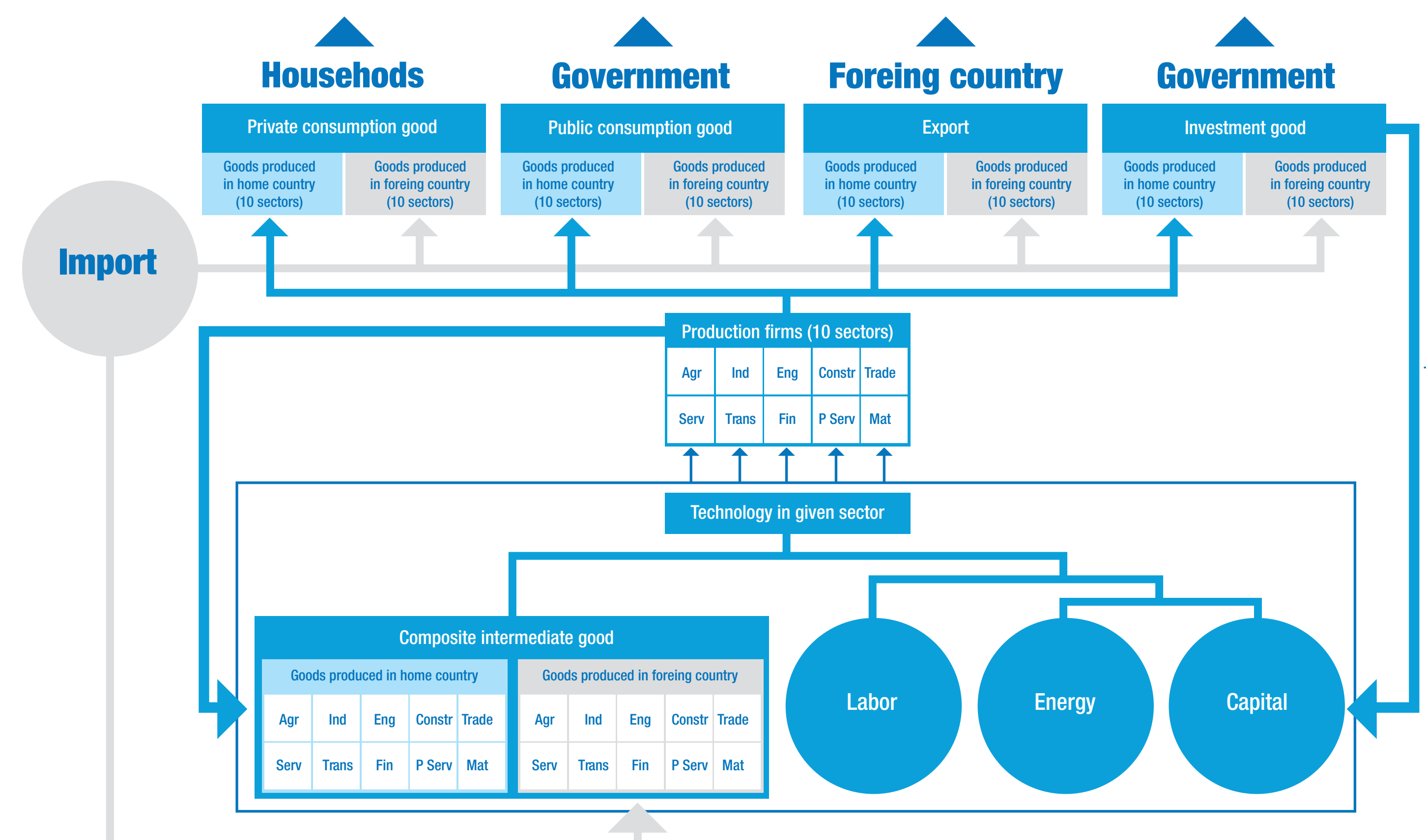
In the first step, the OECD IO matrix is aggregated into the following sectors: 1) AGR: Agriculture, forestry and fishing; 2) MIN_ENE: Mining of energy products; 3) MIN_OTH: Mining of metal and other ores; 4) RPP: Manufacturing of refined petroleum products; 5) IND: Remaining manufacturing industry; 6) ENERGY: Electricity, gas, water supply and sewerage; 7) CONSTR: Construction; 8) TRANS: Transport; 9) SERV: Market services; 10) PBL: Public services. Table 3.1 summarizes this sector aggregation.

In the second step, we conduct a disaggregation of several sectors related to fossil fuels and the electricity sector using the highly disaggregated IO matrix and data from the International Energy Agency regarding electricity generation by source. We disaggregate the sector ENERGY (TTL_35T39) into 1) electricity generation and distribution, 2) distribution of natural gas, 3) distribution of water and waste management. We include the last sector in the industry (IND) sector. Next, we disaggregate the sector MIN_ENE into the main fossil fuels: coal, oil and gas. Finally, we disaggregate the electricity generation and distribution sector into two separate electricity sectors: 1) non-renewable electricity (fossil fuel) generation and distribution and 2) renewable electricity generation and distribution.

Figure 3.2

Production process in MEMO model

Source: Prepared by the authors based on data from the Ministry of Energy and the Ministry of the Environment, Chile



[5] *It is defined as the value of output minus the value of purchased inputs (Abel et al., 2011)*

Table 3.1.

Aggregation of sectors from the OECD IO matrix

ISIC Rev.4 code	Sector	Aggregation
TTL_01T03	Agriculture, forestry and fishing	AGR
TTL_05T06	Mining and extraction of energy-producing products	MIN_ENE
TTL_07T08	Mining and quarrying of non-energy-producing products	MIN_OTH
TTL_09	Mining support service activities	MIN_OTH
TTL_10T12	Food products, beverages and tobacco	IND
TTL_13T15	Textiles, wearing apparel, leather and related products	IND
TTL_16	Wood and of products of wood and cork (except furniture)	IND
TTL_17T18	Paper products and printing	IND
TTL_19	Coke and refined petroleum products	RPP
TTL_20T21	Chemicals and pharmaceutical products	IND
TTL_22	Rubber and plastics products	IND
TTL_23	Other non-metallic mineral products	IND
TTL_24	Manufacture of basic metals	IND
TTL_25	Fabricated metal products, except machinery and equipment	IND
TTL_26	Computer, electronic and optical products	IND
TTL_27	Electrical equipment	IND
TTL_28	Machinery and equipment n.e.c.	IND
TTL_29	Motor vehicles, trailers and semi-trailers	IND
TTL_30	Other transport equipment	IND
TTL_31T33	Other manufacturing; repair and installation of machinery and equipment	IND
TTL_35T39	Electricity, gas, water supply, sewerage, waste and remediation services	ENERGY
TTL_41T43	Construction	CONSTR
TTL_45T47	Wholesale and retail trade; repair of motor vehicles	SERV
TTL_49T53	Transportation and storage	TRANS
TTL_55T56	Accommodation and food services	SERV
TTL_58T60	Publishing, audiovisual and broadcasting activities	SERV
TTL_61	Telecommunications	SERV
TTL_62T63	IT and other information services	SERV
TTL_64T66	Financial and insurance activities	SERV
TTL_68	Real estate activities	SERV
TTL_69T82	Other business sector services	SERV
TTL_84	Public administration and defense; compulsory social security	PBL
TTL_85	Education	PBL
TTL_86T88	Human health and social work	PBL
TTL_90T96	Arts, entertainment, recreation, and other service activities	PBL
TTL_97T98	Private households with employed persons	PBL

In MEMO we directly model CO_{2eq} emissions from the use of fossil fuels: coal, oil and gas. The volume of carbon emissions in a particular sector is modeled as a linear function of the use of these fuels, with coefficients set to match sector data regarding emissions. However, some changes had to be made to the economic sector allocation of emissions, comparing them to the common classifications used for emissions data. For example, typical emissions data classify transport emissions as the use of refined petroleum products, regardless of whether the fuel is used by private cars, non-transport companies or transport companies using trucks etc. However, economic IO data shows the use of refined petroleum products by all sectors (including the household), requiring a disaggregation of these emissions. We do not directly model other, non-carbon emissions, such as those resulting from industrial processes, waste processing, agriculture or captures in the forestry sector. Such emissions are treated in an indirect way in the post-processing phase of the modeling exercises.

The implications for the exercises we perform are as follows. It is possible to model a non-fossil fuel-related intervention (for example in forestry or agriculture) using the CAPEX and OPEX data, and obtain results for its macroeconomic cost. In the case of modeling such an intervention, we simply use the exogenous data regarding the drop in non-carbon emissions or captures. However, in the case of running a carbon tax simulation, the agents in the model only react to the fossil fuel emissions which are modeled directly and do not, for example, reduce output in the agriculture sector to cut non-carbon emissions.

3.3. Mitigation policies

The Chilean Ministry of Finance, in discussion with the Ministries of Energy and Environment, compiled a set of mitigation policies to be assessed using the macroeconomic model. Each intervention is characterized by the sector in which the intervention is conducted, and by the yearly investment costs (CAPEX) and operational costs (OPEX) of the intervention between the years 2017 and 2050. Furthermore, for each intervention both the CAPEX and the OPEX are disaggregated into the products of sectors. For example, the result of an intervention in the transport sector consisting of an investment in electric vehicles will be linked to:

- Imported investment purchases from the manufacturing industry sector, financed by the transport sector.
- An increase in the operational expenditures on electricity by the transport sector.
- A decrease in the operational expenditures in petroleum products by the transport sector.

Both the CAPEX and OPEX are provided as a yearly time series in millions of USD and their sum is shown in Table 3.2 for each intervention.

Table 3.3.

Set of mitigation policies proposed by the government and their value in current USD Millions

Intervention	Sector	Net total CAPEX	Net total OPEX
Distributed generation	Manufacturing	1,357	-7,965
Modal transport change	Transport	298	-2,276
Electromobility – taxis	Transport	4,350	-16,003
SGE Energy Efficiency Law 2.5%	Manufacturing and Mining	7,861	-22,457
Motor electrification - rest of mining	Mining	903	-9,516
MEPS Motors up to 100HP	Mining	414	-5,988
Motor electrification – industry	Manufacturing	401	-9,433
Fertilizers	Agriculture	0	-1,504
Residential electric heating	Residential	4,181	-28,530
SST Industry and mining	Manufacturing and Mining	744	-13006
Electromobility - commercial vehicles 60%	Transport	12,303	-25,497
SST Residential and public	Residential	1,118	-8,643
Commercial public electric heating	Market services	981	-2,159
Motor electrification - copper mining	Mining	1,031	-9,688
Hydrogen - Motor uses	Manufacturing and Mining	12,666	-39,026
Hydrogen - Freight transport	Transport	10,190	-28,831
Energy rating of existing homes	Residential	2,438	-6,498
Electromobility - public transport RM	Transport	3,308	-6,590
Motor electrification - commercial	Market services	3,300	-7,091
District heating	Residential	55	16
Geothermal	Residential	49	-72
Gas burning torches in landfills	Manufacturing	6	1
Biogas generation	Manufacturing	106	-89
Coal phase out	Electricity	6,432	-4,490
Biodigesters	Agriculture	274	665
Thermal electrification	Manufacturing	6,629	-155
Bovine diet change	Residential	0	653
Thermal overhaul of vulnerable homes	Residential	2,938	-1,377
Electromobility - public transport regions	Transport	30,666	-15,253
Hydrogen - Gas pipelines	Gas distribution	1,622	-541
New minimum efficiency standards (MEPS)	Residential	2,642	-1,095
Electromobility - private vehicles 60%	Residential	19,393	-5,425
Afforestation and sustainable management for CO2eq capture	Forestry	1,423	0
Native Forest Compensation	Forestry	1,590	360

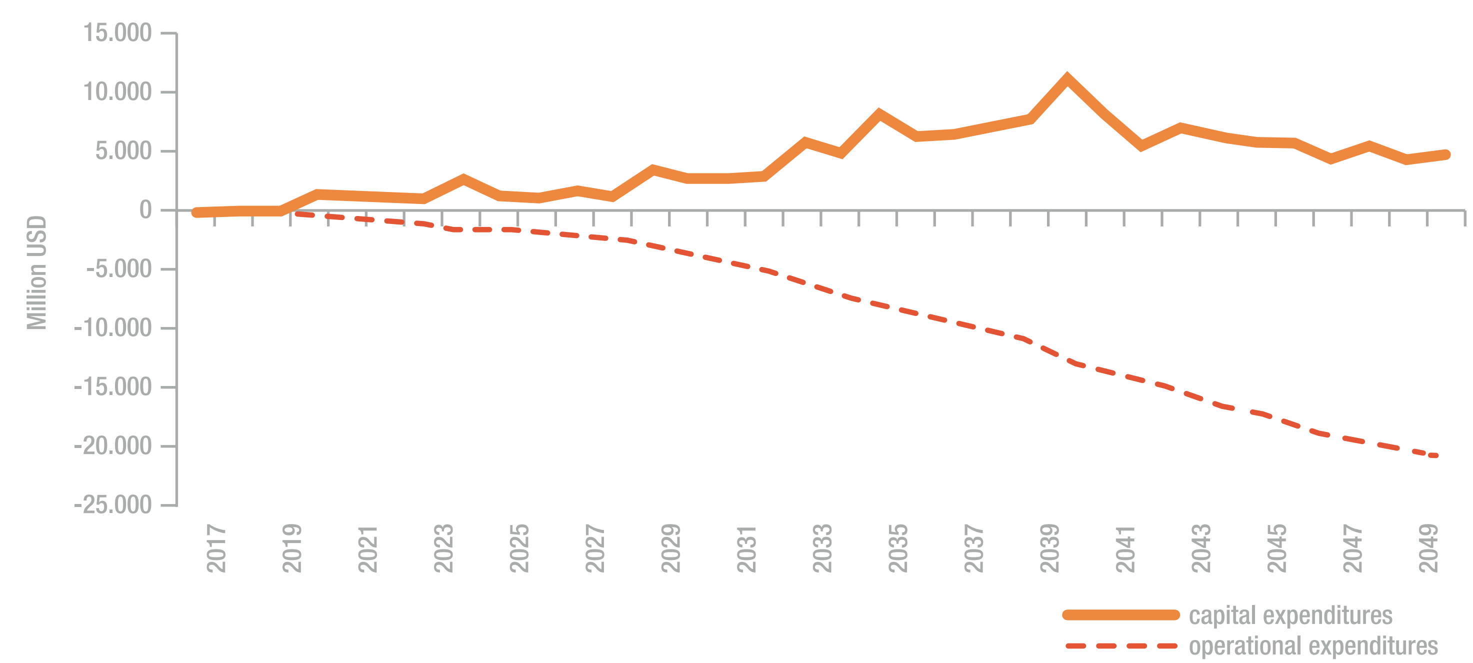
Source: Ministry of Finance with data from the Ministry of Energy and the Ministry of the Environment, Chile

The analysis documented how net capital and operational expenditures evolve over time in Figure 3.1. The total required investment to implement the set of interventions rises gradually to approximately US$11 billion in the year 2040, and then falls to US$5 billion in the year 2050. The net change in operational expenditures that arises from the intervention is much higher in absolute values. The negative values, which correspond to savings, first increase slowly to US$3 billion in the year 2030. After this year the savings start to increase more quickly, reaching US$20.8 billion in the year 2050. The accumulated savings for the entire time period is equal to 277.5 billion at a total investment cost equal to US$141.6 billion.

Figure 3.1

Total net capital and operational expenditures (in million USD) for net-zero emission target by 2050

Source: Prepared by the authors based on data from the Ministry of Energy and the Ministry of the Environment, Chile.



3.4. Simulation setup

The model run several simulations to comprehensively study the macroeconomic impact of the implementation of the mitigation measures against the baseline assumptions, regarding the development of the economic situation in Chile. First of all, we conduct a reference simulation using the CAPEX and OPEX data provided by sector experts of the Ministry of Energy and the Ministry of Environment, which is the main focus of this report.

To conduct the reference simulation, we divide the time series for the CAPEX and OPEX by the assumed path of GDP, in order to arrive at the time series expressed as shares of GDP for each year until 2050. In the next step, we use the Kalman filter to simulate a drop in the value of a given flow and its impact on the rest of the economy. In the case of CAPEX, the flow is the purchase of investment goods, whereas in the case of OPEX, this is the purchase of intermediate use by the firm operating in the sector of intervention. Such a simulation approach is linked with the following implicit assumptions. The analysis assume that the entire economy grows at the rate provided in the baseline growth path by the Ministry of Finance, with no structural changes and with constant relative prices of goods of different sectors. If the assumptions regarding the prices of fossil fuels used by sector experts are different, this will introduce bias in the simulation results. Similarly, if the baseline pathway of the use of fossil fuels differs from these assumptions, some bias will be introduced to the simulation results.

The reference simulation is supplemented with a sensitivity analysis, in which we analyze two separate dimensions which are burdened with the highest degree of uncertainty. First of all, we assess the significance of postponing by 5 years the implementation of measures regarding hydrogen energy and electromobility. The technology behind these interventions is still at an early stage of development, and widespread commercial introduction of these technologies in the coming decade is highly uncertain. The reduction in emissions related to these technologies amounts to 27.2 Million tons in the year 2050, which is close to 40% of the reductions foreseen in the intervention package for the year 2050. Since this a significant technology from the point of view of emission reduction, and there is a high probability the technology will not be cost-effective in the near future, we explore the consequences for achieving carbon neutrality if its introduction is postponed. In this sensitivity scenario we assume the same trajectory of CAPEX and OPEX time series, but commencing with a 5-year delay.

Furthermore, there is a high degree of uncertainty related to the level of capital costs of implementing the measures, as well as savings that they will generate. Therefore, we explore the consequences of an underestimation of the required capital cost by 10% or 20%[6] , as well as an overestimation of the induced savings in operational expenditures by 10% and 20%[7] .

Finally, we conduct a carbon tax simulation in which we determine the level of the tax necessary to achieve net-zero emissions in the year 2050. In this simulation we assume that the carbon tax is an additional measure to the entire mitigation package, and its aim is to ensure net-zero emissions, should the mitigation package turn out to be insufficient.

[6] *Since CAPEX are negative flows, we increase all CAPEX by 10% or 20% and re-run the model.*
[7] *Since most OPEX represent net savings, we reduce all OPEX by 10% and 20% and re-run the model.*
[8] *The baseline growth rate was provided to the Ministry of Energy and to the Ministry of Environment to be used for the estimation of CAPEX and OPEX of the intervention. We use the same growth path here.*

4. RESULTS

4.1. Reference simulation results

Based on described simulations, the study infers that implementing the intervention package could have a positive impact on economic activity in Chile. As can be seen in Fig 4.1, the level of Gross Domestic Product (GDP) is expected to gradually increase relative to the baseline scenario. Towards the end of the simulation period, the level of GDP can be higher by as much as 4,4%, or equivalently US$31 billion. On average, the intervention package will contribute an additional 0.13 p.p. to the average yearly growth rate, which is shown in Fig. 4.2[8] . The positive impact on economic activity is a direct result of the positive net present value of the intervention packages. The required level of CAPEX crowds out investment in other sectors of the economy. However, the improvement in efficiency and savings of fuel use outweigh the former effect.

Figure 4.1

Impact of intervention package on the level of Gross Domestic Product

Source: Prepared by the authors using MEMO model.

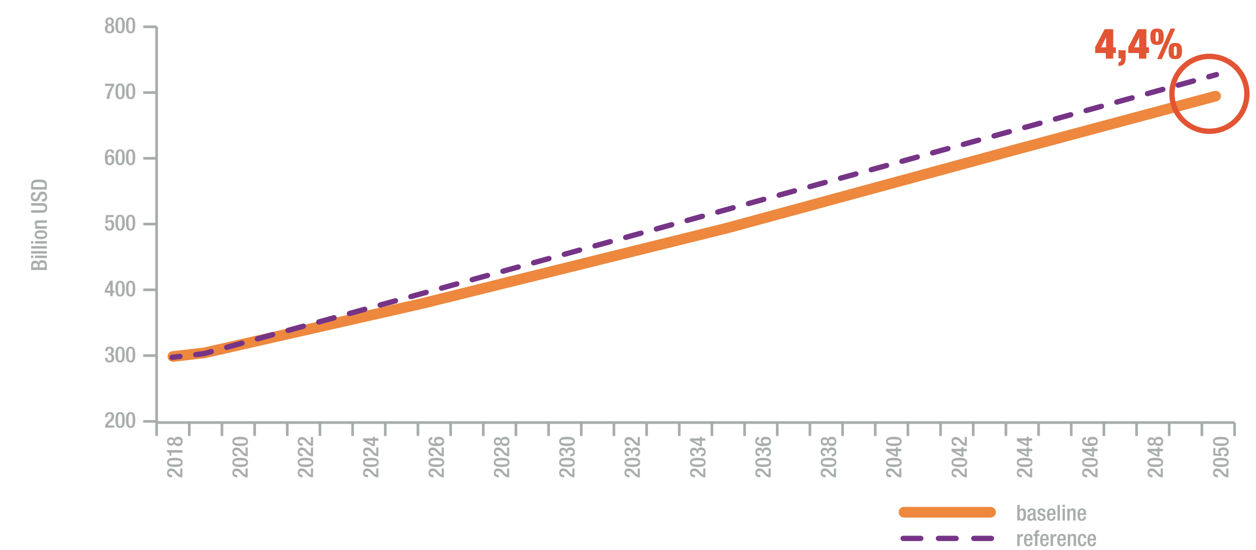
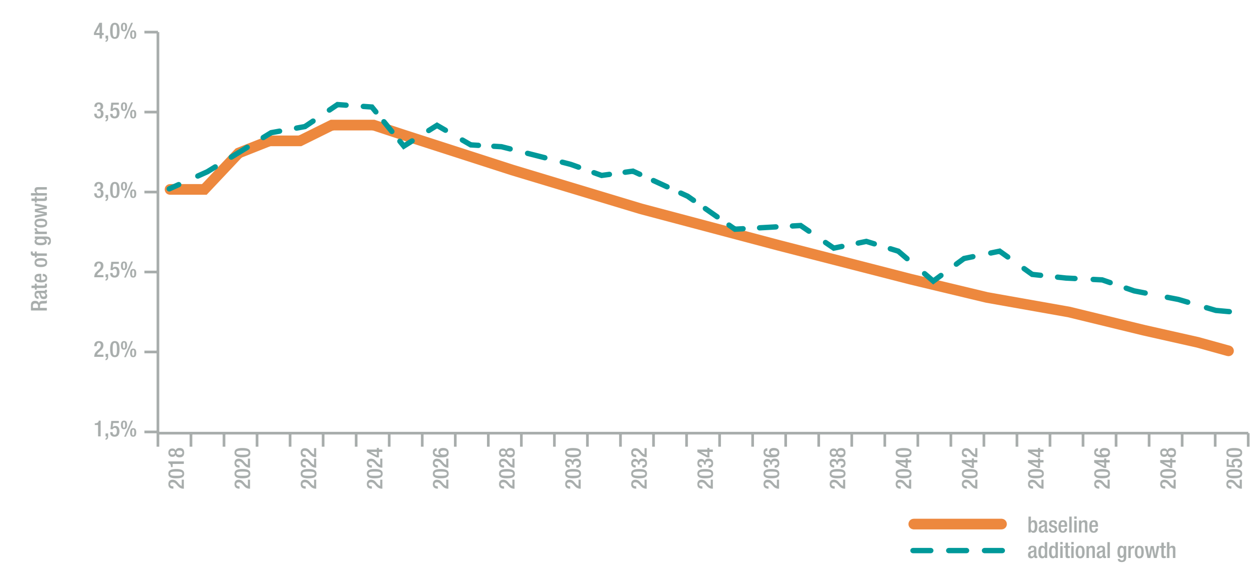


Figure 4.2

Impact of intervention package on the rate of growth of Gross Domestic Product

Source: Prepared by the authors using MEMO model.

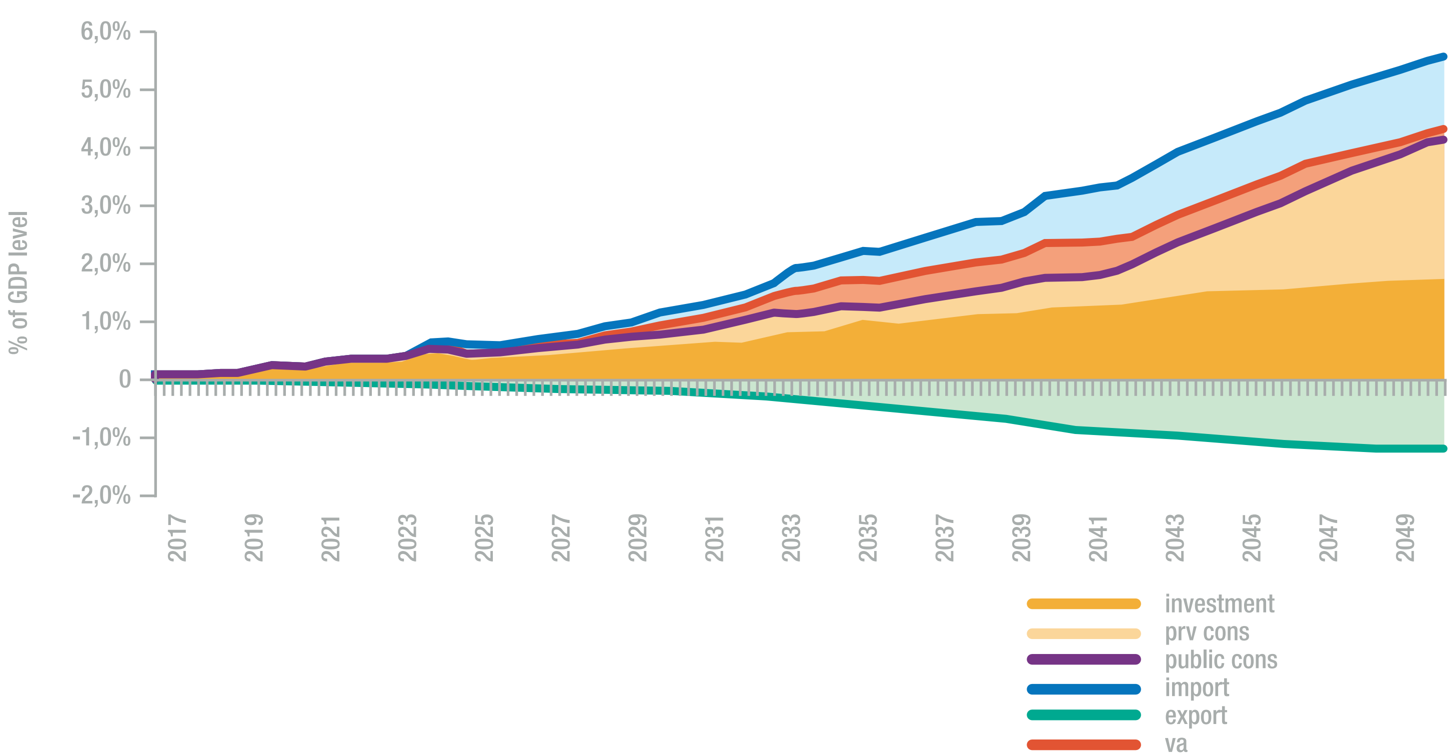


In Figure 4.3 the aggregate growth is decomposed into economic activity to components of GDP: private and public consumption, investment, and foreign trade. There are at least several channels at work here. First of all, implementing the intervention package consists of a reduction in the use of fossil fuels, the majority of which is imported. Reduced imports contribute positively to growth by almost 1.3% in the year 2050. However, the reduction in the demand for imports results in an appreciation of the real exchange rate. A more expensive domestic currency causes goods produced in Chile to be less competitive abroad, and as a result exports decrease by approximately 1.2% in 2050. The overall contribution of foreign trade to GDP is slightly positive. Secondly, firms continually increase their efficiency in line with the growing change in operational expenditures. The efficiency gains cause wages and profits of firms to rise, which leads to a gradual increase in household consumption. Further growth of household consumption can be observed after the year 2040, when the level of required capital expenditures on the intervention package starts to decrease. Finally, the increase in the contribution of investment is a direct result of implementing the intervention package.

Figure 4.3

Impact of intervention package on GDP components.

Source: Prepared by the authors using MEMO model.



The study also provides an analysis of the effects of the intervention package on selected sectors considered to be main emitters of carbon dioxide. Overall, the intervention package is successful in decoupling growth from fossil fuel use. Figures 4.4 and 4.5 show that emissions for Mining, Industry, and Transport sectors could decrease by 62% to 80% relative to the baseline scenario. At the same time, the interventions have a significant positive impact on value added in these sectors. The main driver behind these increases in value added are the efficiency gains resulting from decreased operational expenditures. The Transport sector could accumulate the biggest gains of approximately 18%, whereas the Mining sector could see increases of only 4.3%. The difference in outcomes between sectors mainly results from the fact that most of the product of the Mining sector is exported, while the increase in the real exchange rate and decreased demand from abroad will offset part of the efficiency gains in the sector. The difference in results between these sectors highlights the importance of the foreign trade channel.

A different picture appears for the Electricity sector, which is shown in the left panel of Figure 4.5. Most of the interventions in the policy package assume the electrification of selected industries, which results in increased demand for electricity at the expense of reductions in fossil fuel use. The electricity sector as a whole could, therefore, experience an increase in demand, which counterbalances some of the decarbonization efforts conducted in the electricity sector. Overall, fossil fuel electricity generation might experience a slight drop, whereas value added of electricity produced from renewable sources could increase by up to 12% in 2050.

Figure 4.4

Impact of intervention package on emissions and value added in Industry (left panel) and Mining (right panel) sectors.

Source: Prepared by the authors using MEMO model.

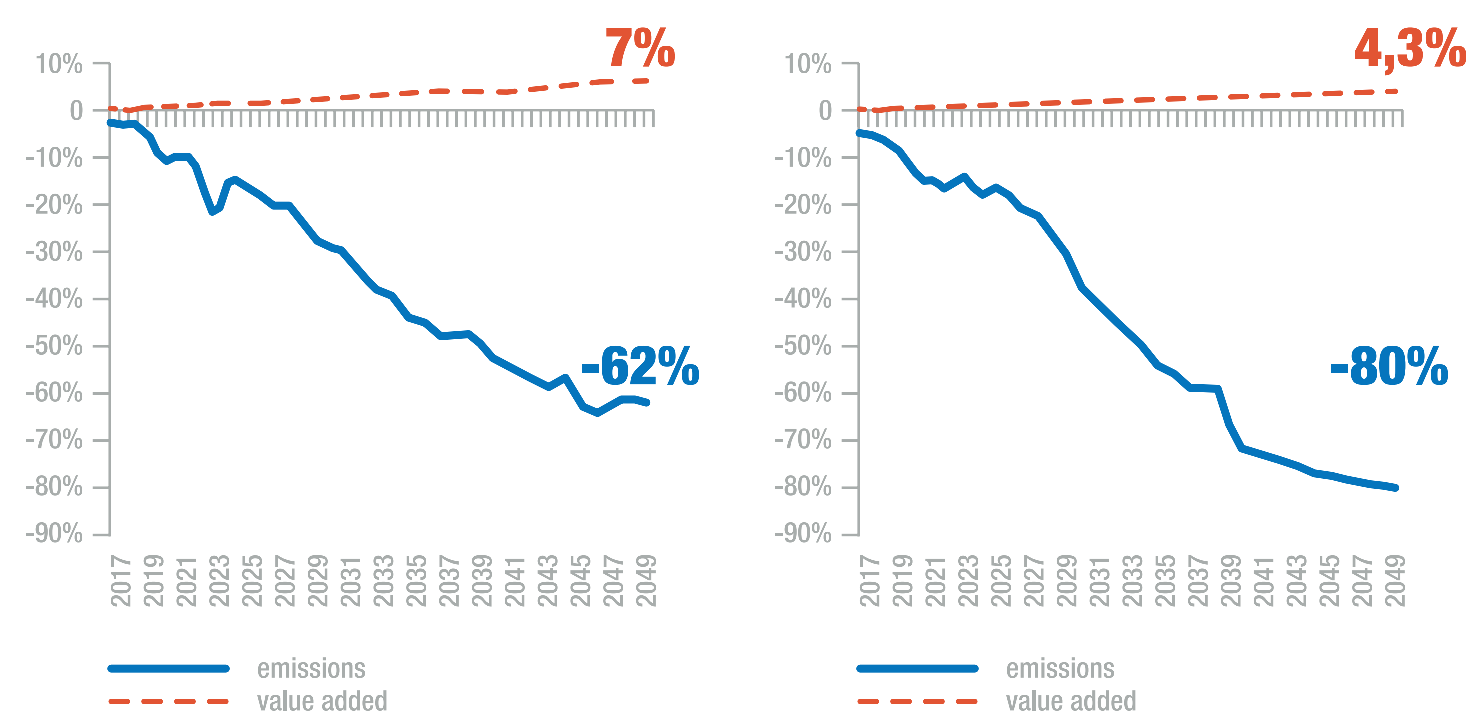


Figure 4.5

Impact of intervention package on emissions and value added in Electricity (left panel) and Transport (right panel) sectors.

Source: Prepared by the authors using MEMO model.

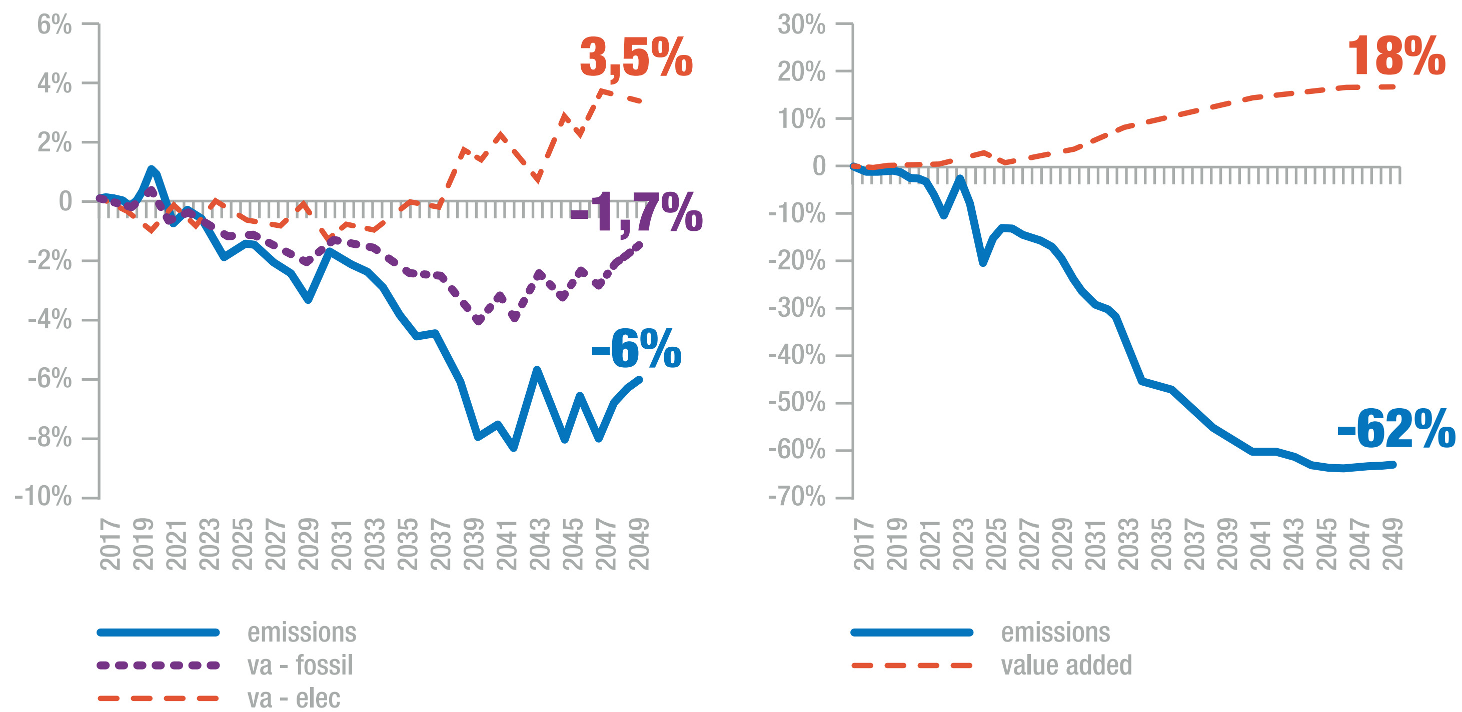


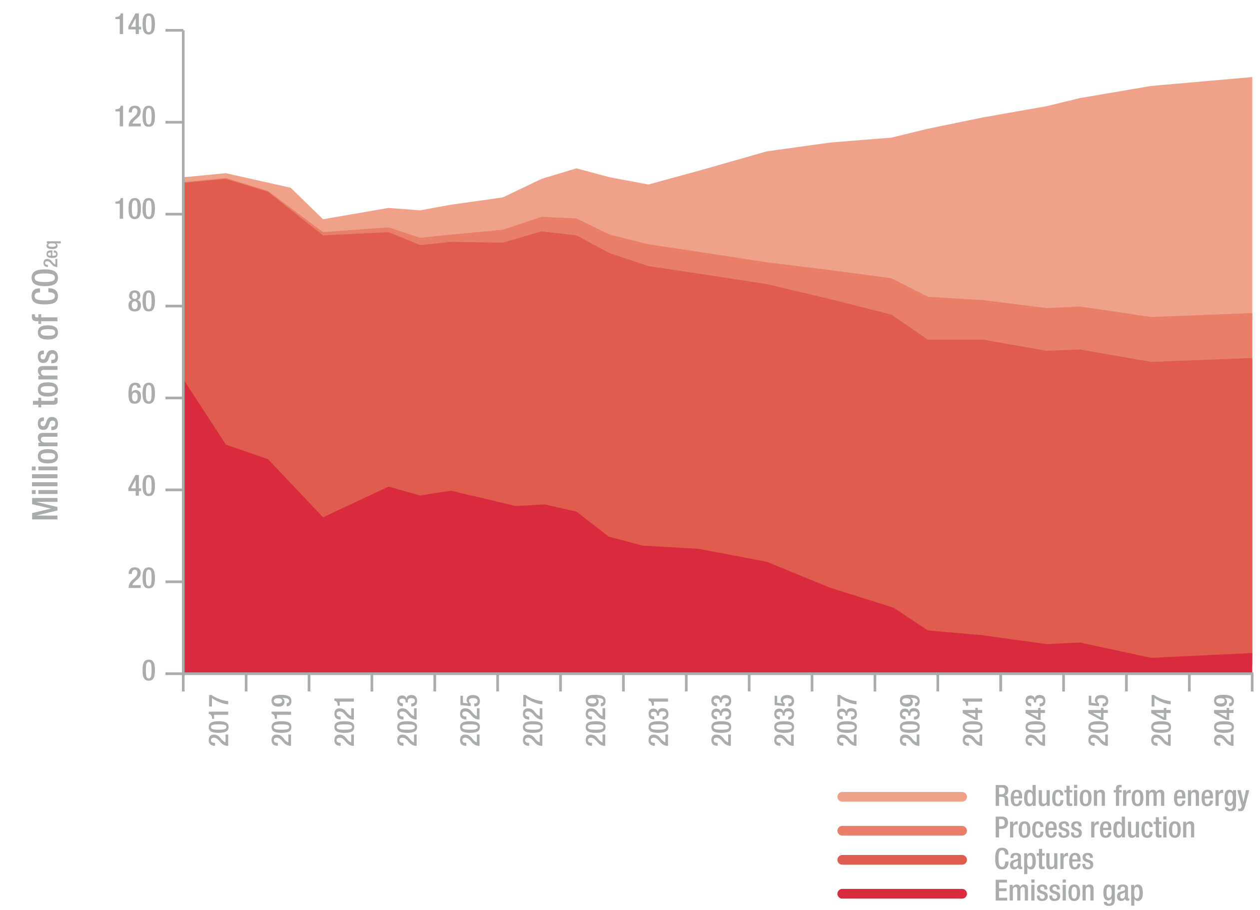
Figure 4.6 shows the evolution of total CO_{2eq} equivalent emissions during the simulation period. In this figure we plot the total reduction in CO_{2eq} predicted by the MEMO model for those interventions which assume a reduction in the use of fossil fuels. The remaining reduction induced by the realization of the intervention package (such as reductions in the agriculture and waste sectors) are shown in light grey as 'process'. Overall, the intervention package could bring us very close to achieving climate neutrality, with the gap in emissions, understood as the difference between total emissions and captures in 2050, that will be equal to approx. 4.5 Million tons CO_{2eq}. The difference between this value and the prediction of sector experts arises from two sources. The first reason is that the macroeconomic model predicts an increase in overall economic activity relative to the baseline, thereby increasing emissions. The second source, can be possible inconsistencies in the data sources used for the construction of the macroeconomic model (national accounts and intermediate use in IO matrix) and data used by sector experts, as discussed in the conclusions.

In these economic simulations, the reduction in the use of particular fossil fuels measured as volume does not exactly match the pathways developed by sector experts from the Ministry of Energy. The discrepancies arise from the fact that this exercise relies on the soft-linking of energy and economic models, and using the output of the former as input to the latter. Furthermore, these models differ in their explicit an implicit assumption regarding future prices of fossil fuels and baseline pathways of the use of these fuels. The main goal of this exercise is to establish the macroeconomic consequences of the implementation of the mitigation measures. In light of the main goal of this exercise, and in order to obtain an accurate estimate of the macroeconomic effects, it is necessary to use input data provided as monetary values, whereas the changes in the volume of the use of fossil fuels is of secondary importance. The drawback of such an approach is biased results for emissions and fossil fuel reduction, but a more accurate picture for the macroeconomic effects, which is the main focus of this report.

Figure 4.6

Breakdown of CO2eq emissions, emission reductions, captures and resulting emissions gap.

Source: Prepared by the authors using MEMO model.



4.2. Sensitivity analysis results

This section discusses the results of the sensitivity analysis of the reference simulation. In Figure 4.7 we show the potential impact on GDP and the emissions gap, under the scenario in which hydrogen and electromobility measures are introduced with a 5-year delay due to external, technical reasons. The delay could have a small negative impact on GDP, with economic activity being lower by 0.85% in 2050, due to the fact that these measures are cost-efficient and have a positive net present value. On the other hand, the emissions gap could be wider by approximately 2.4 Million tons of CO_{2eq}, which is an increase by 50% relative to the gap estimated for the reference scenario.

Figure 4.7

Impact of delaying measures regarding hydrogen and electromobility on GDP (left panel) and emissions gap (right panel) relative to baseline

Source: Prepared by the authors using MEMO model.

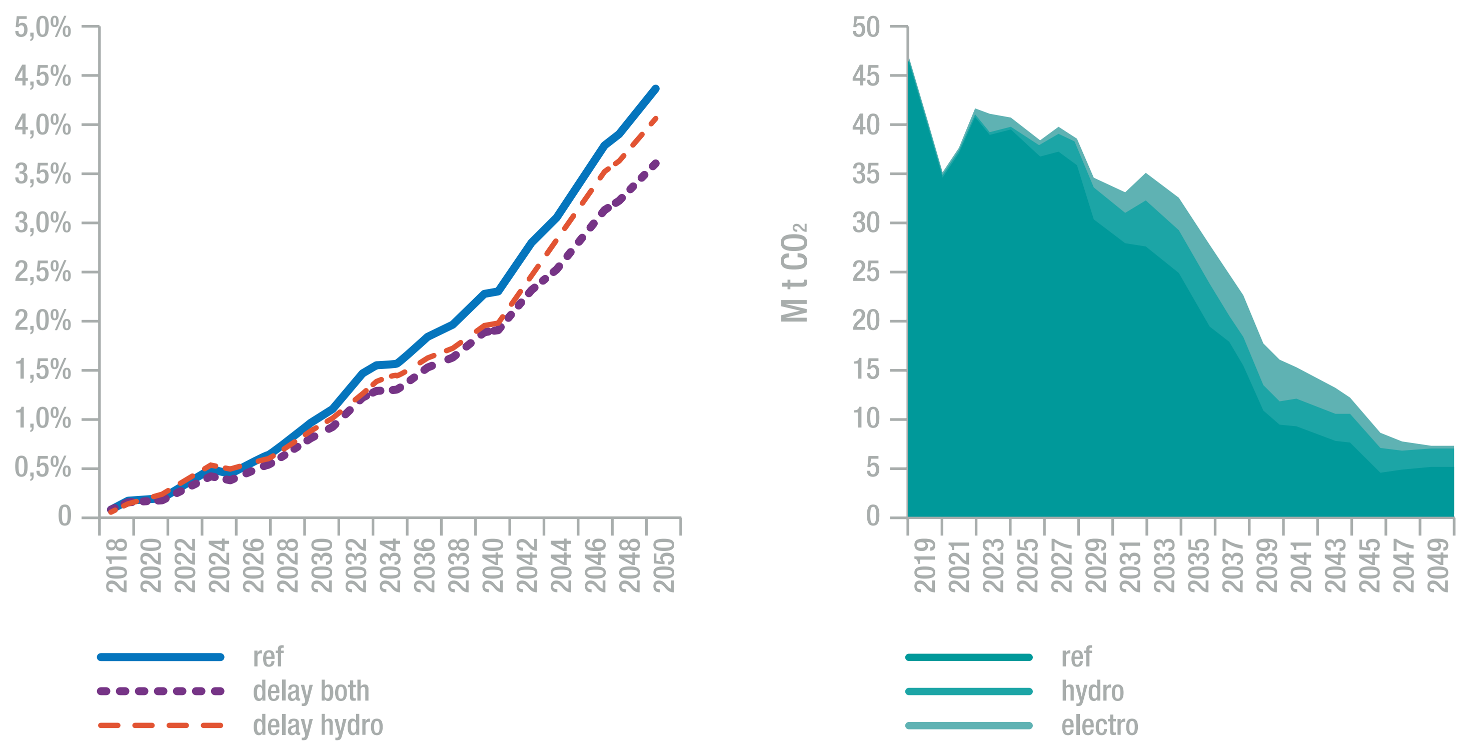
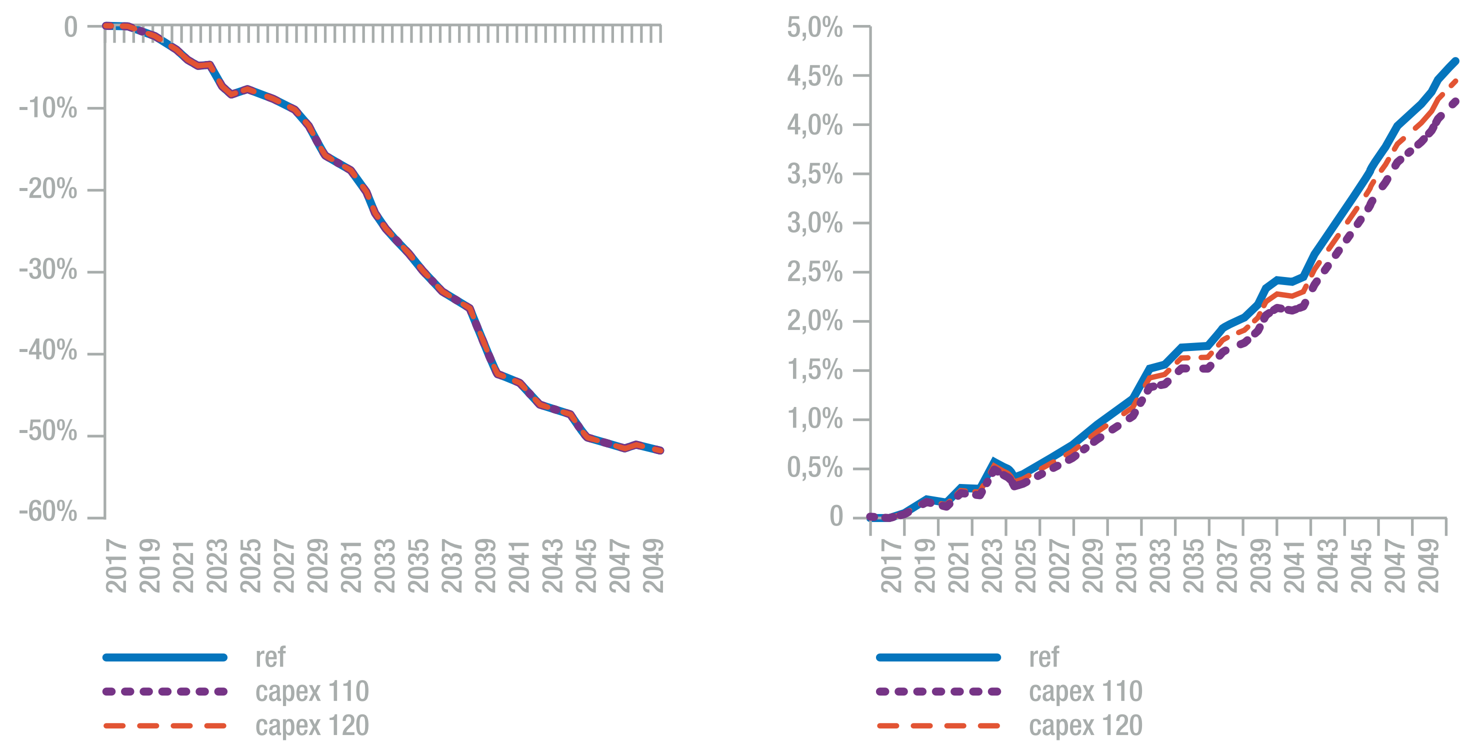


Figure 4.8

Impact of increased CAPEX on the reduction of emissions (left panel) and GDP (right panel) relative to baseline

Source: Prepared by the authors using MEMO model.



The results for the second simulation exploring the sensitivity of results to changes in assumptions are shown in Figures 4.8 and 4.9. In the first of these figures, we show the trajectory of GDP and reduction in emissions for the scenario in which we underestimate the necessary capital costs against the reference scenario. Higher capital costs might have a negligible impact on CO_{2eq} emissions, however, the economy could incur a small cost of approximately 0.14% of GDP in 2050 for a 10% increase in costs (capex 110).

On the other hand, underestimation of the efficiency gains has a more severe impact both on the economy as well as on emissions. The emissions gap could increase by 4.9 Million tons CO_{2eq} in the year 2050, which is a twofold increase if the decrease in operational costs is overestimated by only 10% (opex 90). The reduced efficiency gains migh also impact GDP, reducing it by approximately. 0.5%. A summary of the results of the sensitivity results is shown in Table 4.1.

Figure 4.9

Impact of smaller OPEX savings on the reduction of emissions (left panel) and GDP (right panel) relative to baseline

Source: Prepared by the authors using MEMO model.

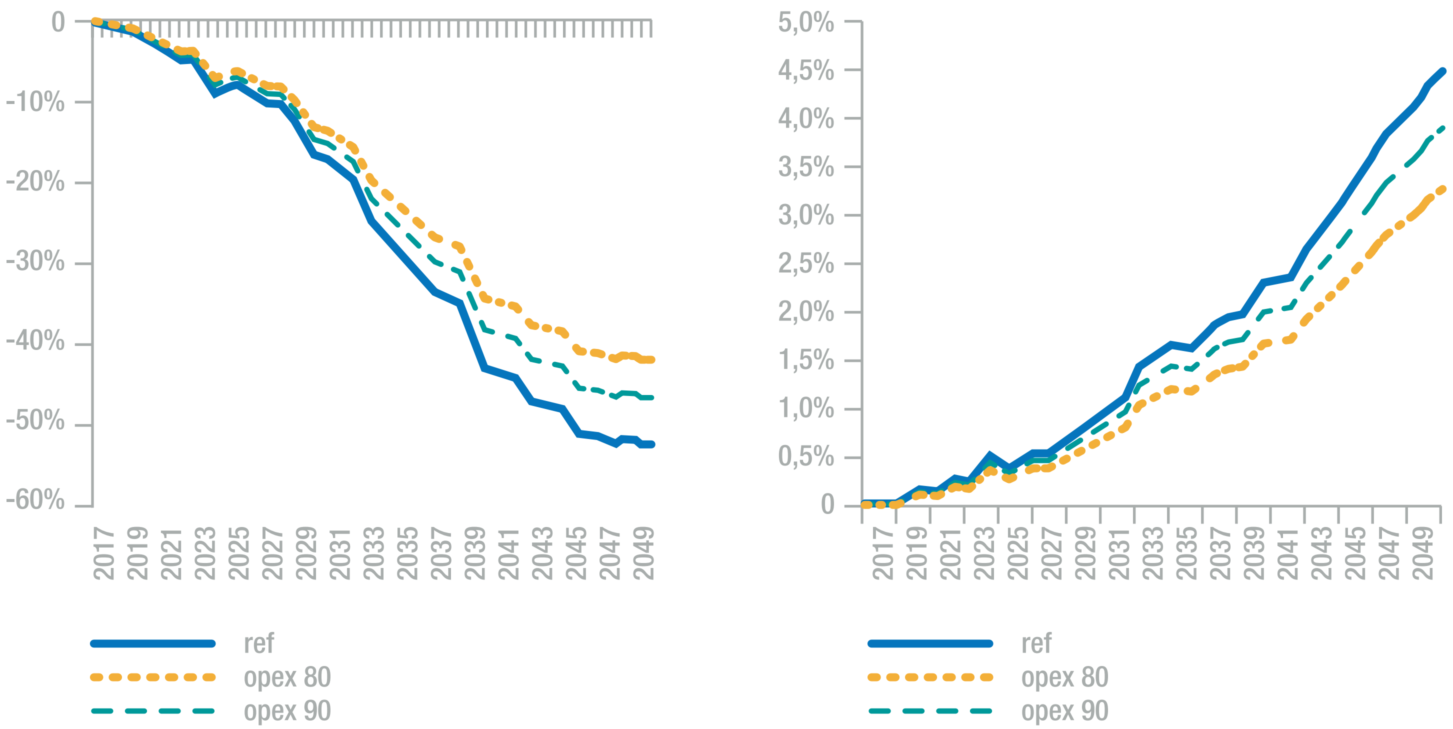


Table 4.1

Summary of sensitivity analysis – results shown as a deviation from baseline for the year 2030 and 2050 for GDP and CO2eq emissions.

Scenario	GDP		Emissions		
	2030	2050	2030	2050	
Reference	0.96%	4.35%	-17.2%	-52.4%	
Opex90	0.81%	3.78%	-15.5%	-47.4%	
Opex80	0.66%	3.20%	-13.9%	-42.3%	
Capex110	0.90%	4.21%	-17.3%	-52.6%	
Capex120	0.85%	4.07%	-17.3%	-52.8%	
Delay hydrogen measures	0.82%	4.05%	-13.3%	-50.6%	
Delay electromobility measures	0.94%	3.90%	-15.7%	-52.1%	
Delay both measures	0.80%	3.60%	-11.8%	-50.2%	

4.3. Carbon tax simulation

The study also shows the macroeconomic impact of increasing the level of the carbon tax in Chile. The study linearly increase the carbon tax rate, from the base level of US$5 per ton in 2017 to a level which reduces emissions by 4.5 Million tons that represents the gap not explained either by the model nor by the captured CO2eq emission as is presented in Figure 4.6, thereby guaranteeing carbon neutrality in the year 2050. Figure 4.10 shows the effect on GDP of implementing such a tax rate. The tax is expected to decrease the level of GDP by a maximum of 0.04% at the end of the simulation horizon. The increase in the tax rate necessary to achieve this reduction is almost US$10.7 per ton. The tax is levied on all emissions related to the use of coal, gas and oil by all sectors (including the household), without taxing indirect and non-carbon emissions.

This result should be treated with caution, since we are assuming the tax is an additional measure to the intervention package, and its goal is to close the remaining emissions gap needed to achieve neutrality. It might be the case that the intervention package depleted most of the technical capabilities of emissions reductions. Should this be the case, achieving the additional decrease in emissions would require a much larger tax rate than the one estimated. The impact of the carbon tax schedule on fossil fuel use is shown in Fig 4.11. The drop reported in this figure is an additional drop to the one resulting from the implementation of the intervention package reported in the previous section. The carbon tax has the strongest impact on the use of coal since this fuel is the cheapest one relative to its carbon content. This result shows that the carbon tax can be an effective measure to decarbonize the electricity generation system, which is currently dependent on coal.

Figure 4.10

Additional impact on GDP of carbon tax increase necessary to close the emissions gap of 4.5 Million tons in 2050

Source: Prepared by the authors using MEMO model.

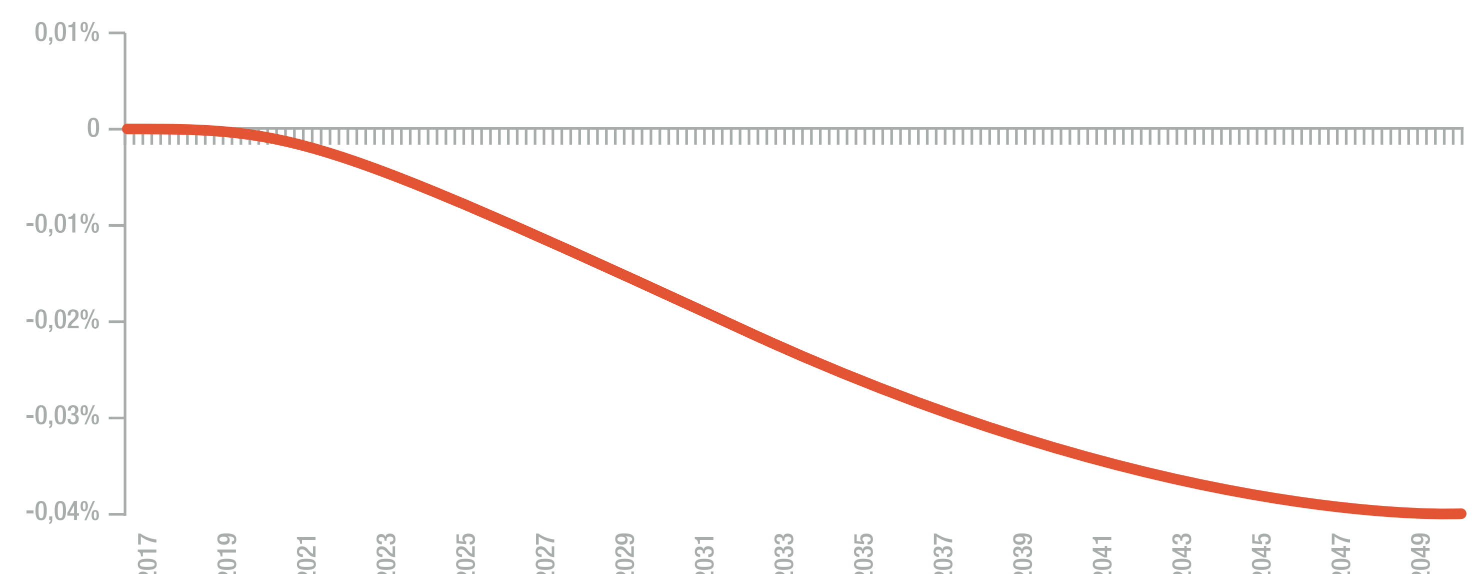
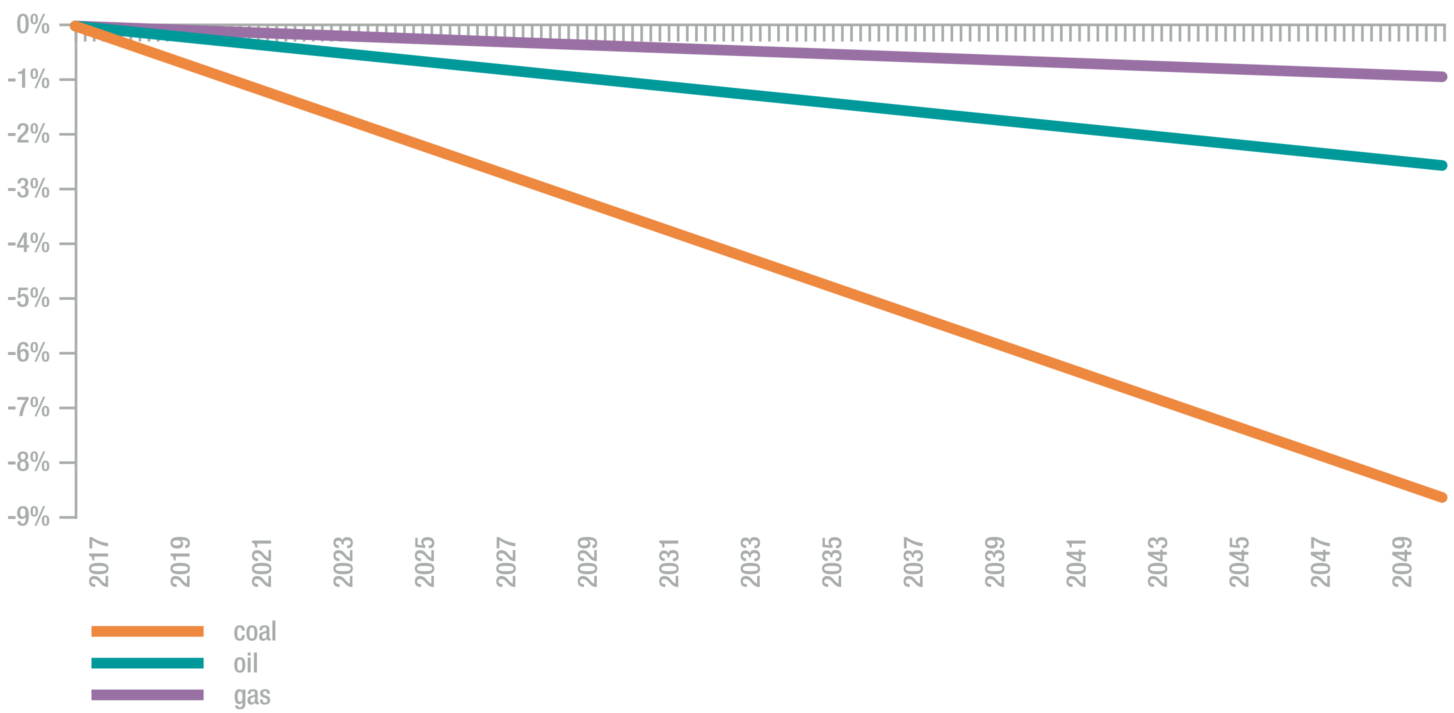


Figure 4.11

Additional impact of fossil fuel use of carbon tax increase necessary to close the emissions gap of 4.5 Million tons in 2050

Source: Prepared by the authors using MEMO model.



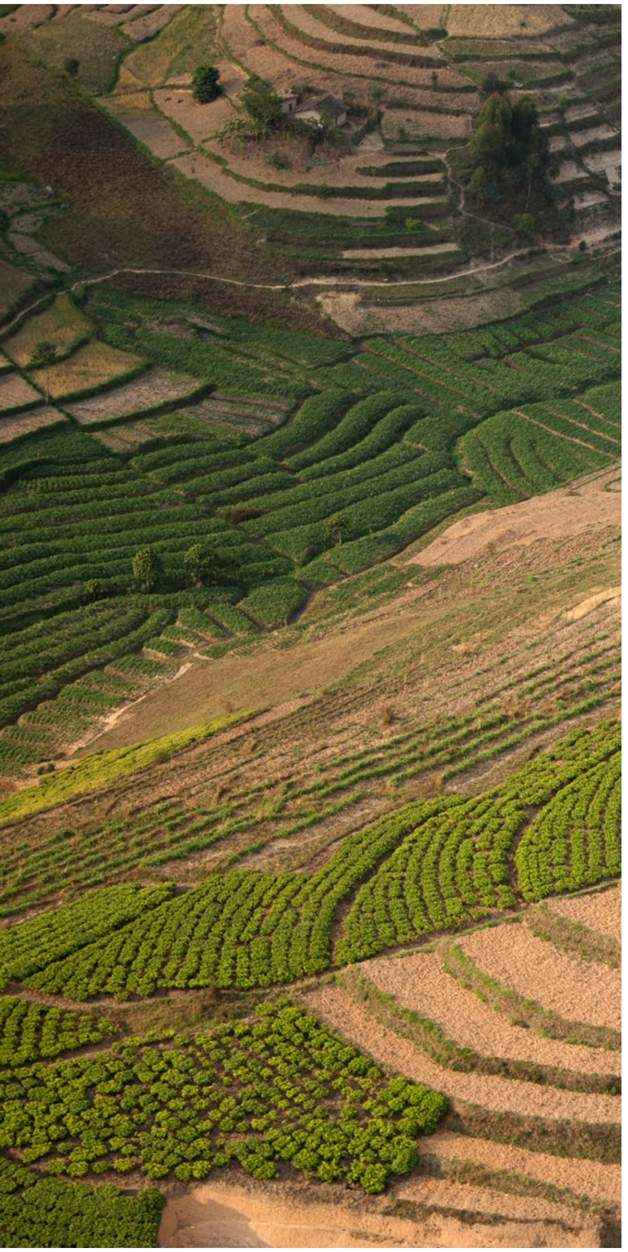
5. Comments and future work

The study intended to update, re-calibrate, and develop a macroeconomic model for Chile to be used in the assessment of mitigation interventions proposed to comply with the recent updated Chilean NDC, and to achieve committed zero net CO_{2eq} emissions by 2050. Using the CAPEX and OPEX estimated and provided by the Ministries of Environment and Energy, the study assessed the impact on value added for the economy, the sectoral activity, the demand side of the economy, and the implications of delaying implementation and varying the costs of the mitigation package. Overall, Chile is a prime example of a country which can greatly benefit from a sustainable transition to a green economy. The results for main macroeconomic indicators are positive, showing that the decoupling of economic activity and emissions is possible.

Results show that under the proposed mitigation package, GDP growth could increase at a rate 0.13 p.p. higher than in the baseline scenario, resulting in an increase of 4.4% of the GDP level by 2050. This is due to increases in value added of investment, private consumption, public consumption, and a higher reduction of imports than exports. The proposed mitigation package could yield a reduction in the use of fossil fuels and the corresponding emissions in main sectors, with a remaining 4.5 Million tons of CO_{2eq} emissions left to achieve neutrality. Higher demand for electricity boosts value added of renewable sources and a moderate reduction in emissions in the generation sector. Sensitivity analysis shows that a delay in the introduction of measures puts the achievement of net-zero emissions in 2050 at risk, widening the gap by approximately 2.4 Million tons of CO_{2eq}, which is an increase by 50% relative to the gap estimated for the reference scenario. Furthermore, results show that overestimation of OPEX savings values has a higher impact on emissions and GDP level than the underestimation of the necessary capital expenditures.

Several caveats need to be considered when analyzing the results presented in this report. First, the baseline is built with the macroeconomic scenario before October 2019. Second, regarding the nature of the model, mitigations measures are simulated independently losing the possible interactions and their effects, and results may change depending on the type of financing, budget closure and CAPEX – OPEX information. Therefore, there are inconsistencies between National Accounts data and the approach used by experts to construct OPEX data, and apart from sensitivity analysis, the study does not vary parameters or assumptions that change CAPEX, OPEX, and baseline emissions.

The results presented in this report show the overall macroeconomic effect of the implementation of the intervention package. While this impact is positive, this analysis could be enhanced and implemented with more in-depth research on several, more narrowly defined issues. For example, the transformation to a carbon-neutral economy will generate winners and losers in the economy. The identification of losing actors and ensuring their support for the economical transformation is crucial. Export-oriented industries, primarily mining of natural resources, stand out as possible losers. Furthermore, there is a high chance that the price of energy carriers could also increase, especially if a carbon tax is introduced to supplement the intervention package. This increase, together with transitions on the labormarket, might induce understandable resistance from the general public. It is therefore crucial to fully understand the redistributive impacts of the proposed policies using, for example, microsimulation modeling based on household budget survey data. In order to ensure public support and clear benefits, research on various co-benefits of a green



transformation should be conducted, for example highlighting the health benefits of reduced air pollution.

Future work will be needed to assess the uncertainty around these evaluations in order to better inform the expected outcomes of these policies. The following steps could be taken in such direction: first, it is necessary to iterate over the assumptions and to build different scenarios for the projected capital and operational expenditures as well as emission reductions for each measure, and run further sensitivity analysis. These exercises will provide a better understanding to policymakers at the government on the robustness of the policy measurement. Second, the projected trajectories for GDP and other economic variables change over time, and therefore it will be required to embed new projections into the measures to reiterate over the projected expenditures and reduced emissions on a consistent basis. Third, the nature of technology changes in the economy, and the structure of the model does not allow to simultaneously assess the interlinkages of the measures and other fiscal tools such as a carbon tax.

Moreover, the study has not analyzed the way the measures of the mitigation package will be financed. Since positive economic and financial implications arise from implementing the mitigation package, the unsolicited participation of the private sector is expected. However, one question for further research that prompts is why these measures are not expected/or have been promoted to be carried out in the baseline scenario? There are several restrictions that may prevent such a smooth and spontaneous transition. There are market and government failures which may hinder a pure market provision of mitigation, as summarized by Krogstrup & Oman (2019). These failures can take the form of common pool and free-rider problems, time inconsistency (such as short-termed decision making), governance problems and interactions with regulation and accounting standards, incomplete and imperfect capital markets, collective action issues and capture by interest groups, and inability to commit. The study recommends to undertake a deep analysis of how each of these hurdles may affect the different measures in order to provide the appropriate mitigation policies. Lessons learned from this exercise are the macroeconomic impacts of sectoral proposed policies in Chile. Further questions should include how to determine the better tools and mix between public and private sector in the implementation of the policies. Complementary work to this first quantitative attempt must go beyond the political economy and management of the implementation of decarbonization plan to achieve the net-zero goal on 2050. For that, endeavor theory and data-driven evidence, like is presented in this work, must contribute to the development and implementation of better public policies to ensure Chile can deliver its ambitious climate change policy.

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