How to Scope the Fiscal Impacts of Long-Term Climate Strategies?

A Review of Current Methods and Processes

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A product of the Helsinki Principle 1 Workstream

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Authors and Acknowledgements

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Abbreviations

BAU	Business as usual
BECCS	Bioenergy with carbon capture and storage
CGE	Computable general equilibrium model
CCS	Carbon capture and storage
DG ENER	Directorate-General for Energy of the European Commission
DG ECFIN	Directorate-General for Economic and Financial Affairs of the European Commission
DMDU	Decision making under deep uncertainty
DSGE	Dynamic stochastic general equilibrium model
EC	European Commission
ETR	Environmental tax reform
EU ETS	Emissions Trading Scheme in the European Union
GDP	Gross domestic product
GTAP	Global Trade Analysis Project
IAM	Integrated assessment model
IPCC	Intergovernmental Panel on Climate Change
LTS	Long-term climate strategy
LULUCF	Land use, land-use change and forestry
NET	Negative emission technology
OLG	Overlapping generations model
RDM	Robust decision making
ROA	Risk-opportunity assessments
R&D	Research and development
SSPs	Shared socioeconomic pathways
VAT	Value-added tax

Contents

Foreword

The Coalition of Finance Ministers for Climate Action is a group of 72 finance ministers engaged in efforts to address climate change through economic, fiscal, and financial policies. Peer learning and knowledge exchange are key ways the Coalition adds value to its Members.

This report is an important step in helping Coalition Member countries design tools to assess the economic and fiscal impacts of climate change. This is a very demanding task, as no readily available tools exist. A long-term engagement is required, and assessment tools always need to be tailored to country-specific circumstances. Despite this, common features to support modelling—and especially to get started—can be identified.

Assessing how to scope the fiscal impacts of long-term climate strategies was identified as a key priority area in the Coalition's 2021 Work Programme. By providing a comprehensive review of current assessment methods and processes, this report showcases the value added of the Coalition. All Members can benefit from the analysis and policy recommendations contained in the report, which are based on country experiences and the views of experts in this area. It should be underlined that achieving progress requires a strong commitment from policymakers to develop modelling competencies (i.e. of officials in finance ministries) as well as to designing analytical tools and modelling expertise.

The Coalition is very grateful to Sitra, the Finnish Innovation Fund, for producing this report. The report is based on a literature review and interviews with experts (25 from academia and research institutions, and 11 government officials from six countries) on how to improve fiscal impact assessments and potential ways forward for ministries of finance. The literature review covers different types of fiscal impact assessments, including studies at the national level on long-term climate strategies and transition and more academic works related to analyzing fiscal impacts (under deep uncertainty) in general. The experts interviewed have vast experience in conducting fiscal and economic ex-ante impact assessments and considering best ways to develop them.

In February 2022, the Coalition organized a workshop on the outcome of this work. It was recommended that, as a next step, Coalition Members would initiate discussions with experts at the country level. Thereafter, a follow-up workshop will be organized to deepen understanding and to share experiences.

Since modelling is relevant in multiple Helsinki Principles, this report will make an important contribution to the Coalition's work more broadly. In particular, the report will provide a useful basis for the Coalition's upcoming training initiative and research activities, and cooperation with Institutional Partners that are in key position to develop assessment tools.

Summary

More than 140 countries, representing 90 percent of global emissions, have announced or are considering net-zero targets. With the transition to net-zero, the structure of the global economy is expected to change significantly. Clean sectors, such as renewable energy, are likely to grow, and emissions-intensive activities, such as oil or coal production, to shrink. The economic structures of individual countries and international trade patterns are likely to change. But much of the decision-making environment is under deep uncertainty, with many potential changes difficult to forecast, and the transition often sudden and nonlinear. How, then, should we prepare for the transformation that lies ahead? What does it mean for our economies and for budgetary planning? What fiscal impacts could we expect?

Scoping the fiscal impacts of moving to net-zero can enable finance ministries to promote sustainable economic policies, prepare and adjust for possible major changes, and maintain budget sustainability in the changing environment. But how to best identify and potentially quantify the potential fiscal impacts from the transition to carbon neutral societies.

This report has been compiled for the Coalition of Finance Ministries for Climate Action under the Helsinki Principle (HP) 1 workstream. It compiles information and experiences on:

- The main impact channels of the transition on fiscal balances.
- Current national and academic studies analyzing climate strategies' fiscal impacts and their research approaches.
- Existing modelling tools and their trade-offs.
- Potential wider research frameworks (such as how to select scenarios to analyze) and practical organization of the studies.

The report focuses on the fiscal impact assessments of climate mitigation policies and the transition to carbon-neutral economies. The physical impacts of climate change—such as floods, droughts, and sea level rise—have implications for fiscal balances and are considered in other Coalition reports.

A range of policies is required to reach net-zero

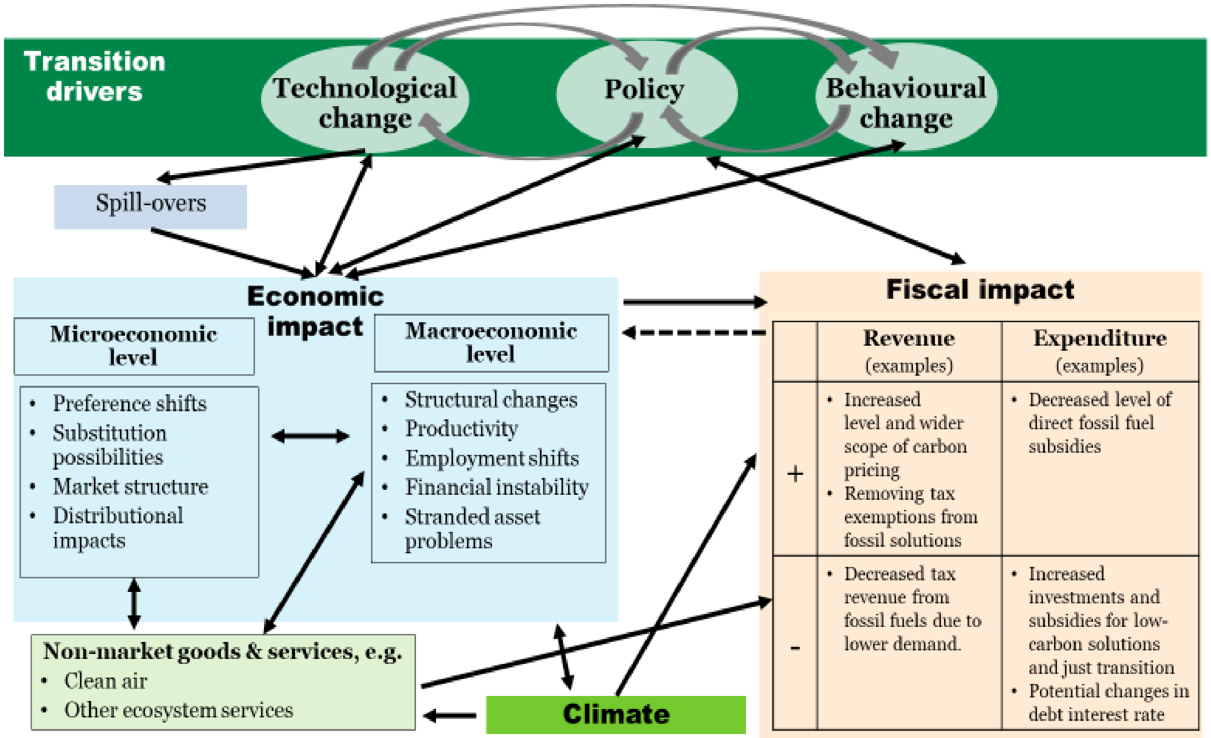
There is a fairly strong consensus on many of the changes linked to the net-zero transition. For instance, achieving net-zero means changes in energy production and consumption, land use, industry, transport, and buildings. In addition, negative emissions are likely to play a key role—whether via natural sinks or technological solutions. But the emergence and implications of disruptive technologies (such as automated vehicles or laboratory-grown meat) can be especially hard to predict. Considerable uncertainty is also linked to the adoption rates of new technologies and the future costs of technologies now at an early phase of development.

To steer national economies toward the changes needed in each sector, policy makers should enact a range of policies, integrating long-term views to avoid lock-ins that are incompatible with climate targets. Understanding the expected impacts of different policies is important in evaluating specific measures to ensure a just transition for all.

Technological, behavioral, and policy changes affect the economy and public budgets – understanding the main impact channels is crucial

The transition to net-zero economies will have many implications for public budgets, and its numerous impacts on public balances interact in multiple ways (figure S1). Understanding the main impact channels serves as a useful starting point for assessing the transition's impacts on public finances and for policy design and assessment in general.

Figure S1: Main impact channels of the transition to net-zero on public revenue and expenditure



First, climate policy, technology development, and behavioral changes are the main drivers of the transition and have microeconomic and macroeconomic effects.

- At the microeconomic level, the transition alters the demand and supply of goods and services through changing prices and shifting preferences and substitution possibilities (such as easier substitution away from fossil fuels in transportation with the rapid uptake of electric vehicles). The transition drivers also alter market structures and have varying effects on different types of households, firms, and regions, meaning they have distributional effects.
- At the macroeconomic level, decarbonization implies structural change in the economy, where all large-emitting operations (such as electricity and heat production or steel manufacturing) need to be replaced with new low-emission solutions. The transition will have an impact on productivity, employment, and value added, possibly causing financial instability and stranding assets.

Second, economic changes have direct and indirect fiscal impacts. For example, lower demand for fossil fuels lowers related tax revenues due to decreased demand. Economic changes might also increase the need for government spending. Climate policy measures, such as carbon pricing and subsidies, also directly affect public balances. The examples on fiscal impacts in figure S1 do not apply to all countries. For example, a higher carbon tax can increase tax revenue, whereas a subsidy for fossil-free technology would increase public spending. The time horizon also matters for fiscal impact assessments—as with a higher carbon tax increasing tax revenue only in the short run and diminishing when emissions decrease. And due to major structural changes in the economy, the overall long-term fiscal impacts are the most difficult to estimate.

The large investments for decarbonization have many impacts. On the demand side, they can reduce the fiscal resources for other purposes, but they are likely to create positive impacts in boosting demand for the new low-carbon solutions and sectors and improving infrastructure, such as creating better transport infrastructure or improved insulation of houses. The structural change in the economy can alter various tax revenues, such as capital or labor tax payments from different industries, but also general consumption tax revenues through impacts on total productivity and consumption. Phasing out fossil fuels can strand assets and impose direct losses in fossil-intensive economies.

Current fiscal impact assessments often combine modelling tools

Based on the interviews conducted and the current assessments studies, quantitative analyses of the long-term fiscal impacts of climate strategies seem rather extensive and complex. Yet, many interesting examples how to analyze long-term climate strategies and required policies and their impacts exist. Most long-term strategies analyzed have combined different modelling tools to scope the potential impacts in a multidisciplinary way. Many use bottom-up energy and technology models together with economic models, such as computable general equilibrium (CGE) models or macroeconometric models. Simpler spreadsheet models have also been used to scope the potential fiscal impacts. In many countries, the fiscal impacts of the net-zero transition can be expected to relate particularly to a few specific sectors (such as coal or oil production, or transport) and there are good examples on how to analyze individual sectors. And microdata-based models have been used to analyze potential distributional impacts.

The way the models are used, and their results communicated, is as important as the model structures

All individual models are simplifications, and the plethora of model categories and individual models have different strengths and weaknesses. All models are built for specific purposes, and even individual models can have many different versions. So, the use of multiple models to scope the total fiscal impacts can provide a deeper and more complete understanding on the possible range of impacts. While no model can cover all required impact analyses and aspects in detail, different models can provide insights on some parts of the whole. And many interviewees stressed that simple assessment methods and tools can already provide a good start.

In addition, communications and transparency about the models and the modelling logic—meaning the way the model arrives at the results—are considered by many experts as important as the actual modelling results. They are also crucial for good policy making, since all models and methods have limitations, and the model outcomes can depend heavily on the assumptions in the model. Until now, most impact assessments on long-term climate strategies have been large multidisciplinary efforts with research expertise from various fields. Many studies have also included extensive stakeholder consultations to assist with scenario selection and the analysis of impact channels.

Long-term decision making involves deep uncertainty. Technological and behavioral changes are difficult to forecast. Both national and other countries' policy changes can affect economies and their fiscal balances. And sudden and nonlinear transitions are possible. To cope with deep uncertainty, running multiple scenarios with the models can scope potential future development pathways and their main determinants. Sensitivity analyses of key parameters and comparisons of results based on different models is another way to scope future pathways.

There are various opportunities for improvements

Despite the many good examples from previous studies, the interviewed experts identified challenges and opportunities for improvement. These relate to data, to scenario selection and baselines, to transparency and communication, to capacities in ministries and research organizations, and to general modelling difficulties.

The general modelling difficulties include technology changes, changes in people's preferences, and disruptive structural changes in markets, analyzing innovation and its potential impacts, and the limitations of assessment tools. There is also a need for models that can analyze discrete changes, nonlinearities such as tipping points, and cascading effects from one sector to the other, financial flows and risks, and bumpy transition pathways. But as one interviewee put it, the perfect is the enemy of good.

Key take-aways for finance ministries

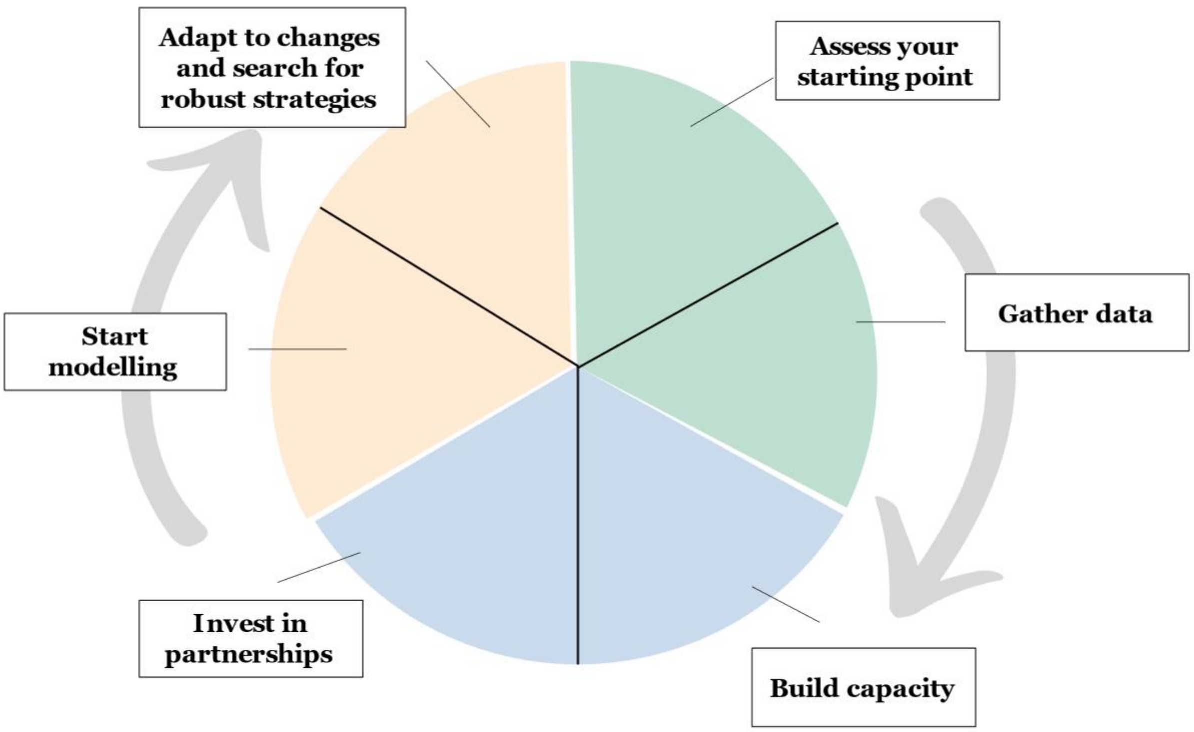
Countries analyzing the fiscal impacts of the transition can consider the following steps, which can be carried out simultaneously in a process that is likely to be iterative, with their relative importance varying in different contexts.

1. **Assess your starting point.** Start by answering the following questions: What actions, technologies, and changes are needed to reach carbon neutrality by the target year? What are the potential direct and indirect channels of climate change policies on the economy and on fiscal balances? What are the interactions among economic sectors? Who would be the winners and losers under different policies? This part of the exercise could be more qualitative, and if you have a long-term climate strategy, use existing information.
2. **Gather data.** Assess your data requirements. Map out opportunities to fill in potential gaps. Use the data and insights of other ministries and research institutions. Cooperate with national statistics offices, experts, and international organizations.
3. **Build capacity.** Consider hiring and maintaining specialists with mastery of modelling tools and methods in the ministry of finance. This is important for obtaining modelling work that is relevant for the ministry's needs, but also for efficient communications and using modelling results for policy making. An efficient team should, at a minimum, include knowledge of both climate policy and economic modelling. Knowledge of approaches for Decision Making Under Deep Uncertainty and Risk-Opportunity Analyses can also be useful.
4. **Invest in partnerships.** Nationally, cooperate with various stakeholders, such as experts from different fields and sectors. Develop models and methods with experts across different disciplines. Use other ministries' knowledge and expertise. Encourage international cooperation between research organizations and policy makers, and secure high-level political and administrative support.
5. **Start modelling.** Once the required resources are in place, start modelling. Even simple spreadsheet calculations can provide a good start. To deepen and broaden the assessment, use more complex modelling structures and multiple complementary models that highlight different aspects of the transition to net-zero. Run multiple scenarios and sensitivity analyses

to scope and stress test the potential development pathways. Conduct risk-opportunity analyses of policy choices. Communication and transparency on the chosen models and their underlying assumptions are crucial.

6. **Adapt to changes and search for robust strategies.** Make the most of the information gained through modelling and embed it as one aspect in the broader decision-making context. Even during deep uncertainty, scope possible future changes, prepare for the most significant ones, adapt to changes, and steer your society toward the best possible pathways. Be prepared to adapt plans and strategies as new information becomes available.

Figure S2: Key measures for finance ministries to consider



1. Introduction and Study Methods

Ministries of finance or economy have a responsibility for public finances, with scoping and preparing for the potential fiscal impacts of climate transition part of the job. Yet, many countries find this task difficult. Therefore, the main question this study deals with is how best to identify and potentially quantify the potential fiscal impacts of the transition to net-zero societies? While qualitative analyses may already provide some insight, quantitative analyses and different scenarios can shed light on the direction and scale of the potential impacts. Such analyses of the potential sign and size of minimum and maximum impacts is referred to as 'scoping' in this report. As the fiscal impacts depend directly from the climate policies chosen, scoping analyses can also provide inputs for assessing optimal climate policy responses and the required educational, industrial and innovation policies, for instance. The Covid-19 pandemic has emphasized the need to scope potential changes that can have massive impacts in societies, even if their probability is small. Based on some of the views of finance ministries compiled for this study, "quantitative and modelling inputs are not only desirable, but also necessary in the policy-making process."

This report has been conducted for the Coalition of Finance Ministries for Climate Action under workstream Helsinki Principle (HP) 1. In line with the Coalition's principles, it aims to share information and experiences on:

- The likely main impact channels of the transition on fiscal balances.
- Current national and academic studies quantifying climate strategies' fiscal impacts and their research approaches to analyze the impacts.
- Existing modelling tools and their trade-offs.
- Potential wider research frameworks and practical organization of studies.

In addition, we have gathered views on some key challenges and opportunities for improvement related to the topic from modelling experts and ministries of finance around the world from interviews. Modelling experts also provided some advice on potential ways forward for finance ministries. The report concentrates on how to scope the potential fiscal impact of transition pathways in line with the long-term climate targets, while considering that the future changes are deeply uncertain.

In addition to the main topics mentioned, we aim to answer related questions, such as:

- How to identify the potentially most heavily affected sectors?
- What are the policies that can achieve the climate goals, and what are their associated fiscal impacts?
- What are the relative merits of different policy options, and how do they have different impacts on public finances?
- How to conduct the impact assessments in practice?
- How to assess potential, but uncertain, major structural changes in society (such as new ways to produce food or automatic vehicle fleets) and their fiscal impacts?

The report analyzes only the fiscal impact assessments of climate mitigation policies and the general transition to a net-zero world globally. In general, these impacts are called transition impacts, which cover both positive and negative impacts resulting from the transition, while transition risks refer only to the risks associated with the transition. Note that climate change impacts, such as floods, droughts, and sea level rise, also have implications for fiscal balances, and these impacts are already materializing. So, adapting to rising temperatures is a major concern for many countries and their ministries of finance. Until now, physical and adaptation impacts of climate change and transition and mitigation related risks have been often analyzed separately (NGFS 2020). The fiscal implications of climate change impacts are also addressed in other Coalition work, particularly in the Helsinki Principle 4 workstream. And unlike work of central banks that focus mainly on climate risks, this report covers both negative and positive transition-related general impacts.

2. Context

2.1 What Needs to Change to Limit Global Warming?

The signatories to the Paris Agreement are committed to limiting global warming to below 2°C, with an aim to limit it to 1.5°C. COP26 decided that allowing the world to warm 2°C is too much and all efforts should limit it to 1.5. In global averages, every decimal point counts: the impacts of a 1.5°C temperature increase are less severe than those of, say, 1.6°C. The more global temperatures increase, the higher will be the associated economic costs due to extreme weather events and other climate risks.

To achieve the target of 1.5°C, the global community will need to reach net-zero emissions around 2050. This requires rapid and extensive emission reductions. In practice, unprecedented transitions are required by all actors and sectors throughout society: in energy production and use, land use, industry, buildings, and transport. And low population growth and declining inequality would help in decarbonizing the global economy, highlighting the need for global co-operation (IPCC 2018).

Most countries have set net-zero emission targets (for instance by 2050), are considering it, or are increasing the ambition of their climate policies in some other way. Reaching net-zero emissions also requires profound changes at the country level. The shift in economic structure can create new opportunities for economic activity and job creation. Some sectors of the national economy, such as renewables, will expand, and other sectors, such as fossil fuel production and other carbon-intensive production, will shrink.

For instance, electrifying passenger transport and phasing out of fossil fuels in energy will change the structure of national economies. Carbon-free electricity can also decarbonize industrial processes. Together, these developments will boost electricity demand and change the methods and locations of electricity production in many countries.

Thus far, reducing emissions from agriculture has been a challenge for many countries. But new farming practices and technology can help curb emissions, and reducing food loss and waste provides further opportunities. A shift to more plant-based diets would also reduce emissions and free up land and other resources (people, capital, energy) now used in meat and dairy production.

In addition to reducing emissions in all sectors, another important question to consider are negative emissions. In general, negative emissions can occur through natural solutions (sinks, such as forests) or technological solutions that draw carbon emissions from the atmosphere or point sources and sequester carbon permanently (such as bioenergy with carbon capture and storage, BECCS). According to a recent modelling work, CCS or negative emissions technologies (NETs) are needed in large scale to achieve the 1.5 degree target globally, but are not available at the required scale (Drummond et al. 2021).

Some changes and their impacts are hard to predict because new sectors and business models can emerge, and the geographic locations of production can change. And the impacts of such changes may be widespread. For instance, if technological advancements lead to wide use of precision fermentation and laboratory produced meat, food production locations might change radically.[1] Circular economy practices and business models are also likely to change how and where materials are produced.

2.2 Required Policy Changes

Optimal policies for reaching net-zero or other climate targets will vary country by country. Nevertheless, learning from the examples of other countries and networks can give valuable insight to policy planning and implementation. There are three main ways to reach net-zero:

- Increase material- and energy efficiency.
- Switch to low-carbon energy, material, and land-use solutions and practices.
- Increase carbon sinks.

To steer the national economy toward carbon neutrality in a just way, politicians have many alternative instruments to choose from. Policy instruments fall in some of the following categories: carbon pricing (via taxes or emissions trading schemes), subsidies (such as for renewable energy investments), regulations (such as fixed phase-out deadline for coal) or provision of information (such as campaigns). Some policies combine elements from different categories—policy makers can use output-based rebating where carbon tax revenues are recycled back to companies in proportion to their output (Fischer 2021).

Understanding the expected impacts of climate policies is important for effective policy making. In addition to impacts on emissions, the expected impacts on employment and public balances, as well as cost-efficiency (abatement cost per reduced ton of CO_2) warrant the attention of policy makers. And assessing the impacts on different groups of people and different geographical areas is important to evaluate what type of measures should be considered to make the transition fair and just. For instance, a carbon price increase can be part of a wider environmental tax reform where the additional tax revenue can be recycled back to the economy. Ways to do this include decreasing other taxation, such as labor or corporate taxes, lump sum transfers to (most affected) households, and increasing R&D funding (Pigato 2019).

To reach a national net-zero or other climate target in the next 10 to 30 years, effective policies must be put in place today. Many solutions are already commercially used, but some of the needed solutions are still at piloting phase (UNEP 2017). Therefore, to enable the utilization of solutions that are currently at earlier phases of development, and to avoid lock-ins in solutions that are incompatible with climate targets, long-term views need to be integrated in policy choices today (Volg-Schilb et al. 2018).

It is up to the policy makers to choose which measures to use. In opting for measures, politicians may give special attention to cost-efficiency, distributional impacts, or acceptability. If acceptability is seen as an important issue due to large hikes in energy prices or increasing energy poverty, less cost-efficient measures that avoid the direct impact on energy prices can also be optimal, such as subsidies or regulation (IMF 2019).

Electrifying passenger cars has been identified as a solution for decarbonizing transport and countries have chosen different policies to steer development toward this outcome. The UK has announced that it will end the sale of new gasoline and diesel cars and vans by 2030 (Government of the United Kingdom 2021). Germany offers subsidies for the purchase of EVs (Appunn 2021), and Norway has set an exemption from value added tax (VAT) on zero-emission vehicles (Norsk Elbilforening 2021). Various countries simply impose carbon pricing or fuel taxes on fossil fuels hoping to increase the demand for EVs.

For negative emissions, the Committee on Climate Change in the UK (CCC 2019) included CCS in scenarios to reach net-zero emissions in the country by 2050. Based on the scenarios, the Committee stated that

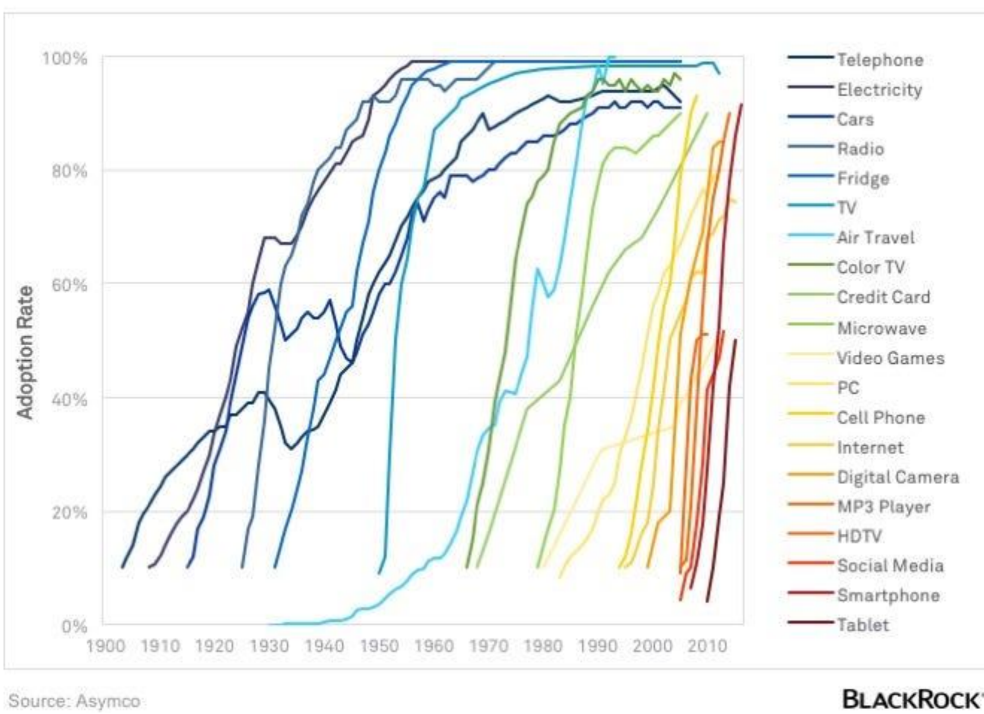
"CCS is a necessity not an option." It advised the government to take an active role in leading CCS-related infrastructure development, including long-term contracts and investment incentives.

Grubb et al. (2021) give a warning on policy criteria and selection. Concluding that in the recent expansion of wind power and solar PV: "The policies that played the most critical role were neither public R&D, nor the instruments that economists typically recommend as the most efficient. Instead, they were policies that targeted resources directly at the deployment of these technologies—through subsidies, cheap finance, and public procurement." Cost-benefit analysis, commonly used in policy making, did not recommend the use of any of these targeted policies. In general, they were implemented despite, not because of, the predominant economic analysis and advice.

2.3 Deep Uncertainty Over World Developments

Apart from analyzing what policies can cut down emissions along the required pathways, policy makers need to keep in mind that the world around us is changing rapidly. For example, the speed of adopting new technologies (the so-called S-curves for the adoption rates of new technologies and ideas) has been increasing rapidly over time, as figure 1 shows. At the beginning of the last century it took about 10 years to go from 5 percent adoption rates to around 80 percent, but with most recent technologies, it has taken only a few years. While the S-curves are typically presented for new technologies, behavioral changes also tend to take less time to become mainstream nowadays thanks to the new information technologies.

Figure 1: The speed of technological adoption has been rising



Source: Business Insider 2015.

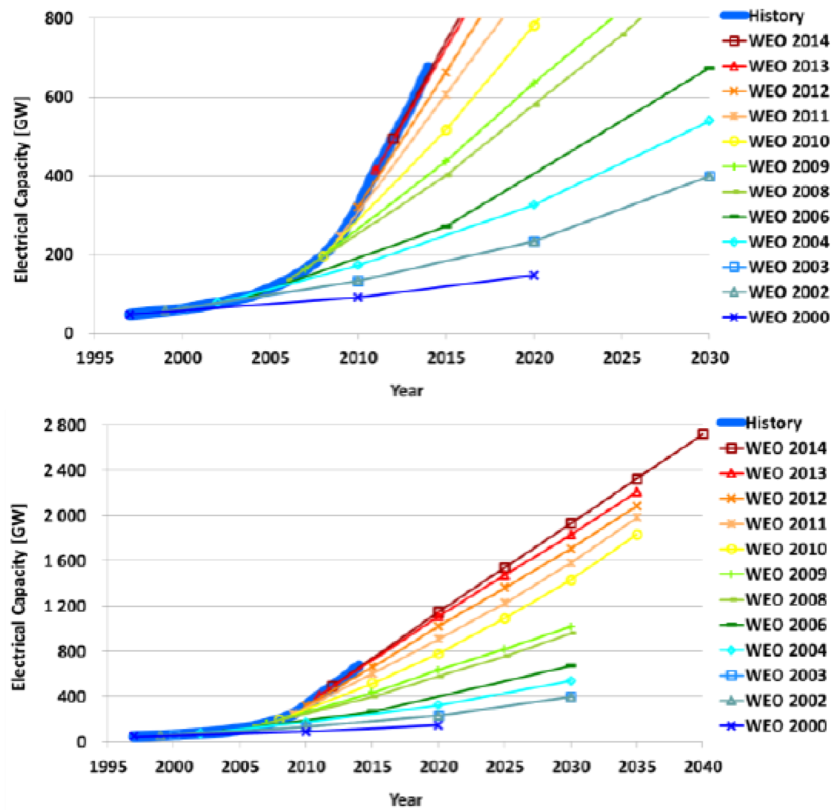
In addition to the various technological changes and improvements expected, disruptive innovations and unexpected new technology improvements are also possible. New business models and innovations can create new markets and destroy old ones. [2] For instance, the transition from horse carriages to automobiles was a disruptive market change that built many new industrial sectors for manufacturing and fuel production and destroyed the old markets for horses.

Similar market disruptions are possible in the future, though hard to predict. In agriculture and food production, alternative meat products or even laboratory grown meat could disrupt the markets and potentially shift trade patterns in food value chains (Djanian and Ferreira 2020). In transport, again, automatic vehicles have been predicted to potentially reduce the size of the current vehicle stocks significantly (RethinkX 2018). In textile production, new technologies and circular economy practices may alter current production operations (Ellen McArthur Foundation 2017). New digital technologies—such as artificial intelligence, machine learning, big data, the internet of things, blockchains and 3D printing—are a key part of many new low-carbon and circular economy innovations helping manage, optimize, and predict complex systems. Advances in digital technologies could boost additional new innovations needed for the sustainable transition. (Geels et al. 2021, Tamminen et al. 2020).

But it is difficult to forecast which new technologies, business models, and behavioral changes will break through when they are in their early development stages. Forecasting adoption becomes somewhat easier only after the population has begun to adopt the technology. There is widespread uncertainty about what might happen or be possible even in the near future in many sectors. Predicting the relative costs of different technologies is tricky, especially over the long term, and this adds to the difficulty of forecasting technological adoption. Automatic, electric robotaxis have already been introduced for consumer use in China and the United States,[3] but it is impossible to say whether and when people will find this new technology safe enough to use on a mass scale.

Uncertainty about what is possible in the near future becomes evident from past forecasts of the world's best energy sector experts on the capacity expansion of all renewable energy sources. Many renewable energy technologies were still relatively new in 2000, and a 2000 forecast for the 10 years to 2010 was around 300 percent lower than actual capacity in 2010 (figure 2). Since then, the forecasts have improved as it became evident that these technologies are expanding quickly, but even the medium-term forecasts for the next six years in 2014 were still underestimated by nearly 30 percent, forecasting capacity to be about 1,200 GW without hydro power by 2020. In 2020, the total global renewable energy capacity in the world accounted for 1,588 GW without hydro power (IRENA 2021).

Figure 2: New renewable capacity excluding hydro power in the world, forecasts from annual World Energy Outlooks of International Energy Agency compared to history



Source: Metayer, Breyer, and Fell 2015.

Sometimes forecasts also overestimate quantities or rates of adoption. New assessments may conclude that some solutions previously seen as promising might look less so due to limitations in raw material availability (battery minerals for electric vehicles, biofuel raw materials) or shifts in relative production costs.

As an example, bioenergy use in the Nordics was predicted in 2016 to be 570 TWh by 2050 (Nordic Energy Research 2021a). Five years later, in 2021, model results for a least-cost scenario to reach carbon neutrality in the Nordics put total bioenergy use at slightly more than 400 TWh by 2050 (Nordic Energy Research 2021b). The reason for this significant difference is the updated prognosis of future biofuel demand. The report also notes the challenges linked to scaling up bioenergy production as land use is under increasing pressure in most countries globally.

Another uncertain area of development, besides the fields of technology and raw materials, involve the litigation concerning country responsibilities to address climate change. For example, the Dutch Supreme Court in 2018 upheld the previous decisions by other courts, finding that the government has obligations to reduce emissions based on its human rights obligations, and to do so at a faster pace than it had planned (Hoge Raad 2019). The court decision made the Dutch emissions target more stringent by five percentage points: from –20 percent to –25 percent in 1990–2020 (ibid). After the Paris Agreement in

2015, the number of climate-related litigation cases worldwide has increased: more than 50 percent of the court cases between 1986 and 2020 were brought since 2015 (The Geneva Association 2021).

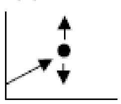
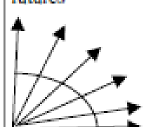
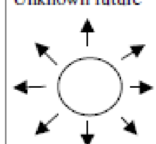
Many say the decision making environment is characterized by deep uncertainty. Marchau et al. (2019) compared the different levels of uncertainty about future developments with six main levels (figure 3). At the two extremes there is complete certainty on future developments at one end and total ignorance at the other. Between them, four levels of uncertainty differ with respect to the knowledge assumed about four aspects:

- The future state of the world, or context (X).
- The model of the relevant system for that future world (R).
- The outcomes from the system (O).
- The weights that various stakeholders will put on the outcomes (W).

For levels 1 and 2, single system models[4] can still be used to analyze the small perturbations of the model input parameters on outcomes or used to assess the probability distributions of the possible outcomes. By comparison, under deep uncertainty, or level 4 (a and b), analysts either struggle to (level 4a) or cannot (level 4b) specify the appropriate models to describe interactions among the system variables, select the probability distributions to represent uncertainty about key parameters of the models, or value the desirability of alternative outcomes (Marchau et al. 2019).

Figure 3: Levels of uncertainty for analyses and decision making

Table 1.1 Progressive transition of levels of uncertainty

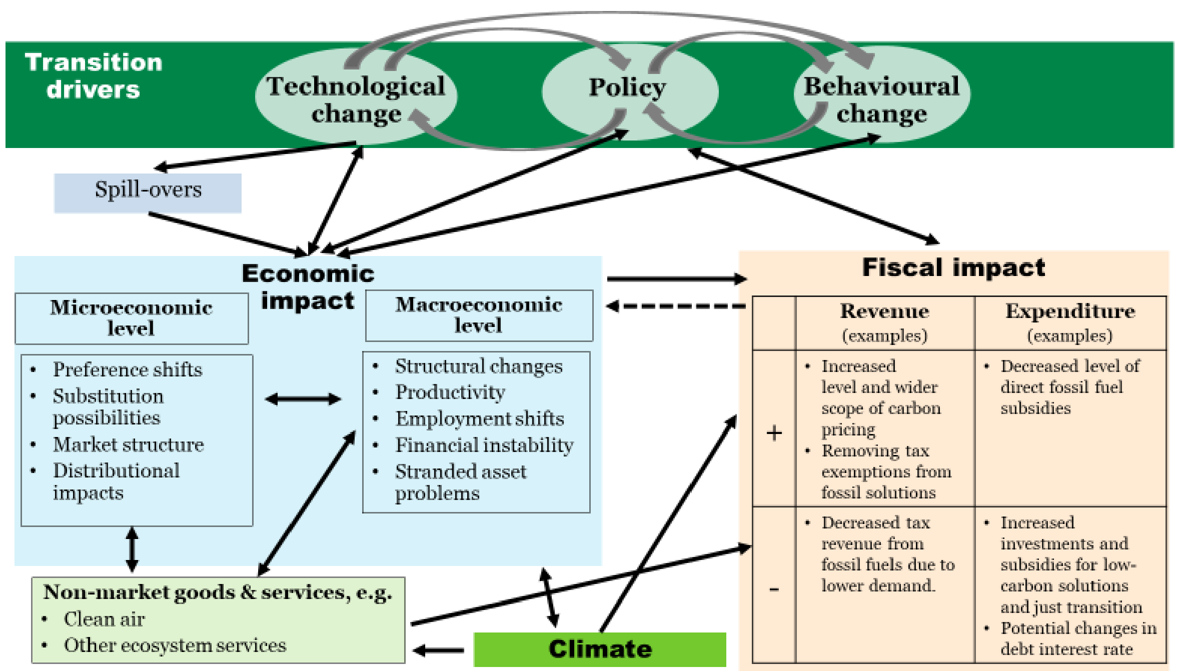
	Complete determinism	Level 1	Level 2	Level 3	Level 4 (deep uncertainty)		Total ignorance
					Level 4a	Level 4b	
Context (X)		A clear enough future 	Alternate futures (with probabilities) 	A few plausible futures 	Many plausible futures 	Unknown future 	
System model (R)		A single (deterministic) system model	A single (stochastic) system model	A few alternative system models	Many alternative system models	Unknown system model; know we don't know	
System outcomes (O)		A point estimate for each outcome	A confidence interval for each outcome	A limited range of outcomes	A wide range of outcomes	Unknown outcomes; know we don't know	
Weights (W)		A single set of weights	Several sets of weights, with a probability attached to each set	A limited range weights	A wide range of weights	Unknown weights; know we don't know	

Source: Marchau et al. 2019, p. 9.

3. The Main Channels of the Net-Zero Transition for Public Balances

The transition to net-zero economies will have many implications for public budgets (Delgado et al. 2021, Pisani-Ferry 2021, Andersson et al. 2020, and Baur et al. 2021). It will be fueled by policy, technological, and behavioral change factors that interact (figure 4). For instance, policies can drive technological progress and technological development. Many economic impacts stem from changes in relative prices, demand, and supply—and translate to fiscal impacts through, for instance, lower tax revenues or increased government spending. Developing clean technologies and shifting consumer behavior cannot be entirely altered by policy making in a country, even if policy can influence them to some extent. For example, cheaper new low-emission solutions can provide incentives for users through price changes or cost reductions.

Figure 4: Main impact channels of the transition on public revenue and expenditure



In addition to the impacts of the transition on public balances, physical risks due to climate change affect public balances as well. These risks include extreme weather events and rising average temperatures, and adapting to these changes requires more spending on infrastructure, among other things. Climate change can also reduce natural capital stocks, such as fisheries or forests.

Understanding the impacts of both the physical risks and the transition on public balances is important to ensure the long-term sustainability of public finances. Physical risks are discussed in a paper by Dunz and Power (2021) where the examination covers "climate-related risk transmission channels" regarding both physical and transition risks. In the following only the impact channels of the climate transition are discussed in more detail, building on Dunz and Power (2021) and other recent literature (for example Pisani-Ferry 2021, Baur et al. 2021, and Batten 2018).

3.1 Transition Drivers

Mitigation policies aim to reduce greenhouse gas emissions and ultimately to decarbonize the economy by discouraging emission-intensive economic activities and encouraging less polluting activities. The government can do this with carbon pricing, regulation (including green procurement policies), standards, R&D incentives, investment and other subsidies, or information.

While climate policy is a major driver for technological and behavioral change, these drivers also develop regardless of domestic policy. This is especially true in the modern globalized world where technological solutions and behavioral trends spread rapidly. Therefore, global climate mitigation efforts can affect individual countries, whether they push for strong domestic climate policies or not.

Climate policy and mitigation efforts, along with the technological and behavioral change they bring, are likely to only intensify in the future. Progress on the temperature stabilization goals of the Paris Agreement implies immediate and rapid transitions to low-emission economies. Individual countries' possibilities to change course are limited. Larger economies can have a greater impact on things like technology development with heavy investments in R&D, but small open economies are especially vulnerable to the shocks caused by global trends, such as changes in international trade patterns or in technologies and behavior.

3.2 Economic Impacts

Transition drivers have direct and indirect economic impacts at both microeconomic and macroeconomic levels. Direct impacts refer, for example, to the impact of a carbon tax on emission-intensive firms' costs. Indirect impacts refer to all the economic impacts in the economy through the networks and interactions among economic actors. An indirect impact from the carbon tax could be a decrease for the intermediate inputs needed in the production of the carbon-intensive products or a general decline in consumption of all products due to higher energy prices and resulting higher share of income going for energy consumption.

At the microeconomic level, climate policy measures, like carbon pricing or regulation, will have immediate impacts on goods and services produced and consumed. General preferences or behavioral changes at household or company level may increase the demand for certain products and services while decreasing it for others. Technological changes may improve substitution possibilities from high-emission products to lower ones. New technologies and innovations may also increase productivity with effects on prices, wages, and profits. Policies, behavioral changes, and technological changes can also alter market structures and either increase or decrease such things as market competition.

The changes in the markets or in the provision of nonmarket goods and services are likely to have macroeconomic implications—on employment, productivity, inflation, and asset valuations among others. Decarbonization (whether driven by policy or not) implies structural change in the economy, where all operations in society that produce emissions need to be replaced by new solutions. Some current industries will fade away while new ones will emerge. Firms will need to invest and adjust their operations in line with market changes. In the long run, the global demand for fossil fuels is expected to fall when countries aim to reach their climate targets. Companies in the fossil fuel sector might face lower earnings, increased funding costs, and stranded assets (Grippa et al. 2019). The risk could materialize also for financial institutions that have fossil-related assets in their portfolios, as with a greater likelihood of credit defaults.[5] But the demand for clean solutions will increase, shifting earnings toward companies and investors providing them.

Financial instability could cause further macroeconomic problems. When physical or transition risks materialize suddenly, and asset prices adjust accordingly, concerns arise about financial stability (Grippa et al. 2019). Currently, asset prices might not fully capture the physical risks and required policy action needed to limit the global temperature increase to 2°C or less (ibid). Investors also have an important role in enabling the transition (Battiston et al. 2021).

The transition effects should not be overlooked and will likely include significant negative supply shocks, investment surges, large adverse consumer welfare effects, distributional shifts, and pressure on public finances (Pisani-Ferry 2021). Rapid transition away from fossil energy could reduce the supply of energy and have adverse macroeconomic consequences. And if climate policy is too gradual in the years to come, the transition is likely to prompt precipitous adjustments later. But a gradual transition would allow enough time to replace the physical capital stock, while technological progress would reduce energy costs (Batten 2018).

Even if the transition happens gradually over time, the structure of national economies is likely to change, as is the composition and volumes of exports and imports. For fossil fuels it seems inevitable that their exports will decline over time. But the impact of the transition on general competitiveness, changes in global value chains, or new potential export products and services are difficult to analyze with any certainty and depend on the country in question. International trade policies related to climate measures, in particular the planned Carbon Border Adjustment Measures, can have widespread impact on trade patterns.

Understanding distributional impacts is essential for a fair transition to a carbon neutral society. Distributional impacts can be addressed by informed policy making: for instance, the carbon tax revenue can be recycled back to the economy, and transfers can diminish the burden on the most vulnerable groups, such as poorer households, with restrictions on their possibilities to adjust to the changes or to specific regional areas most affected.

The transition implies shifts in employment to cleaner industries. In the short term, there might be mismatch between the skills needed and skills possessed by workers. The employment transition will imply more public expenditure, for education and transfers, and it may lower income tax revenues.

The change in the economy can have impacts on the climate. If all countries reduce emissions rapidly, in line with the scientific advice for reaching the Paris Agreement goals, the impacts of climate change may be less severe, with less likelihood of extreme weather events, which in turn, means less harm to physical and human capital (and less need for government expenditure to be directed at dealing with the consequences of extreme weather events).

3.3 Fiscal Impacts

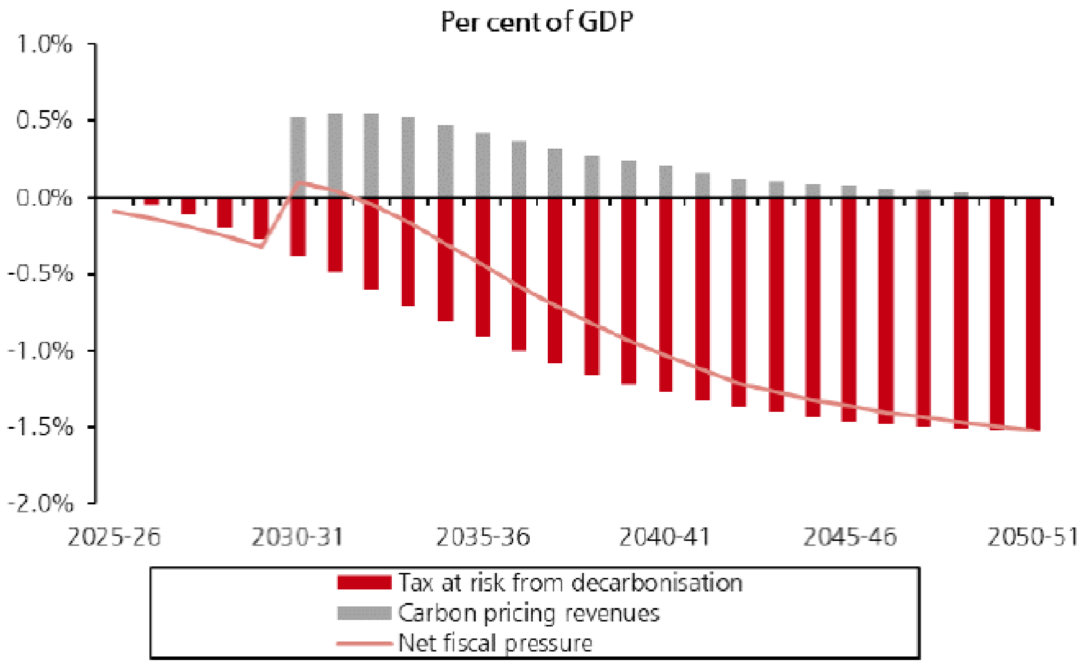
Economic and policy changes can have direct and indirect impacts on public balances. The economic impacts translate to fiscal impacts through, for instance, a decrease in carbon tax revenues due to lower demand for fossil fuels—or greater government expenditure on training programs due to an employment shift. Policies can, for example, increase tax revenue in the short run if, say, the carbon tax level is increased, or can increase public expenditure if government subsidizes low-carbon investment.

Different climate policy instruments have differing economic and fiscal implications. The varying direct economic impacts result in different types of indirect fiscal implications from the policies. Carbon pricing directly affects energy price, but it is the most cost-effective measure to reduce carbon emissions. With other measures, such as subsidies and standards, an increase in energy prices can be avoided but they are typically more costly per abated unit of emissions. Baur et al. (2021) point out that information on the structure of policies is essential to assess the overall fiscal impact of policies. For instance, the government can make the use of a specific clean technology compulsory, or it can subsidize its uptake. The two alternatives, obviously, have different direct fiscal impacts, with a subsidy increasing public expenditure whereas a technology requirement would have indirect impacts though, for instance, economic efficiency.

The time horizon matters for fiscal impact assessments. In the short term, decarbonization policies are expected to increase energy prices, burdening households and companies (see Batten 2018, IMF 2019, Andersson et al. 2020, and Pisani-Ferry 2021). But if carbon pricing is implemented comprehensively, the tax revenue increase could be substantial (IMF 2019). Many countries have already introduced carbon taxes, but only some 20 percent of global GHG emissions were covered by carbon pricing schemes in 2021,[6] and in many cases the carbon tax level is lower than the need (OECD 2021). The government can soften the economic and social impacts of carbon taxes by recycling the revenue back into the economy. As carbon emissions decline over time, revenues from carbon taxes will also decline. In general, for every current tax revenue and expenditure item, in addition to the possible new ones, the changes can vary substantially over time, depending on the economic and policy changes. Currently, most countries subsidize fossil fuels. Hidden subsidies, in tax exemptions or exceptionally low tax rates, are common. Phasing them out would increase tax revenues in the short run.

The overall long-term fiscal impact is most difficult to estimate, due to extensive structural and policy changes in the economy. Figure 5 provides a good example of possible dynamic, direct tax revenue impacts over time from the illustrative scenario analysis in the UK Net-zero report (HM Treasury 2021). The analysis covers only direct impacts on tax revenue under some assumptions, but not all economywide indirect impacts and their subsequent effects on fiscal revenue. Further, it is based on an illustrative projection of future carbon prices drawn from the average price levels recommended by the IMF for the 2030s. The carbon price assumptions are not based on UK government policy. Based on this analysis, the UK tax revenue at risk from decarbonization could increase over time. Until about 2035, rising carbon tax revenues might lower the total tax loss, but after that the carbon tax revenue could also decline, due to decarbonization. See the next subsection for more information on the British study.

Figure 5: UK example on estimated tax revenue impacts



Source: HM Treasury 2021.

Although significant investments are underway to decarbonize the energy sector and to boost energy efficiency, substantial further investment is needed (Andersson et al. 2020, Pisani-Ferry 2021). On a global level, the International Renewable Energy Agency's 1.5°C scenario predicts the annual investments to amount to around USD 5700 billion between 2021 and 2030, and to USD 3,700 billion between 2031 and 2050 (IRENA 2021). Compared with the annual investment level of around USD 2,100 billion in 2019, this means an increase of 270 percent in the coming years. The share of public funding is expected to fall, but in absolute terms the public investments would need to more than double in 2021–2030 from 2019 levels. For example, OBR (2021) assumed illustratively that on average some 27 percent of the total transition investments would be borne by the public sector, assuming the minimum share to be 13 percent and the maximum 41 percent. Yet, these shares seem uncertain.

The investments have many impacts. On the demand side, they can reduce the fiscal resources available for other purposes. Typically, investments in clean energy, energy efficiency, and clean infrastructure will boost aggregate demand in the short run. In the medium run, consumers are likely to enjoy, for instance, better transport infrastructure or improved insulation of houses (Pisani-Ferry 2021). In addition, there are possibilities for positive spill-over effects when other actors in the economy adopt new innovations. On the supply side, mitigation policies will likely have an impact on capital stock valuation and the direction of innovation, resulting in increasing innovation efforts for clean technologies and decreasing investments in fossil capital stock. As noted earlier, employment is likely to shift toward green industries.

The structural change in the economy can have significant fiscal consequences. It can alter various tax revenues, such as capital or labor tax payments from different industries, but also general consumption tax (VAT) revenues through impacts on total productivity and consumption. Delgado et al. (2021) also highlight the importance of anticipating the risk of lower tax revenues in fossil exporting countries and planning for the transition by taking other fiscal measures. If companies face problems, their tax contributions to the government are likely to fall. In some countries, the government is also a major owner of fossil reserves with stranded asset impacts and direct losses in fossil export. If asset valuations drop significantly and exports fall, the overall evaluation of the country as a lending counterparty by international financiers may be reconsidered, and the debt financing costs altered. In addition, government may need to compensate for the affected regions, firms, or workers, which can impact the country's borrowing costs (Dunz and Power 2021). If financial risks realize and a wide-spread financial crisis occurs, the banking sector may need to be supported by public funds. On the other hand, countries importing fossil fuels can benefit from less dependence on fossil imports. However, as fuel taxes are an important source of tax revenue in many countries, importing countries will also need to cover the expected decline tax revenue.

Importantly, the economic impacts on non-market goods and services (such as clean air, ecosystem services) will have fiscal implications—as reduced health expenditures and more solid income and corporate tax revenues due to less sickness absenteeism.

To conclude, the impact channels of the transition on public balances are numerous and interact in multiple ways. Understanding the main impact channels is a useful starting point for assessing the transition's impacts on public finances and for policy design and assessment in general.

Table 1 summarizes the previous examples on different positive and negative implications for public balances. Note that these vary by country and over time: for example, carbon tax revenues should fall with carbon emissions.

Table 1: Examples of possible positive and negative transition effects on fiscal balances

	Positive	Negative
Revenue	• Increased level of carbon tax: at first revenue will likely increase but will fall over time with decarbonization. • Wider scope of carbon pricing. • Increased tax revenue from industries benefiting from the transition. • Increased tax revenue from general consumption through impacts on total productivity and consumption. • Decreased fossil fuel subsidies, including hidden subsidies such as tax exemptions.	• Decreased tax revenue from fossil fuels due to lower demand. • Decreased VAT revenue if aggregate consumption falls due to higher commodity prices (linked to higher carbon pricing). • Decreased tax revenue from industries suffering from the transition. • Direct losses in fossil exports and losses through stranded assets if the country owns fossil reserves themselves.

Expenditure	• Decreased health expenditure and more stable income and corporate tax revenues through decreased sickness absenteeism.
	• Decreased (tax) subsidies to high-emission land-use practices.
		• Increased investments in:
		  ○ clean energy
		  ○ energy efficiency
		  ○ clean infrastructure
		• Increased subsidies for low-carbon innovations and systems (such as clean transport).
		• Increased expenditure on a just transition including:
		  ○ retraining the workforce
		  ○ directly compensating most affected households or regions
		• Support to carbon capture methods and their R&D.
		• Higher debt financing and repayment costs.

4. Methods and Tools to Assess Fiscal Implications of the Transition

In theory, the assessment of the fiscal implications of long-term climate strategies is fairly straightforward. According to many interviewees and the available literature analyzing the fiscal implications of climate strategies, the required steps are roughly these:

- Assess possible long-term mitigation pathways in line with the Paris Agreement and their possible economic, social and financial impacts.
- Assess different policy options required to reach the needed mitigation pathways in a politically and socially sustainable manner, and the socioeconomic and financial impacts of these policies.
- Analyze the fiscal implications of the combined long-term economic, financial, and policy changes.

In practice, this is easier said than done. Based on the interviews and the assessment studies carried out so far, the analyses seem rather extensive and complex. They often demand multidisciplinary skills, various modelling tools, and extensive consultations and stakeholder engagement.

The previous literature on the topic conveys similar messages. For example, Ekins and Speck (2014) considered that: "Macroeconomic modelling is essential to understand the effects of climate change mitigation policies on countries' fiscal position. Despite uncertainties in such models, care should be taken to include in their projections the effects of stimulating new technologies for emission reduction, and any development impact assessment of the policy instruments should take account of any ancillary costs and benefits arising from their application. Finally, climate change calls for long-term fiscal planning using models and scenario projections to explore the uncertainties associated with particular climate change outcomes." They recommend the use of different types of models for the tasks including climate, energy system, economic, and financial sector models. Similarly, Batten (2018) concluded that the "full account of the economy-wide labor market effects of climate policies require the use of some form of general equilibrium modelling, either in the in the neoclassical tradition with complete markets and instantaneous price adjustment or in a neo-Keynesian framework with some form of market friction."

While there are numerous impacts to account for and various assessment challenges to consider and tackle (section 5), there already are good examples, tools, and methods to start with. Many of the experts interviewed also stressed that countries can start with simpler methods and tools if they do not yet have extensive multidisciplinary modelling tools available at national level (section 6).

Here, we summarize some of the current assessments related to the topic, available assessment methods and tools for the analyses, and the practical organizations of the (fiscal) impact assessments.

4.1 Modelling Approaches in Existing Studies

In the following we briefly summarize some of the current assessments on long-term climate strategies. This section doesn't provide analysis on the optimal way to analyze the topic, but merely reviews the current methodologies. See sections 5 and 6 for analyses and advice on the modelling needs.

First, we highlight some wider economic or cost-benefit assessments of comprehensive long-term strategies that have not reported or analyzed fiscal impacts in detail. Next, we summarize some more theoretical assessments of required and best policy options, which mainly concentrate on analyzing a few individual policies or small policy packages. Then, we present some detailed sector-specific analyses of the fiscal impacts of the low-carbon transition—and the few studies found that have looked at the fiscal implications of the long-term climate strategies and the various policies they include.

The academic and policy-related research on the possible risks and implications of climate transition have developed quickly in the recent years. In addition to academics and ministries, central banks and fiscal and financial supervisory organizations have started to assess risks of the climate transition to the financial sector. The following cover only a few examples of the current work analyzing the total impacts or only the risks, and possibly excludes many interesting examples. The list only includes studies published until October 2021 and is solely focused on ex-ante assessments. Ex-post assessments can be vital for improving ex-ante assessments (see section 1 for an explanation, but preparations for possible future developments 10 or 30 years ahead typically require ex-ante scenario analyses.

4.1.1 Impact Assessments of Long-term Climate Strategies

The starting point of most analyses of long-term climate transitions needs be to a wide assessment of the possible pathways to the long-term target. This impact assessments summarized here aim to answer two questions:

- What technological, behavioral and policy changes would be needed to reach the long-term climate target?
- What are the expected economic or social impacts of different scenarios consistent with the climate target?

As stated by one interviewee, this first step of analyzing potential long-term target consistent pathways is crucial to translate or "demystify" what the long-term climate targets mean in practice. In the end, the long-term targets can typically be translated into concrete targets and changes in different sectors (section 2). For example, decarbonization might mean in practice that transport sector should be emission-free by a certain year and the main means to achieve this include such things as the extensive use of electric vehicles and low carbon fuels in heavier transport segments. Weitzel et al. (2019) also highlight that modelling possible long-term pathways can inform near-term climate policy on the required speed and ambition.

There typically are different pathways to reach the long-term climate targets. The cost-effectiveness and impacts of the different pathways on economic actors can vary substantially. In many countries, the different pathways are examined in long-term climate strategies and supporting impact assessments. Some of these impact assessments on long-term strategies include economic impact assessments or cost-benefit assessments. (Table A3.1 in appendix 3 includes a short list of examples from different countries including the methodologies used in the studies. Assessments that include more detailed analyses also on the fiscal impacts are discussed below.)

In most of the long-term strategies analyzed, a combination of different models is used in a multidisciplinary way to assess the possible pathways. As Weitzel et al. (2019) put it, a multidisciplinary modelling toolbox can help to explore the multifaceted consequences implied by a pathway to reach a given climate target.

First, many analyses use some bottom-up energy and technology models—such as TIMES, PRIMES, and POLES models used in the various European studies and in the Canadian LTS, see table A3.1) or complex integrated assessment models (for example AIM/Enduse in the Indonesian LTS) to assess the possibilities to reduce emissions with technology and fuel switches and new technologies. Sector specific models are also used to help in the assessments of important sectors not covered by the energy models in good enough detail (agricultural, transport, and forest models).

Second, the assessments are extended with economic models, such as computable general equilibrium (CGE) models or macroeconometric models to calculate the total macroeconomic, sectoral, and income effects. Distributional impacts have been analyzed typically using microsimulation models. In some cases, combined economic-energy models are used. Additional explanations on the different types of models used are in subsection 4.2.

Long-term developments are always uncertain. Multiple scenarios of possible developments can provide a better view on the possible development pathways than a single most-likely scenario. No modelling tool is typically fully optimal on its own. For example, the Canadian LTS includes estimations on possible pathways completed by four different modelling groups, with most groups using again multiple modelling tools in their estimations. (See subsection 4.3 for examples of large scenario analyses from Chile, Costa Rica, and Peru.)

The Network for Greening the Financial System (NGFS) has developed six global scenarios and general advice to help their member central banks and financial supervisory boards assesses the financial risks of climate change. The scenarios cover both physical risk and transition risk. NGFS (2020) generated the scenarios by using integrated assessment models for the climate and energy pathway analyses and a macroeconometric NiGEM model to analyze the potential macroeconomic implications. The members of the network report that many have extended their national transition risk analyses with CGE based modelling to better cover sectoral developments, with 31 members are using the climate scenarios to identify, assess, and understand climate risks in their economies and financial systems (at firm or bank balance sheet level). A few central banks or supervisory authorities have already concluded their studies (NGFS 2021). Compared with other economic studies, these concentrate on risk only, while the transition is likely to have various positive impacts on the economy, and on the evaluation of financial balance sheet impacts.

4.1.2 Relevant Policy Option Assessments

In addition to long-term impact assessments, countless studies examine the fiscal implications of individual climate policy options or groups of policy options. The main purpose of these studies is typically to inform policy makers about the potential implications of the options and to provide comparative evaluations of policy options. The policy assessments summarized here aim to answer three questions:

- What policy options could be used to reduce emissions in line with the long-term target?
- What general economic or social impacts could each policy option on its own or set of policy options have?
- Based on some specific indicators, such as general GDP impacts, what policies or mixes of policies seem optimal to reach the target(s)?

Many of the studies concentrate on the analyses of Environmental Tax Reforms, where carbon taxes are raised while other (distorting) taxes are decreased or subsidies to support the low-carbon transition are increased. These types of assessments are crucial for analyzing the best and most cost-effective climate policy options or combinations of measures. Many of them also analyze the fiscal impacts of climate policies along the low-carbon transition, but in a relatively stylized manner, typically concentrating on a few possible policy options. Compared with the assessments of entire climate strategies covering different taxes, subsidy, and regulatory measures even for individual sectors, the focus in these policy assessments is typically narrower and somewhat more theoretical (see table A3.2 in appendix 3). Referencing all policy-relevant ex-ante studies is beyond the scope of this study.

These policy-focused studies also provide interesting examples of the possible ways to analyze the fiscal impacts of climate policies. Many of them use similar types of energy and economic models (such as CGE and macro models) as the long-term climate strategy impact assessments discussed above. Weitzel et al. (forthcoming)[7] extend these models further with more disaggregated and microdata-based analyses to examine labor market and distributional impacts in more detail. Both are essential for the planning of fair climate policies and therefore for the potentially required public subsidies to assist in labor market transitions or to lessen the income effects to poorest households.

In addition, numerous other types of models are used. For example, the IMF and OECD use macro and CGE models that are extended with detailed in-built energy and emissions analytics for assessing environmental tax reforms (such as the IMF-ENV CGE model,[8] G-CUBED model of Warwick McKibbin, and OECD's ENV-Linkages CGE model respectively). For example, Jaumotte et al. (2021) and IMF (2020) analyze large global assessments of mitigation packages in line with the net-zero target of 2050 with different types of revenue recycling options. Both studies include assessments of global fiscal impacts. The OECD (see Bibas et al. 2021, Chateau and Mavroeidi 2020, and Dellink 2020) has good examples for modelling material fiscal reforms that could promote new circular economy business models necessary for reducing emissions and natural resource use. Varga et al. (2021) have built a new energy-extended DSGE model for the European Commission, which they use to assess the impacts of different types of climate policy packages, concentrating on environmental tax reforms. Using a stock-flow consistent (SFC) model, Monasterolo and Raberto (2018) assess the trade-offs that governments can face when financing the transition with a carbon tax or green sovereign bonds.

The IMF has examples of how to use a less complex energy-economy model to analyze potential fiscal implications of climate strategies and policies. The CPAT spreadsheet model projects the use of fossil fuels and other fuels by the power, industrial, transport, and residential sectors based on an assumption of GDP growth, elasticities, energy efficiency improvements, and international energy price forecasts. Different climate policy options impacts on fiscal balance are analyzed with the model, as for Mexico and the United States (Parry 2021, Black et al. 2021).

Many studies conclude that environmental tax reforms could generate the required emission reductions with the least economic impacts compared with other policy options. On the impacts of stricter regulations, Varga et al. (2021) find that this would reduce GDP significantly more in the EU area by 2050 according to their new DSGE model, compared with carbon taxes with recycling. Conversely, Weitzel et al. (forthcoming) find that regulation-based policies would lead to GDP and consumption losses similar to a market-based approach when feeding in bottom-up information from an energy system model into a CGE model. Weitzel et al. conclude that their results indicate that carbon pricing does not necessarily have strong advantages in efficiency terms in their modelling framework. The comparison of these two studies based on different modelling systems likely highlight that the model details also drive some of the results.

4.1.3 Sector-specific Assessments

In many countries, long-term climate plans and their impact assessment show that some specific sectors are likely to face significantly larger impacts than others. Similarly, the fiscal impacts from the climate transition can often be expected to relate particularly to some specific sectors. This applies especially to fossil-fuel exporters, which are expected to face major problems with stranded assets. For example, Solano-Rodriguez et al. (2019) have estimated that in Latin American and Caribbean countries stringent global climate action could reduce the fiscal revenues from fossil fuels to $1.3–2.6 trillion, down from $2.7–6.8 trillion if (fossil fuel) reserves were strongly exploited. Welsby et al. (2021) find that royalties from natural gas would drop by 80 percent. Domestic fiscal management is expected to have limited potential to increase revenues, so governments may need to diversify their fiscal revenues away from oil production.

The sector-specific assessments summarized here aim to answer such questions as:

- What impacts might the long-term climate transition have on a given sector?
- What policies would be needed to reduce the sector-specific emissions in line with the long-term target?
- What measures or policies could mitigate some of the negative effects in the sector?
- What happens to the tax or expenditure revenues related to the sector in different transition scenarios?

These studies use mostly sector-specific (bottom-up) models that describe the possible technological and behavioral changes in a sector in detail (see table A3.2 in appendix 3). The fiscal implications are based on these sectoral details, and they seem to be calculated with simpler spreadsheet assessments in many studies. None of these studies use general macroeconomic models, but the coal and oil sector studies of South Africa and Uganda have global sectoral models behind their fiscal assessments.

In addition, various transport-related studies have been carried out in Costa Rica, Slovenia, and the United States (table A3.2). In many developed countries the transport sector now brings in substantial fiscal revenue, which the expected electrification of the sector may reduce substantially. In most of these studies, different transport-specific tax changes, together with tax revenue implications, are included in the analyses. Yet, based on the views of various interviewed experts, it might not be optimal to search for additional tax revenue only from the transport sector. So, even if the transport (or fossil fuel) sectors would impose large fiscal impacts, larger economywide analyses of the ways to balance budgets would seem desirable in many cases.

4.1.4 Current Fiscal Impact Assessments of Climate Strategies

The fiscal impact assessments of complex and typically various types of policy options including medium- and long-term climate strategies seem to be a challenging task. Yet, there are only few relatively recent and interesting examples (table 2). These impact assessments aim to answer such questions as:

- What technological, behavioral and policy changes would be needed to reach the long-term climate target?
- What would be the general economic or social impacts of different scenarios consistent with the climate target?
- What general fiscal impacts, or detailed tax and expenditure impacts, do the different transition pathways have?

Table 2: Examples on impact assessments of medium or long-run climate strategies including fiscal impacts analyses

Country and study	Research team	Timeframe	Assessment tools used	Scenarios and policies covered
UK: Fiscal risks report (2021)	Office for Budget Responsibility (OBR) with estimates based on work of Climate Change Committee and Bank of England	2000–2051	• Assessments by tax and spending category with spreadsheet models. • Work based on long-term scenarios produced by the Climate Change Committee including economic costs and saving analyses, and by the Bank of England for the price of carbon necessary to achieve net-zero and its economic implications.	• Impact on public sector debt: illustrative reference scenario + eight alternative scenarios. • Illustrative scenarios to look at cost of public debt: Baseline + five alternative scenarios. • Different assumptions, such as net-zero pathway, tax changes, public sector spending on net-zero investments, and productivity growth.
UK: Net-zero Review (2021)	HM Treasury	2000–2051	• Assessments by tax and spending category with spreadsheet models. • Internal government estimates.	• Illustrative policy assumptions (such as carbon tax based on IMF recommendation) and analyses especially of possible tax revenue reductions and increases.
Spain: Impact assessment of the Spanish National Energy and Climate Plan (2020)	Basque Centre for Climate Change (BC3) with the Spanish Ministry for Ecological Transition (MITECO) (Large taskforce for the assessments)	2021–2030	• Sinergia-TIMES energy model • DENIO (dynamic neoclassical econometric input-output model) • Electricity sector model, ROM • Health impact model TM5-FASST • SEI -model for non-energy emissions	• Modelling the entire Energy and Climate Plan, including estimations on various policies and public investments needs.
The Netherlands: Evaluation of the Climate Agreement (2019)	CPB, Netherlands Bureau for Economic Policy Analysis, in cooperation with PBL (Netherlands Environmental Assessment Agency)	2021–2030	• MIMOSI: micro-simulation model for taxation, social security, wage costs and purchasing power. • Excel based estimations for projections of the size of the budgetary impact and the financial burden. • Worldscan CGE model for macroeconomic effects.	• 122 measures included in the Climate Agreement (covering various regulations, spending increases and tax changes).

Country and study	Research team	Timeframe	Assessment tools used	Scenarios and policies covered
EU: IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773- A. Clean Planet for all (European long-term strategic vision) (2018b)	European Commission (especially Joint Research Centre), Cambridge Econometrics	2015–2050	• 4 different energy models (such as POLES-JRC and PRIMES) • 3 agriculture and land use models • Model for non-CO2 gases and air pollution • 3 economic models (JRC-GEM-E3 (CGE model), QUEST (DSGE model), E3ME (macro-econometric model)	• 8 different scenarios on possible mitigation pathways. • Macroeconomic impacts analyzed for 2 main scenarios with different assumptions concerning the labor market, carbon pricing in the ETS and non-ETS sectors, behavior of firms in ETS sectors, and the use of carbon-based revenues. • Fiscal impacts not reported in detail.
Finland: Long-term development of total emissions, Development of emissions and sinks in the agricultural and LULUCF sectors until 2050, and Carbon neutral Finland 2035—Scenarios and impact assessment	VTT Technical Research Centre of Finland, Finnish Environment Institute SYKE, LUKE Natural Resources Institute Finland, Merit Economics	2010–2050	• TIMES-VTT model: energy production and energy systems, including production scenarios for harvested wood products • REMA model: energy consumption of the building stock • DREMFIA -agricultural model • MELA software: development of forest resources • FINAGE -CGE model for economic impacts	• 4 different scenarios on possible mitigation pathways until 2050. • Some climate policies modeled in addition to tax revenue recycling with lump sum payments.
Slovakia: A LOW-CARBON GROWTH STUDY FOR SLOVAKIA: implementing the EU 2030 climate and energy policy framework	World Bank in partnership with the Government of Slovakia and E3 Modelling	2015–2050	• Compact-PRIMES Energy model for Slovakia • ENVISAGE-Slovakia, Applied General Equilibrium Model (CGE)	• 4 different scenarios on possible mitigation pathways until 2050. • Some climate policies modeled including rising EU ETS price, energy efficiency regulations, and policies promoting renewables.

Note: See table A3.1 in appendix 3 for more information and detailed references on all the studies.

As the table shows, most these assessments are large multidisciplinary reports using various assessment tools to analyze the impacts and their cross-effects (the indirect impact from interactions between sectors or different policies affecting the same sectors). Many studies use similar energy and economic models, but sector-specific and microdata models seem common. In the most detailed fiscal assessments in the UK and Dutch reports, public balance implications are assessed for detailed tax and spending category levels (similar to the sector-specific fiscal impact assessments). In addition, in the UK reports (OBR 2021 and HM Treasury 2021) the fiscal assessments examine not only the public balance but also the impacts on borrowing and debt. Such detailed budget item analyses are often based on simpler spreadsheet models, but the estimations are based on the more general energy, sector, or economy-wide impact assessments done with other models. The long-term studies for the EU, Finland, and Slovakia analyze the possible public policy choices in less detail, providing mostly some illustrative examples on the policies and their impacts.

In addition to these published reports, there is ongoing and planned research to assess the fiscal impacts of climate transition. The Finance Ministry of Denmark is planning to use its new GreenREFORM modelling framework,[9] which combines sectoral models—such as intra yearly heat and power dispatch, transport model with vehicle vintages, waste management, agriculture, and LULUCF—with a dynamic CGE model to assess the potential fiscal implications of Danish climate strategies. The project is more innovative than the assessments mentioned above in several respects. For example, firms and household respond to new policies with foresight and sluggishness, including in discrete choice adaptation of abatement technologies. And the various sectoral models have a so-called hard-link to the CGE model. In many other studies, the different models are run separately and information between them is shared from one model to the other by the modelers, not automatically by the models (so the models include a so-called soft link). Box 2 below contains additional information on linking different models.

A Finnish research consortium—including ETLA Economic Research, Finnish Environment Institute (SYKE), and Demos Helsinki—has been commissioned to identify the key channels for climate change to affect Finland's public finances. It will also provide quantitative estimates of the magnitude of the public finance impact of climate change—and of policy measures to mitigate and adapt to it using previous scenario and impact assessments. Fiscal impacts are analyzed by combining the outcomes from three complementary economic models: the NIGEM medium-run global macroeconometric model, the GTAP multisector, multiregion, static general equilibrium model, and the national FOG, dynamic overlapping generations model well-suited to study the sustainability of public finances.

The European Commission, DG ENER, has also commissioned a study on the Macroeconomics of Energy, part of which addresses the fiscal implications for EU countries of the energy transition. The research is being carried out by a consortium of E3 Modelling, Cambridge Economics, and TRINOMICS. It uses the PRIMES energy system model and two economic models: the GEM-E3 CGE model and the E3ME, global macro-econometric model. The study is partially based on new data collected on current energy taxes.

While the OBR (2021) study on fiscal risks and HM Treasury Net-zero Review (2021) seem already detailed on their fiscal impact assessments for the long term, the HM Treasury (2021) reports plans to develop the economic and fiscal impact assessments further. The report specifies that "net-zero is expected to lead to significant structural changes to the UK economy. Understanding the nature and scale of these changes and the potential impact of policy choices will be vital as government manages the transition to net-zero. Macroeconomic modelling tools can help to weigh the complex interactions between the economic channels and gauge the implications for the structure of the economy and to estimate the scale of their macroeconomic impacts. Models developed to look at net-zero would need to be able to represent:

demand dynamics, structural changes, and the open economy. The transition to net-zero may result in large changes to the economy through various channels, and HMT is interested in understanding this transition from different angles, such as the fiscal consequences of economic change. Different models will be better suited to answering the different questions" (p. 120).

The European Commission is also developing an approach to take into account climate change and climate transition related risks in the standard EU Debt Sustainability Analysis framework. Their first considerations on the topic are included in the EC Debt Sustainability Monitor 2019 report (2020b), but the work is still ongoing.

The practical organizations of the studies listed in table 1, the scenarios included in them, and some of their lessons are discussed in more detail below.

4.2 Available Assessment Tools for Analyses

The main questions we now aim to briefly answer are:

- Why have the existing studies used so many different modelling tools?
- What are these tools able to model and what are their respective strengths and weaknesses?

However, a detailed assessment of all modelling tool categories and individual models is beyond the scope of this report. The focus here is on the assessment of fiscal implications. As the statistician George Box wrote: "All models are wrong, but some are useful" (Box and Draper 1987). Or as many of the interviewed experts said in one way or another: "It is impossible to model everything using one model and then explain what drives the results."

All models are simplifications of the world. The ones for longer-term projections are typically coherent, numerical frameworks that help assess possible future scenarios and the varying impacts associated with each. Long-term model scenarios typically do not provide forecasts on what is likely to happen, but different scenarios on how the world could developed under different assumptions to inform policy making and risk management.

So, in addition to choosing what models to use to inform policy making, policy makers and researchers need to consider how to use the models—what general research methods to use. For example, Marchau et al. (2019) describe in detail some of the general methods recommended for policy making under *deep uncertainty*. These, together with a short summary on the practical arrangements of the impact assessments done until now, are explained in more detail below.

Most models are built for a specific purpose, and all types of models and also individual models have their strengths and limitations. The strengths are typically associated with the original main purpose (such as modelling the energy or transport system in detail), while outside the main field more simplistic assumptions about the world are often made. In many cases, the models solely concentrate on modelling a specific area of society, such as a specific sector, in detail. But large general equilibrium or macroeconomic models, whose main purpose is to model the entire economic system, often lack detail on sector-specific assessments (such as the transport system) unless they have been extended to model that as well.

As can be seen from the previous descriptions on some of the current assessments on long-term climate strategies, there are various types of assessments tools, methodologies and models that can be used to assess the fiscal implications of long-term climate strategies. Table A2.1 in appendix 2 gives a brief overview on few main model categories that have been used or could be used in the assessments, together with some of their common strengths and weakness for long-term fiscal impact analyses. The list of model categories, and their strength and weaknesses, is not inclusive and provides only basic information on them all. The strengths and weaknesses do not apply to all individual models within the category due to the large heterogeneity of models in even the same model category. In short, the table provides information on the following main model categories:

- Economic models: computable general equilibrium (CGE) models, macro-econometric models, dynamic stochastic general equilibrium (DSGE) models, input-output models, agent-based models, overlapping generations models, microsimulation models, spreadsheet models, and stock-flow consistent (SFC) models.
- Climate and energy models: bottom-up technological energy models and integrated assessment models (IAM).
- Sectoral models, such as global oil, coal, or national transport sector models.

What makes the choice of tools even more difficult is that *within each category there are different types of models. There may be different versions even of an individual model* (most models can be modified at least to some extent for the estimation task at hand). Therefore, it is common to adjust the choice of tools based on the research questions and on the availability of data and different types of tools. This mainly explains the use of multiple different models in the current assessments. While no model can cover all aspects, different models can provide details on some parts of the puzzle.

For example, many climate and energy models, sectoral models, microsimulation models and spreadsheet calculations cannot account for indirect impacts through the value chains or for general equilibrium effects unless they are extended or linked to other models. With indirect impacts, there is, say, a notable change in one sector that produces change in the other parts of the economy through sectoral linkages. General equilibrium effects account in addition for impacts on, say, labor incomes or investment needs and for the subsequent effects on different sectors. Most large changes in the economy are likely to have both indirect and general equilibrium effects on the economy also affecting the public sector (box 1). For example, a decline of a single large sector in an economy, such as coal or oil production, may affect the total demand for supporting services, intermediate goods and the (employees') consumption of different goods and services. Therefore, GDP and tax revenues can decline more than what would be expected based only on analyzing the oil or coal sector alone. But energy system and sector specific tools can be vital for analyzing tax or expenditure changes that depend on detailed sector specific structures and changes, such as taxes based on kilometers driven or number of a specific type of vehicles.

Box 1: Different Scopes of Economic Impacts

Economic impacts of policies or changes, as in demand or supply, are often described in various states or scopes.

First, the policies or changes have direct impacts. This refers, for example, to the additional cost from a carbon tax paid by the producer to the government. If the producer adds the whole carbon tax to the price of the product, the price increase for the consumers caused by the tax is also a direct impact (an income effect that lowers the real income of the consumer). If the consumer demand for the product decreases due to the higher price, this is typically also counted as a direct impact of the policy.

Second, direct impacts lead over time to indirect impacts. Indirect impacts refer typically to impacts occurring through the value chains to other sectors (or regions or firms) as a result of the direct impact in some sectors. In the example provided, indirect impact can include lower demand for the intermediate inputs required to produce the (taxed) carbon-intensive product and layoffs of employees by firms producing the carbon-intensive product.

Third, when there are profound changes in the economy, the direct and indirect impacts may generate general equilibrium effects in the long run. These impacts take into account how the direct and indirect impacts will affect such things as prices, supply, consumption demand or wages in the whole economy and how the economy might balance the total demand and supply in the markets over (long) time. General equilibrium effects are sometimes also called "induced effects." They account for such things as substitution effects in the purchase of intermediate inputs due to price changes and for possible ripple-down impacts in the economy. If, say, many employees are laid off due to the carbon-intensive sectors going down and the sector, together with their networks (downstream and upstream links to other sectors) are relatively large, this can affect total consumption and wage levels in the economy. Over time, the laid-off employees will find new jobs in other sectors or exit the labor market.

In comparison, the wider economic models, such as CGE, macro econometric, DSGE and SFC models, can often cover both direct, indirect, and general equilibrium impacts[10] of policies and changes. They can model also behavioral changes and substitution effects from the use of one production factor to another within sectors. Importantly, they cover often various tax instruments, and tax changes can interact each other. Yet, for example regulations and standards can be more difficult to model with these wide economic models compared, for instance, to energy system or sectoral models since the economic models have less sectoral or technological specifications.

For example, Timilsina et al. (2021) show in an analysis of China's NDC targets that model results on the required carbon tax level (and government revenue changes) are over 300 percent bigger when only a CGE model is used compared to results based on both a bottom-up energy system model (TIMES) with a soft link to the same CGE model. They report that other studies of China and other countries have found similar findings on the differences in results made with top-down models only or with linked model setups. The large difference in the required carbon tax results mostly from the inclusion of energy efficiency regulations in the energy system model. The CGE model cannot take their impact into account and therefore overestimates the required carbon tax level. Energy efficiency regulation-based reduction in emissions are included in the energy-system model and therefore the required additional carbon reductions to be achieved with a carbon tax is lower in the linked model setup.

Models that combine energy/technology details to an economic model are one way of tackling some of these problems. Examples of such models include the ENV-Linkages CGE model of OECD, E-QUEST DSGE model of the European Commission, G-CUBED macromodel of Warwick McKibbin, IMF-ENV CGE model of IMF and CPAT spreadsheet model of IMF-WB. Similarly, the Danish GreenREFORM model combines an energy module to a CGE model, and the energy module can also be used on its own without the CGE model. But some interviewees mentioned that the calibration of the models, particularly DSGE models, becomes difficult when you add environmental aspects to it.[11] Many interviewees found that assessments combining multiple models are typically needed (box 2).

Box 2: Linking Different Models in the Analyses

In many cases, it can be better to model specific impacts or sectors with a separate model, and replace the endogenous model responses in the macroeconomic models with these sector-specific model results (subsection 4.1). The reason is simply that the underlying processes can be modeled in a more detailed way in the technology and sectoral models. But how to do the model linking if multiple different models are needed for the analyses?

There are two main ways to link different models to each other: with a soft-link or a hard-link.

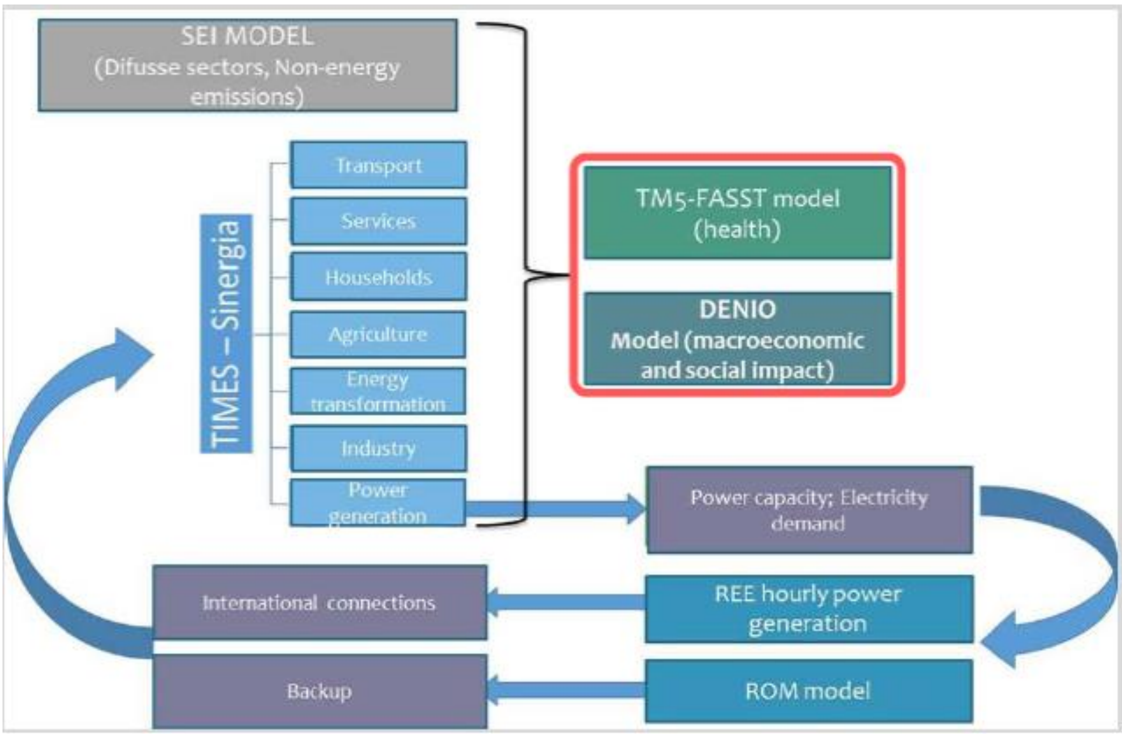
Soft-link: an iterative process where the modelers or models transfer some model results from one model to another. With soft-linking the first model is solved before the results are transferred to the next model. This can be done only once, in which case it is called one-way linking. Another option is to do this in an iterative process multiple times until convergence within central parameters is achieved. For example, box 2 figure 1 presents the flow of model runs and results transfers between the various models used in Spain's National Energy and Climate Plan impact assessment. Most of the links are one-way soft-links between the models, but between the TIMES energy model and REE and ROM models there is another round of result transfers.

Hard-link: two or multiple models are fully integrated and solved in a simultaneous optimization run. For example, the Danish GreenREFORM includes a modular structure with a hard-link between the different sector modules and the general CGE model. Hard-linking includes integrated energy-economy models (some individual models mentioned earlier in the text) and integrated assessment models (IAMs). In some of these integrated models either the energy or economy is modeled in a simplified form, but with large heterogeneity between the solutions.

Delzeit et al. (2020) and Krook-Riekkola et al. (2017) provide additional information on the linking procedures and their differences in energy-economy modelling.

The views of the interviewed modelers differ on model linking. Some find that a hard-link between energy and economy models provides more robustness to the results and behavioral aspects can be covered wider. Others view hard-linking as complex and resulting in models that are not user-friendly. Soft-linking seems to be popular, but some prefer to not to link models at all. Also, in soft-linking the calibration of models (in particular with an iterative process) can be difficult and take time. In other words, there are pros and cons for all options, and no general optimal solution is available.

Box 2 Figure 1: Models used and links between them in the Spanish National Energy and Climate Plan impact assessment (2020)



In addition to deciding how to analyze the possible cost-effective emission reduction pathways, an important consideration concerns the regional coverage of the models. For example Weitzel et al. (2019) characterize this in the following way: “global model results can help narrow down the scenario space for national analyses, but local situation needs to be always taken into consideration… because climate change is a problem on a planetary scale, bottom-up feedback—from the national to global level—should be given careful consideration, too.” For example, in Canada, a multisector, multiregion CGE model has been developed to assist in provincial analyses of mitigation policies impacts (Böhringer et al. 2015).

Similarly, the sectoral coverage of the models varies. Typically, DSGE, SFC, and macroeconometric models have fewer sectors modeled than CGE models do. This can complicate the introduction of detailed policy changes (such as a new tax affecting a few detailed sectors) in these models.

In addition, the long-term impact assessments frequently require often broad analyses of different sectors before the net fiscal implications off the possible pathways can be derived. For example, it may be important to analyze economic, social, health, environmental, financial, and political impacts to derive the full fiscal impacts. For instance, health improvements due to reduced local air pollution have been found to be important possible co-benefits from transport sector mitigation policies with potentially large fiscal implications. To analyze them, modelling or assumptions would need to be made concerning how much the local air quality improves in the scenarios and how this affects public health and therefore health expenditure. The possible public spending requirements related to a just transition and distributional considerations are typically important. Often, these impacts need to be modeled using microsimulation models instead of general macroeconomic models. A number of interviewees stressed that political impacts and acceptability of changes and policy measures is challenging, but crucial, to analyze. For example, IMF (2019) propose that to enhance the acceptability of required carbon pricing, broad strategies are needed that include how carbon revenues will be used, assistance to vulnerable households and firms, gradual price reforms, stakeholder consultation, and public communications.

It is also important to consider potential financial implications, given that in many countries the transition and mitigation policies will require massive increases in investment. SFC models have a common strength to assess this aspect as they endogenize the role of finance and its complexity and connect it to economic decisions. So, potential financial opportunities, constraints, or financial risk amplification effects in the context of climate risks and policies can be analyzed. This is of relevance when assessing climate financial risks and climate policy impacts in the light of the finance-economy-climate feedback (double materiality) (Gourdel et al. 2021), the role of investors climate sentiments for a smooth low-carbon transition (Dunz et al. 2021a), private debt dynamics (Bovari et al. 2018), the compounding COVID-19 and natural hazard shocks (Dunz et al. 2021b), or the effectiveness of green fiscal, monetary, and macroprudential policies (Monasterolo and Raberto 2018, 2019, Dafermos et al. 2017, 2018, Dafermos and Nikolaidi 2021, Ponta et al. 2018).

It is also important to consider the timing of the impacts. Change is often non-linear, even with fairly rapid changes in technology use and behavior (section 2). A number of interviewees advised that the transition be analyzed dynamically, as it is important to scope and analyze the timing of the impacts. Many CGE models are used for longer term policy and structural economic evaluations. Various behavioral and substitution parameters can be adjusted in them for long-term analyses, and their common assumption on market balancing is better suited to the long-term than for short- to medium-term analyses. Many CGE models compare the current situation to individual future years statically, but dynamic recursive models analyzing long-term adjustment paths are also common. The Danish GreenREFORM model is even a forward-looking dynamic CGE-model. Macro econometric models and DSGE are typically better for short to medium-term assessments. They can also be used to analyze economic cycles and fluctuations. While some of them can be used for long-term assessments, in many cases the calibration of the behavioral functions to historic data limits the possibilities to analyze larger behavioral changes in the long run. For these reasons some research teams have used both long-term CGE modelling and macroeconometric models in their assessments.

Transparency and ease of explaining the model results is crucial for good policy making. The different models and model categories also vary in this respect. First, detailed reports on the structures of the models are available for many individual models. Yet, the actual code of the models or detailed databases are mostly not public due to privacy and copyright issues. But some examples of open-source codes are found. For example, the code for the Danish GreenREFORM model is planned to be published and publicly available. In New Zealand, the Climate Commission provides public versions of their C-PLAN CGE model, DIM-E microsimulation model and ENZ, energy and emissions, model.[12] Many models can be also obtained by buying a license (such as the global GTAP CGE model), which improves transparency.

Second, when it comes to the ease of explaining the results and their drivers, the simpler spreadsheet models can be easier to explain than complex CGE, DSGE, or combined energy-economy models. Yet, the restrictions of the models need to be also taken in account in communications and in policy advice. In this respect, simple models can leave more open questions related to how the results might possibly change if, for instance, additional drivers or limitations could be accounted for. With complex models, it can be difficult to explain what factors drive the results the most and how. For example, different assumptions on elasticities, behavioral changes, or external factors (the so-called exogenous factors that the model takes as given) might change the results.

Therefore, sensitivity runs on the key parameters of the models are also important. Barron et al. (2018) and Böhringer et al. (2021) provide comparisons of results from similar climate policy scenarios done with different models. In both articles significant differences are found due to model specifications, while some results are roughly consistent especially in model runs for short- and medium term. Barron et al. (2018) conclude that, in model runs beyond 2030, the uncertainties are too large to make quantitative results useful for near-term policy design. Such multiple models comparing exercises can be also important to determine whether some effects stem from policy changes or from model specifications. In addition to model specifications and parameter choices, various assumptions by the modelers (related, say, to general population growth rates or to interest rate levels) can affect the results significantly.

One of the key limitations and challenges mentioned by most modelling experts is the lack of good and reliable data, even though globally significant efforts have already been made to develop large databases and update them regularly. There is more discussion on the topic in the next section.

4.3 Practical Considerations Related to Impact Assessments

Before selecting the best modelling tools to use, researchers and governments need to consider the general research framework, meaning what to model and how. Similarly, ministries interested in the potential fiscal implications of long-term climate policies and transition need to consider how to implement the study in practice. Who will do the research and modelling work? How would the ministry be involved in it? How to include stakeholders in the process, and how to communicate the results? Here we look at some of the current approaches and ideas concerning these topics.

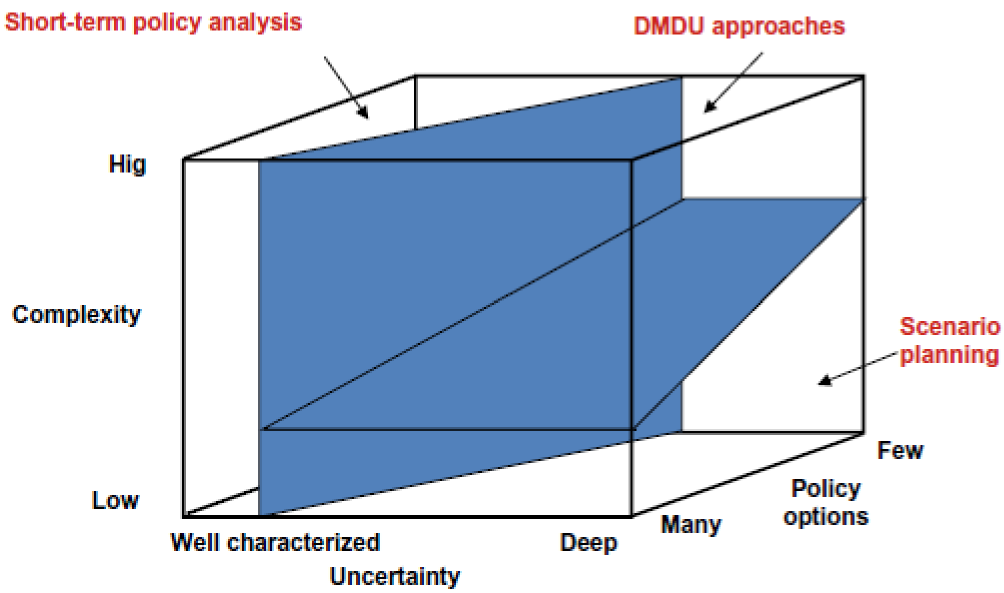
4.3.1 What to Model and How?

Long-term assessments are always mere scenarios of uncertain future developments. Therefore, decisions need to be made on the selection of scenarios to be analyzed and the baseline to compare them to. On the one hand, most of the current assessment studies on long-term climate strategies and possible policy options include multiple different scenarios (see table 1 and tables A3.1 and A3.2 in the appendix 3). For example, the Decision Making Under Deep Uncertainty (DMDU) approaches, such as Robust Decision-Making method (see below), can cover even thousands of different scenarios in a systematic way (see Marchau, 2019; Groves et al. 2020; Benavides et al, 2021, Quirós-Tortos et al. 2021). In contrast, the medium-term analyses done in Spain and the Netherlands on the detailed national climate and energy plans concentrate on analyzing the policies covered in the plans, without multiple scenario comparisons.

In general, a variety of scenarios can provide a more complete view on plausible long-term pathways and the differences and trade-offs between them. But conducting larger scenario analyses typically requires significantly more resources, and it can complicate the communication of the results. Marchau et al.

(2019) describe different approaches for (policy) decision making (figure 7). They consider that the benefits of the most resource intensive DMDU approaches would outweigh the costs only if: the uncertainties are deep rather than well characterized, the selection of possible policies is wide compared to narrow, and when the system complexity is high. The system complexity refers to how well experts know or disagree on the proper models, probabilities, and system outcomes. While the DMDU approaches refer to the actual selection of actions and policies, they can also provide ideas for fiscal impact assessments under deep uncertainty (and naturally for the selection and adjustment of long-term policies if they have not yet been well described).

Figure 7: Selection of policy assessment approach



Source: Marchau et al. 2019.

Marchau et al. (2019) present five different DMDU approaches (such Dynamic Adaptive Planning, Dynamic Adaptive Policy Pathways, Info-Gap Decision Theory, and Engineering Options Analysis), but only Robust Decision Making (RDM) has been used until now in the field of climate policy planning. RDM also provides good frameworks for scenario-based impact analyses. Rather than using computer models and data as predictive tools, in the RDM approach models are run myriad times to test decisions against a wide range of plausible futures.

Molina-Perez (2016) used RDM to analyze the conditions for the Green Climate Fund's investments and climate policy to enable the international diffusion of sustainable energy technologies and meet the objectives of the Paris Accord. An integrated assessment model was used to estimate the global outcome indicators, including end-of-century temperatures, GHG emissions, and economic costs of the policies—and to evaluate seven alternative policies across a diverse set of future pathways.

The Inter-American Development Bank (Groves et al. 2020, Benavides et al. 2021, Quirós-Tortos et al. 2021) also provides useful examples on how to deal with the large uncertainties related to possible future developments in their cost-benefit analyses of the long-term climate strategies of Costa Rica, Chile and Peru. They use RDM and repeat the emission and benefit and cost calculations, based on simple assessment frameworks. For example, in the Costa Rican study, they analyze 3,003 plausible futures, reflecting different assumptions over 300 uncertainties. Key uncertainties covered in that study reflect in general underlying socioeconomic and technological conditions that drive emissions (driver uncertainties) and factors affecting the effectiveness of decarbonization actions (decarbonization uncertainties) (table 3).

Table 3: Key uncertainties in the cost-benefit assessment of Costa Rica's National Development Plan

Sector	Driver Uncertainties	Decarbonization Uncertainties
All	• Economic growth rate	
Transport	• Demand for transport (linked to economic growth) • Cost of fuels • Infrastructure costs for electrification, fuel changes, and modal changes • Technological costs • Elasticities of demand for different modes of transport • New technology adoption rates	• Growth of electric and hydrogen public transport • Growth of electric private and freight transport • Growth of hydrogen heavy freight • Growth of share of non-motorized transport and public transport use
Electricity	• Cost of new renewables	• Development of new renewables to meet increasing demand
Buildings	• Population • Household occupancy rates • Commercial economic activity	• Household energy use • Percentage of household electrification • Energy use per amount of economic activity • Percentage of commercial electrification
Industry	• Cement and other industrial production • Decarbonization rates of cement and other industrial products • Industrial value added	• Decarbonization rates of cement and other industrial products (both a driver and decarbonization uncertainty) • Energy demand per value • Efficiency of non-electrical energy use • Increase in electrification of industrial activity
Waste	• Population • Industrial activity • Waste per capita and value of industrial production	• Share of waste that is recycled and composted • Percentage of sewage treated • Methane captured in landfills
Agriculture, livestock, and forestry	• Agriculture and livestock value added • Change in area used for cultivation and grazing	• Energy efficiency in agriculture and livestock • Amount of electrification of agriculture and livestock activities • Change in carbon intensity of agricultural production • Change in carbon emissions from animals and manure • Deforestation rates • Change in carbon sequestration by wet, moist, dry, palm, and mangrove forests

Source: Groves et al. 2020.

Scenarios are often developed in deliberative processes with stakeholders. Exploratory modelling techniques can map a wide range of assumptions to their consequences without privileging one set of assumptions over another. They are useful when no single model can be validated because of missing data, inadequate or competing theories, or an irreducibly uncertain future. As soon as some scenarios and uncertainties have been developed, statistical Scenario Discovery (SD) algorithms can help to identify and display the key factors that best distinguish the different futures (Marchau et al. 2019).

The research community has developed some readily available scenarios on possible global emission mitigation pathways with internally consistent story lines. These Shared Socioeconomic Pathways (SSPs) can assist countries in obtaining views on possible global developments. The quantitative projections for each SSP are publicly available.[13] In addition, the Network for Greening the Financial System has developed six global scenarios to assist central banks and financial supervisors to analyze both physical and transition risks related to climate change. Data on the scenarios they have generated are also publicly available.[14] For example, NGFS (2020) notes that the transition can be assumed to occur either with coordinated policy, investment in new technologies and gradual capital replacement, or in a disorderly way with late, sudden, and unanticipated changes in policy, the economy and financial system. While the global scenarios can provide ideas and good examples, countries need to consider what scenarios are most useful for their situation. For the analyses of fiscal impacts, a particular emphasis is required on different policy options and the associated fiscal impacts.

Grubb et al. (2021) and Geels et al. (2021) advocate also for risk-opportunity assessments (ROA) instead of traditional cost-benefit analyses in policy selection. Grubb et al. (2021) stress that “many of the most important benefit of a low carbon transition—like the creation and development of new technologies, supply chains, business models, jobs, and new markets—are not knowable with confidence. Omitting these elements from the calculation creates a bias toward inaction.” In addition, traditional cost-benefit analyses often overlook the effects of policies on processes of change[15] in the economy and concentrate on quantifying both the costs and benefits, while the latter can be hard to monetize. Therefore, instead of assessing merely the most likely or average impacts with cost-benefit analysis, ROA aims to map both risks and opportunities in a wider range, looking at all impacts over the distributions even if they cannot always be quantified. In ROA, analysts will also consider processes of change in the economy and aim to provide different metrics on the risks and opportunities. In practice, Grubb et al. (2021) propose that the risk-opportunity assessments can be divided to the steps presented in figure 8. More details on each of them and on ROAs in general can be obtained from Grubb et al. (2021) and Geels et al. (2021).

Figure 8: Steps in risk-opportunity assessments

Figure 11: Steps of the risk–opportunity analysis framework

Source: Grubb et al. 2021.

4.3.2 Research Teams, Stakeholders, and Communications

Most of the impact assessments on long-term climate strategies (see references in subsections 4.1.1 and 4.1.4), are the result of a considerable multidisciplinary effort. The research teams often include experts from different fields, such as engineers, climate scientists, a wide range of economists, and forest, agricultural, and environmental experts. As one of the interviewees pointed out, multidisciplinary skills are typically needed since "economists often don't know much about carbon." On the other hand, especially assessments on possible policy measures, such as the references in subsection 4.1.2, have been also conducted by smaller research teams consisting mostly of economists.

In many studies civil servants from different ministries have participated in the studies in one way or another. Ministries often steer the impact assessments or provide valuable information and data for the researchers. In the UK, HM Treasury conducted some calculations on potential revenue losses and gains for the HM Treasury Net-zero report (2021), but their calculations relied heavily on the multidisciplinary assessments done earlier for that report. In Denmark, the GreenREFORM model is now being developed to function as a shared tool for analysis between the Ministry of Finance and other government institutions. Researchers at the Danish Research Institute for Economic Analysis and Modelling (DREAM)[16] and the University of Copenhagen, who are developing the model, will eventually make the model publicly available. In addition, the federal government of Canada has a long history on maintaining different models and modelling expertise in-house. This has allowed the federal government to conduct model-based policy assessments internally. Their modelling capacities cover both larger macroeconomic models and micromodels for distributional analyses.

The NGFS (2021) reports that central banks and financial supervisory boards have spent anywhere from one to more than 30 FTEs (full-time equivalents per year) on their climate related financial risk assessments covering both physical and transition risks (often based on the joined 6 global scenarios developed by the NGFS), with most dedicating between one and ten FTEs to the assessments.

In many cases, the practical modelling efforts have been done by researchers and consultants. Various countries have indicated in the HP1 survey related to LTSs and in the interviews that they lack the resources and tools to conduct required economic or fiscal impact assessments related to long-term climate strategies.

Broad stakeholder consultations were part of the Dutch and Finnish impact assessments. Stakeholder processes engaging with academics and experts from different fields, private sector and civil society representatives or sub-national and city level policy makers have been used to determine the variety of scenarios or policy packages to analyze. In many cases, external expertise on particular issues is also required as it is impossible to have all required knowledge within research teams or ministries. Weitzel et al. (2019) suggest that stakeholder process could also "create a vision and sense of direction, to combine different views into an integrated perspective for sustainable development, to trigger a debate on the corresponding long-term planning, and to inspire as well as enable stakeholders." Yet, the practical management of such large stakeholder processes consumes time and resources. So, it is important to conduct them efficiently and to ensure clear ownership.

In scenario analysis and modelling, it is not just the details of the model(s) that matter. One also has to understand well the logic and limitations of the results to communicate them efficiently and clearly, so that the general public can understand them. Many interviewees highlighted the fact that communicating model results and the logic behind them is almost equally important as the modelling details (what model was used and how). Familiarity with the modelling tools assists in understanding their logic, for example how different assumptions may affect the results. Almost all interviewed modelling experts recommend having people with in-depth expertise on the methods and modelling tools within the ministries. These skills should not be limited to a few persons but should be maintained at organizational level with a long-term focus. Many also mentioned that it is hard to even steer external research work on long-term impact assessments if the person in the ministry overseeing the research work is not a modelling expert. In-depth expertise and clear communication strategies are also a crucial part for successful policy making and fiscal risk preparation.

5. Opportunities to Enhance the Assessment of Fiscal Impacts

While there are a range of tools to use, some examples on how to apply them in practice and lot of ongoing development work in various organizations, it seems that in many cases the interviewed experts had more open questions than answers concerning them. Here we summarize some of the key challenges and opportunities for improvement. The main areas relate to data, modelling challenges in general (common for all models), scenario selection and baselines, transparency and communication of modelling results, and capacities in ministries and research organizations.

5.1 Data

Databases required for modelling have been developed for decades and in many cases good data are already available. For example, the large economic models often use social accounting matrixes (SAMs), which extend input-output information to represent the flows of all economic transactions, and many statistics offices provide national SAMs. In addition, vast global databases covering multiple countries' SAMs or input-output data can be obtained from different organizations. For example, countries can buy the Global Trade Analysis Project (GTAP)[17] database, covering 121 countries' SAMs together with trade and energy data compiled in a consistent way, or Eora multiregion input-output tables covering 190 countries.[18] World Input-Output Data (WIOD)[19] provides input-output structures for 43 countries for free, and EXIOBASE[20] provides multiregional environmentally extended supply-use tables and input-output tables for 44 countries. On the technological side, the International Energy Agency has hosted IEA-ETSAP[21] (Energy Technology Systems Analysis Program) international community for decades to collect and maintain technology data.

But the availability of and access to data are often mentioned as a key issue. One problem relates to long-time time lags in data updates. For example, in many available global economic databases, the latest versions of important social accounting matrixes date to 2014. As a result, the economic models assume all economic structures and value chains to be represented by the situation in 2014, unless the modelers update the data from other data sources. In reality, economic structures change constantly. Also important are technology catalogues representing relative prices and costs between different technologies and fuels and their future projections. If they have time lags of 5–10 years, analyses of, say, uniform carbon taxes are not sufficiently informative. Technologies and their costs are progressing rapidly at the moment, and obtaining up-to-date data is difficult.

Data coverage is another concern. In many models the representation of the government is at rather aggregate level and more detailed representation would be needed for good fiscal impact analyses. In other words, tax and expenditure instruments are often covered only at relatively aggregated levels, while even hundreds of different budget items would need to be analyzed. So, many interviewees recommended starting with gathering detailed data on current fiscal instruments before modelling fiscal implications. Many economic models also cover only monetary values, but have no or only limited information on physical inputs, such as numbers of commodities used or vehicles in stock. In addition, countries with big informal sectors face the problem that major parts of their economies are not covered in any databases. Finally, energy data are also often incomplete, and even IAE data do not include energy data for all countries.

Comparability between different data sources and uncertainties in the data are an additional challenge. First, researchers often need data from many sources. To build consistent datasets, researchers need to be aware of the constraints and compatibility of the varying sources. In many cases, the data users are not experts in all the fields from which they need data, creating possibilities for the misuse or misinterpretation of data. Second, even with excellent energy experts and the most up-to-date data in use, uncertainties remain about technologies and their costs for long-term projections. For economic models, it may also be difficult to build up data for new, emerging industries. Potential numerical changes to parameters on behavioral choices, substitutions, or technological developments are similarly difficult judgment calls. Estimates of tax passthroughs are also often rough and uncertain.

5.2 Modelling Tools

In addition to model category and model specific restrictions, there are many common challenges and constrains related to analyzing the potential fiscal implications of long-term climate strategies. Six wider topics are highlighted in the interview answers and in the existing literature:

1. Analyses of technology changes.
2. Analyzing changes in people's preferences and disruptive structural changes in the markets.
3. Modelling climate policies.
4. Analyzing innovation activities and their potential impacts.
5. Limitations in assessment method coverage on important areas, such as political impacts, natural resource use, biodiversity, energy security, or financial implications.
6. Models with discrete changes and without smooth transition pathways would be needed.

First, forecasting cost curves, relative prices, and penetration rates of different technologies is uncertain. Yet, most energy and technology models require these data and modelling results to determine cost-effective emission-reduction options and the size of emission reduction potentials from technology switches. For example, many energy and IAM models suggest that carbon capture technologies are required, but the future costs and capture potentials of CCS, BECCS, or DAC are uncertain. In addition, fossil fuel price trends and the price of different renewable energies are difficult to forecast even for next few years. Substitution potentials and the speed of substitution from current high emission products to new alternatives is also difficult to judge. For example, the rate of substitution from fossil-based plastic products to new low-emission plastic or biodegradable alternatives is hard to analyze, while some of these new products are already emerging on the markets.

Second, changes in people's preferences and disruptive structural changes in the markets are extremely difficult areas to analyze. The use of fossil fuels and emission-intensive technologies, goods, and services need to go down, but what sectors, goods, and services might develop instead? In some cases, weak signals[22] can provide hints on what might be expected, but it is often useful to prepare for significantly varying scenarios of transition. For example, what if people change their preferences for food and vegan diets? Or if laboratory grown proteins, produced locally, replace meat production in large scale? Or if automatic vehicles can dramatically decrease the need for private cars and significantly reduce the vehicle stocks and need for truck and taxi drivers.

It is possible to change preference parameters, as in CGE models, but the values for new parameters need to come from some other source. CGE models cannot tell what the new parameter value could or should be. Energy, technology, and sectoral models might be capable of providing some inputs for such scenarios, but technological projections and forecasts based on historic data are uncertain and often cover only a small set of possible future pathways. In many cases models are rather deterministic (in other words they generate the same end results based on the starting point), so uncertain structural changes are difficult to model. Modelers can also impose or determine larger changes to modelling results themselves. Qualitative analyses by (sectoral) experts are one option to analyze potential major changes in behavior, preferences, or markets. But this option also has limitations. Most interviewees stressed that these are difficult areas to cover in the current modelling frameworks. SFC models could provide a complementary perspective as they embed heterogeneity, heuristics, and behavioral patterns that contribute to emerging phenomena and out-of-equilibrium states of the economy. But more research is required.

Zenghelis (2017) describes the problem field thus: "Static optimization models simply presuppose the things we want to know and invariably miss the dynamics of technological revolutions and social feedbacks, as well as the role of new networks, changing expectations, and social norms in driving these changes. The further out the forecast, the larger the uncertainties and the chance that structural breaks push the economy onto new paths driven by new technologies, institutions and behaviors. This makes model projections at best illustrative, especially when trying to forecast the impact of nonmarginal impulses such as climate change impacts or the transformation of the global energy system."

Even where visible changes are already emerging, modelling can be difficult. For example, modelling of circular economy businesses and new circular sectors has gained attention. Yet, Laubinger et al. (2020) conclude that "most circular economy model scenarios are rather stylized and mostly revolve around raw materials. Only a few studies have intended to model the effects of newly emerging circular business models (e.g. product-service-systems) or the effect of 'soft' policies (e.g. labelling or awareness campaigns)…it is challenging to find sufficient information to make robust assumptions on the future developments of new business models or socio-technical trends such as digitalization and automation. Furthermore, analyses of skills shifts and future skills demands in a more circular economy are still scarce." Many interviewees proposed that more multidisciplinary research would be needed to improve the modelling of potential behavioral or structural changes.

Third, there are often challenges with modelling climate policies in the long term, while fiscal impacts depend heavily on the detailed policies. In many cases, the policy options are not known in detail, and researchers need to make their own assumptions on what policy packages might be or should be introduced. Considerations of the required policies can demand extensive multidisciplinary efforts. Typically, long-term climate strategies include a wide mix of different policy measures, and researchers might also need to bundle them in some way to model them. In addition, many economic models are not able to readily model the impacts of regulations or standards. Energy and technology models are often able to cover standards and regulations, but to estimate the general economic effects, these results need to be linked to economic models. Analysis of many overlapping policies in the same sector can be similarly demanding. Further, policies could also affect people's preferences and the introduction and usage of new technologies, but these types of mechanisms are hard to introduce to any model. For example, Ekins and Zenghelis (2021) note that "models also miss the importance of early public intervention to tilt the economy onto a new, more productive, path. They understate the degree to which leadership matters."

In addition, barriers to the introduction and usage of new technologies need to be understood in greater detail. Seetharaman et al. (2019) find several economic, institutional, technical, regulatory, and sociocultural barriers to hinder countries from moving from the high to the low emission pathway. And political factors and general resistance to change can create barriers to use of new low-carbon innovations. Similarly, financial barriers can impede scaling up of low-carbon investments, particularly in emerging and developing countries (Battiston et al, 2021). Thus, detailed sectoral, financial and policy information may be needed to analyze the potential long-term pathways and the changes required to reach them.

Fourth, given the limitations to forecast the uptake of potential new technologies or winning sectors of the climate transition, support for research, development, and demonstration activities is needed. Some interviewees mentioned that the impacts of different mitigation policies on innovation activities cannot typically be covered well in modelling. Despite ongoing academic work on the topic, it is still unclear to what extent such things as R&D subsidies or carbon pricing boost innovations in model setups, though it is possible to include increased R&D spending and carbon pricing in the models. It is similarly difficult to analyze, even in the short run, how mitigation measures or new innovations might affect firms' or countries' global competitiveness.

Agarwala et al. (2021) note that countries delaying investment and transition could miss out on first-mover advantages, learning by doing, and global competitiveness. They also stress understanding the processes that drive innovations and the policies supporting them to lower transition risks. CCC (2019, box 7.2) emphasizes that the dynamics of innovation are wide ranging. Innovations create new supply chains and business lobbies, which push for more policies to support the new technologies. Falling costs and increasing expectations again boost investments and additional innovations. As a result, innovation occurs often far faster than typically assumed. Better consideration and modelling would be needed on the processes driving and steering innovations and their adoption, including strategic complementarities, network effects, expectations, and roles of different actors. Potential crowding-out and crowding-in effects of investments could be beneficial to analyze as well (Drummond et al. 2021).

Fifth, political impact, natural resource use, biodiversity impacts, energy security, and financial implications, have been difficult to analyze with current methods or there has been less focus on them. Political economy constraints are mentioned as a particularly important aspect that needs to be better considered. While carbon pricing has been concluded to be the most cost-effective policy measure in various studies and could provide additional revenue to support new low-carbon innovations and investments, most countries have rather modest price levels due to political constraints and worries about energy prices and distributional impacts. The subsequent use of a large mix of typically overlapping policies again complicate the impact assessments.

Natural resource use and biodiversity impacts are stressed as another important area that needs to be better covered. The world faces a severe ecological crisis and cannot afford to solve just one part of it—climate change. Restrictions on the availability of rare earths or sustainable biofuel sources can limit the potential of different mitigation options significantly. Energy security poses additional restrictions on potential pathways. And again, developing countries face major modelling limitations on the informal sector, while it can form major part of their economy.

Financial or general macroeconomic impacts, such as inflation or interest rate impacts, are also mentioned as areas to improve as they can affect public balances. And interactions between financial sector and economic models are relevant within the low-carbon transition, and their assessments seem to often require complementary modelling approaches able to capture these interactions (Monasterolo 2020, Pollitt and Mercure 2018).

Sixth, there is also a need for models that can analyze discrete changes, nonlinearities, financial flows and risks, and transition pathways that are not smooth. Discrete changes and nonlinearities refer to such as tipping points in the systems from one state to another, cascading effects from one sector to the other, and nonlinear transitions in technologies and behavior. Most models are better with incremental changes, not discrete ones. The non-smooth transition pathways should also be analyzed for the longer term, while CGE models typically present rather smooth transition pathways unless modelers can impose additional information and dynamics into them. Static comparisons of long-term steady states do not provide information on when some of the largest changes are to be expected, while timing is important to consider in public budgets. Interviewees advised against the use of static cost-benefit analyses, nor can CGE models typically be used to determine the optimal timing of mitigation policies. Many interviewees felt that much more effort should be dedicated to analyzing the potential dynamics over time. Longer-run models without market balancing and models that could show multiple equilibriums were also mentioned as areas to develop.

Some interviewees felt that development work should start by creating even better theories for the models to build on, and some recommended comparisons between risks and opportunities. Grubb et al. (2021) and Geels et al. (2021) advocate risk-opportunity assessments instead of traditional cost-benefit analyses in policy selection.

5.3 Scenario Selection and Baselines

Scenario uncertainty is another major challenge identified by various interviewed modelers (see Marchau et al., 2019). It refers to the difficulty of identifying external developments that will be relevant for long-term future system performance and, perhaps more important, for the size and direction of these changes.

Stakeholder processes and (sector) expert consultations have been a way to analyze potential future developments and to develop various scenarios for the impact assessments. For example, the robust decision making (RDM) method compares vast number of scenarios. Some interviewees recommended a workshop with rather heterogeneous people for scenario development. In addition, different questions can help in the search for good scenarios to analyze. With multiple scenario assessments, ministries can make (deep) uncertainty a key part of the assessments. Yet, some interviewees pointed out that all scenarios should at least be somewhat plausible. New methods can also help to limit the number of scenarios. For example, Seeve and Vilkkumaa (2021) propose a mathematical method to identify a small but diverse set of plausible combinations of uncertainty levels from large sets of possible uncertainty combinations.

Running multiple scenarios has complications and downsides. Running linked energy-economy models or modelling frameworks multiple times consumes time and resources. While modelling capacities and digital solutions (such as machine learning, AI, and cloud services) reduce the time to run complex models, they can still take considerable time to run (depending on the model and its complexities). RDM assessments, with even thousands of scenario runs, are therefore often not possible with such methods, and researchers need to find a way to limit the number of runs. If simpler modelling methods can provide views on the main impacts, the number of scenarios can typically be increased. Second, communicating results can be difficult, and politicians might have hard time understanding the meaning of the numbers.

In typical impact assessments of individual policies, it is common to compare the results of policy scenarios against some baseline of how the world might go on without the policy. The results are presented as percentage changes against this baseline to obtain only the impact of the policy change. But in scoping the potential fiscal impacts of different types of scenarios, the analyses get more complicated. Many interviewees and the literature warn that baselines without climate action provide a false projection on the future developments, as it is common to assume that there would be no costs associated with the doing nothing scenario. Yet, the Stern review (2006) showed that the costliest option is associated with not limiting the global warming. The latest IPCC reports (2018, 2021) show that the societal costs will be smaller, the more and faster we manage to limit climate change. Note that climate change, natural resource overuse, and biodiversity losses diminish capital and natural stocks—but are seldom included in the baselines.

This leads to the difficult choice of a baseline. Dellink et al. (2020) state: "the costs of complying with future emission constraints are directly linked to the structural characteristics of an economy exhibited in a hypothetical business-as usual (BAU) situation without such emission constraints". Böhringer et al. (2021) add that BAU projections also determine the magnitude of additional abatement requirements. Therefore, baselines need to be adjusted constantly as new information becomes available and improves. Some interviewees mentioned that they adjust short and medium-term baselines multiple times a year and long-term baselines annually. But previous (old) research results with different baselines also complicates assessments. One option in scenario-based fiscal impact assessments is to not use any baseline projections. Drummond et al. (2021) did not compare the linked global model scenario results—extending to 2050 and 2100 from TIAM-UCL global energy model and GEM-E3 global economic model—against any baseline.

5.4 Transparency and Communication

Given the limitations of all modelling tools and approaches, transparency on the strengths and weaknesses of the approach is essential. Many advocate for open source models, but most of them are not open source, though there are detailed manuscripts on their assumptions and mechanisms. References to models as black boxes are common, even if the manuscripts are good. Opening the source code could improve transparency, but is unlikely to avoid black box comments. Some interviewees felt that black-box comments stem from unfamiliarity and inexperience with the models—and that policy makers could get more confidence and insights on model results if they were able to use the tools. But others point that it still takes time and effort for people to truly understand the logic of the model results, even if they can use and run them. Transparency on the way the models are developed also helps. In most cases, the development work is concentrated in academia and in research organizations.

In the communication strategy it is important to think about the end user and their needs for using the results. Communicating results should be as simple as possible so that "even your grandmother understands them," but that can be difficult. The more complex the models, the harder it is to explain the logic behind the results. By contrast, simpler modelling techniques often leave many questions open, and policy makers can be left wondering if the policy advice would be different if additional constrains or impacts could be accounted for. While running various scenarios may provide more robust views on policy options and their impacts, it is harder to explain results based on various scenario assessments. The communication style and transparency of the modelling tools and methods can affect whether policy makers or the public believe or understand the results. Individual numeric results can have a life of their own when people don't really understand what they mean. Once faulty interpretations have spread widely, it is difficult to correct them.

Franta (2021) provides examples on how some CGE modelling results by economic consultants were used by big oil companies to delay climate actions in the United States for many decades. The models used included rather simplistic assumptions and lacked analyses of the benefits of climate action. But in the political debate, only the final numbers were used as arguments to hinder and delay climate policies without any major discussion on the limitations of the results or their correct interpretation.

5.5 Capacities in Ministries and Research Organizations

Ministries differ in their resources, both human and financial, to conduct or commission studies. Almost all interviewees emphasized that it is important to have some modelling capacity and knowledge within the ministry. If a ministry is not used to perform modelling scenarios, it is at least important to have capacity within the ministry to interpret the results and to communicate them to other relevant stakeholders. In many cases ministries are also in charge of the commissioning and managing research projects, which many find demanding in the absence of modelling skills. There is little value in conducting modelling exercises without the capacities and skills to use the results obtained and communicate them to the policy makers in a clear and accessible way. The deeper the modelling capacity in the ministry, the better that officials can judge the relevance of the assumptions, the uncertainty about the results, and the key sources of uncertainty. This makes the policy advice based on the results much stronger. But many organizations pointed out that finding people with required modelling skills can be difficult.

The research organizations developing and maintaining modelling tools and approaches also differ in available resources. Ekins and Speck (2014) also discussed the issue: "Modelling of any kind is a skilled and complex activity if the models are to deliver useful insights. Their utility depends not only on their valid construction but the maintenance of an expert team that can run, develop, and interpret the model in the light of current events." In many cases, resources are restricted, and many modelling tools are developed and maintained by single individuals. So, there is a threat that the skills and knowhow could disappear with personnel changes.

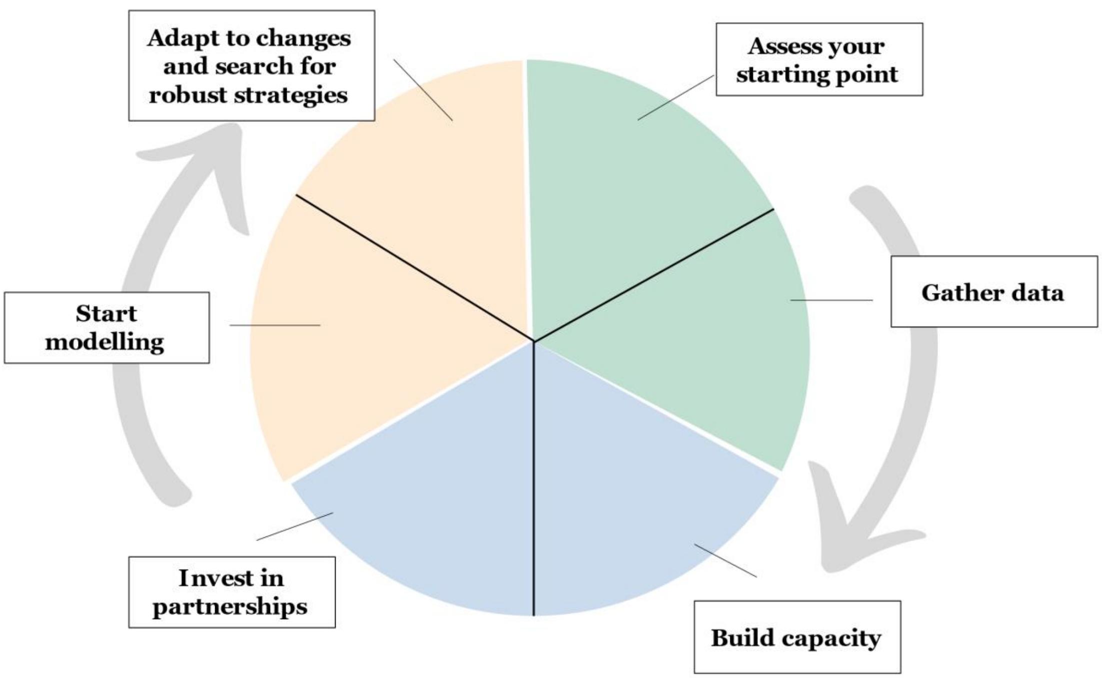
6. Key Takeaways for Ministries of Finance

This section synthesizes the recommendations from the interviewed modelling experts and previous studies on ways forward. The lessons can be summarized as follows:

1. Assess the current situation
2. Gather data
3. Build capacity
4. Invest in partnerships
5. Start modelling
6. Adapt to changes and search for robust strategies

Each recommendation is discussed in detail. As countries are at different stages of the process, the relative importance of these measures may vary. Many measures can be executed at the same time, and the process is likely to be iterative, with findings and judgments adjusted as new information become available.

Figure 9: Key measures for finance ministries to consider



6.1 Assess the Current Situation

Because countries' economic structures and planned emission reduction strategies vary greatly, no one size fits to analyzing the fiscal implications of climate strategies. But the interviewees shared basic principles to consider when countries are starting with scoping the potential fiscal implications of the climate transition, also relevant for scoping the possible fiscal impacts of climate change and adaptation.

At the outset, it is important to gather information on current practices and resources to assess gaps and plan a way forward. It is necessary to analyze the potential impact channels and their importance for the country. This could be more qualitative and build on existing long-term climate strategies and general pathways to mitigation targets. What actions, technologies, and changes are needed to reach carbon neutrality by the target year? What are the potential direct effects of climate change policies on the economy and on fiscal balance? What are the indirect impacts? What are the interactions between sectors? Who could be the winners and losers of different policies? The key is to have a deep understanding on the economy and how it operates. Many countries may already have this analysis in hand.

6.2 Gather Data

A critical factor in modelling is good and comprehensive data. So, it is important to assess the data requirements and opportunities to fill any gaps. Global databases can provide a good start, but in practice fiscal impact assessments require detailed data on current fiscal structures. Sectoral coverage of the modelling can vary, but data and information are likely required from various sources. Data on energy consumption, prices, sectorial outputs, and planned policies are often challenging to access. Some modelling experts advise forming harmonized calculations of the current carbon pricing in different sectors to get a better view on the starting situation. Line ministries and research institutions often possess valuable data and insights. Cooperating with national statistics office and international organizations and experts can also assist in the data gathering.

6.3 Build Capacity

One of the strongest and clearest recommendations, provided by nearly all interviewed experts, is for the finance ministries to hire and maintain people who comprehend the required methods and modelling tools within ministries. This is essential to obtain modelling work that is relevant for the ministry's needs, but also for the communication and use of modelling results for policy making. As mentioned, many interviewees stressed that the communication of the model results and the logic behind them is important. Familiarity with the modelling tools assists in understanding their logic. Many see that it is hard to even steer external research on long-term impact assessments if the civil servant overseeing the research work is not a modelling expert.

The modelling skills in the ministries should not be limited to a few individuals, with some four or five people a preferable team size. A diversified team is in a better position to address a complex issue, and it should have at least basic knowledge of both climate measures and (economic) modelling. Climate measures refer to environmental policies and emission reduction technologies and practices. In-house knowledge of energy and climate modelling can be a great advantage, but economic modelling knowhow is required to assess the fiscal implications. Knowledge of DMDU (Decision Making Under Deep Uncertainty) approaches and risk-opportunity analyses (ROA) can also be useful to enhance the scope and quality of the assessments in environments under deep uncertainty. It would be best to maintain and develop the essential skills in house, so that the work is less vulnerable to disruptions due to staffing changes. In general, there is a big shortage of people with the required skills in many countries.

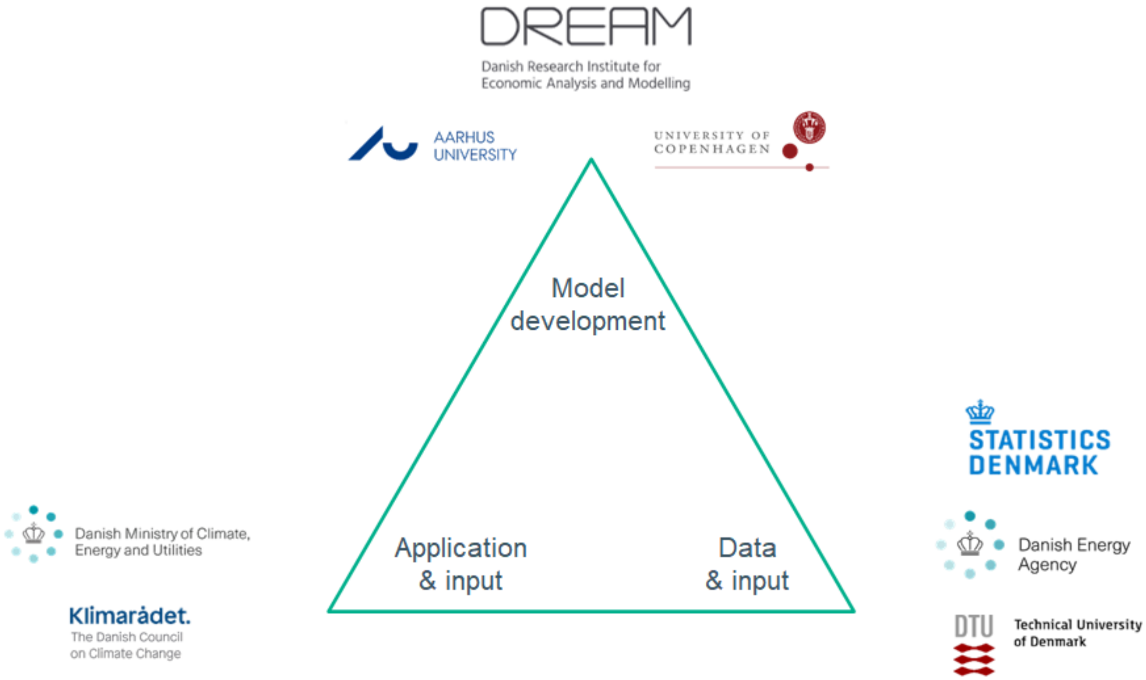
Model development also requires resources. It takes time to develop the models, the modelling capacities, and the required data resources within research organizations or ministries running their own models. So, it is essential to resource the model development work and continuity in modelling skills within research organizations and ministries with a long-term focus. This is also essential to enable flexible updates in the impact assessments and policy requirements, since the world is changing fast and impact assessments done today can be outdated in a short time as technologies, policies, and people's behavior change.

Some interviewees also stressed the need for good resources and tools for the analysis of the distributional impacts of a just transition. Good analyses and tools can help in understanding the expected distributional impacts and in formulating effective policies to alleviate any negative impacts and enhance the expected positive ones. And involving sector specialists and models in the impact assessments and in model development can produce better views of the most affected sectors. As soon as ministries get the basics done, there are various tools and impact areas to extend to and deepen the analyses of the fiscal impacts in total.

New Zealand shows how to build research and modelling capacity and strengthen the climate policy advice for the various ministries, including the Treasury. It formed a Climate Change Commission in 2019 with the Climate Change Response (Zero Carbon) Amendment Act, which passed with multiparty support. The purposes are to provide independent, expert advice to the government on mitigation and adaption measures and to monitor and review the government's progress toward the goals. Strengthening modelling capacities related to climate change and the transparency of the modelling tools has been key. The Commission maintains models required for the climate policy analytics (such as an energy and emission bottom-up model, a CGE model, and a microsimulation model), all publicly available. It also cooperates with various ministries, holding cross-agency meetings on climate change modelling every four weeks with senior analysts.

Denmark also shows how to build both modelling development and capacity through collaborations between researchers and the finance ministry. The GreenREFORM model has been developed and maintained mostly by the DREAM research group and the University of Copenhagen, but the Ministry of Finance and other government institutions have been closely involved, with various other institutes involved in the work (figure 10). For example, the Statistical Office provides data and input development together with the Danish Energy Agency and Technical University of Denmark. The Ministry of Finance emphasizes political buy-in to get started with capacity building and finds that an open and transparent process, including many stakeholders, is key to success.

Figure 10: Danish cooperation model for the GreenREFORM model



Source: Danish Ministry of Finance.

6.4 Invest in Partnerships

National cooperation with various stakeholders and multidisciplinary development of the models and methods is recommended, since expertise from various fields and sectors is usually needed. Good stakeholder management skills and practices are therefore important in impact assessment projects, but also in developing capacities and models. Finance ministries often need knowledge and expertise from other ministries. So intergovernmental cooperation in the development work and in the impact assessments should be strengthened. Many interviewees also call for international cooperation between research organizations and policy makers. For example, the Coalition of Finance Ministers for Climate Action, or some global modelling platforms, could promote additional knowledge exchanges or even model and data development work.

High-level political buy-in can help drive the capacity building and model development processes and ensure that adequate resources are allocated at national level. A long-term view is essential since governments and their priorities can change but model development takes time.

6.5 Explore Potential Impacts Through Modelling

Once the required resources are in place, the next step could involve some quantitative analysis through modelling. While more complex energy and economy models can often provide more detailed impact assessments, many interviewees stressed that even simple spreadsheet calculations can provide a good start. To deepen and broaden the assessments, more complex modelling structures and complementary modelling approaches that highlight different aspects of the transition can be used.

Ministries could conduct the quantitative analysis in-house or commission it from external sources, as long as some modelling capacity is created in-house. The most suitable approach depends on the available resources and other characteristics and preferences of the country.

Many feel that modelling in a time of uncertainty, rapid change, and path-dependence and reinforcing network effects will be of limited use for forecasting, and that the focus should be on scenario stress tests and risk-opportunity analyses. When the long-term decision-making environment is characterized by deep uncertainty, technological and behavioral changes are difficult to forecast, and both national and other countries' policy changes can affect economies and fiscal balances, and sudden nonlinear transitions and tipping points are possible. Different complementary modelling approaches and risk-opportunity assessments can then provide a wider view on the potential impacts and best policy options. With ROA, the aim is to consider all the significant opportunities and risks entailed by a policy, including the potential for the system to develop in ways that create new options and for the resilience of the system to unforeseen problems. By comparison, typical cost-benefit analyses tend to focus on average cost and benefit estimates, but these are difficult to conduct in environments under deep uncertainty.

Running multiple scenarios with the models to scope potential future development pathways and their main determinants is a key option to manage deep uncertainty. Sensitivity analyses of key parameters and comparisons of results based on different models is another way to scope uncertainties.

6.6 Adapt to Changes and Search for Robust Strategies

In the transition to carbon-neutral sustainable economies, only change seems certain. We are not good at predicting its speed, or sometimes even its direction. At best, we can aim to scope the possible future changes, prepare for the most significant ones, adapt to changes, and steer our societies dynamically toward the best possible pathways. In many cases, change is not expected to be smooth and linear, but sudden and nonlinear.

Regardless of the possibilities to scope the fiscal impacts in detail, ministries should analyze robust policy choices and strategies that can strengthen the required and desired developments and smooth the transition to most affected parties. For fiscal impacts, some interviewees stressed the general importance of good innovation policies and a just transition to smooth the transition as much as possible.

Geels et al. (2021) note that governments seeking to sustainably boost productivity and innovations should strategically design, rather than passively forecast, the future. To support innovations and productivity, public policy choices should go well beyond carbon pricing and R&D subsidies, and include wider instruments. These include direct infrastructure investments, purchase subsidies, loans or capital grants, standards, regulations, targets, and institutional reforms. Grubb et al. (2021) highlight the importance of innovations and need for rather wide policy considerations to boost them. Both stress the need for risk-opportunity assessments, rather than traditional cost-benefit assessments, to analyze best policy choices.

For a just transition, some sectors (such as coal, oil, natural gas, and peat production) will decline and the employees and entrepreneurs in these sectors may require public support to find new opportunities. Therefore, labor and educational policies, including life-long learning support, will be essential to help societies adjust to the transition and benefit from the vast market opportunities in the newly developing low-carbon and circular business models. For public finances, this can mean an increase in expenditure in the short run, but in the long run societies investing in a just transition could benefit for instance from a more stable economy, less unemployment, and better social cohesion (Saget et al. 2020).

In addition to the robust decision making and risk opportunity analysis methods, finance ministries could consider other policy planning methods designed for environments under deep uncertainty to find robust climate transition strategies from the viewpoint of public balances and to identify key interventions. For example, Dynamic Adaptive Planning (DAP) and Dynamic Adaptive Policy Pathways (DAPP) methods stress adapting plans and strategies dynamically as new information arrives. Both also find monitoring mechanisms to be important for obtaining up-to-date information on the latest developments. If monitoring indicators reach a trigger or tipping point, an adjustment of plans will follow (Marchau et al. 2019). Because countries differ, the best solutions and assessment methods need to be considered at national level, but international cooperation can also help with this.

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Appendix 1: Interviewed Experts and Ministries, and Interview Questions

Interviewed Experts

Organization	Expert
World Bank	Andrew Burns, Global Lead, Macroeconomic Modelling, Macroeconomics & Fiscal Management
World Bank	Hasan Dudu, Senior Economist
OECD	Rob Dellink, Senior Economist
OECD	Elisa Lanzi, Senior Economist
IMF	Jean Chateau, Senior Economist
IMF	Florence Jaumotte, Deputy Division Chief, Research Department
IMF	Ian Parry, Principal Environmental Fiscal Policy Expert
University of Cambridge	Dimitri Zenghelis, Special Advisor, Bennett Institute for Public Policy
Danish Research Institute for Economic Analysis and Modelling (DREAM), Denmark	Jens Sand Kirk, Project Director, GreenREFORM
BC3 Basque Centre for Climate Change, Spain	Inaki Arto, Research Professor
VTT, Technical Research Centre Finland	Tiina Koljonen, Research Team Leader
Merit Economics, Finland	Juha Honkatukia, Research Director
CPB, the Netherlands	Maurits van Kempen, Economist
CPB, the Netherlands	Sander Hoogendoorn, Senior Economist
E3 Modelling	Leonidas Paroussos, Managing Director
University of Oldenburg, Germany	Christoph Böhringer
European Commission, DG ECFIN	Jan in 't Veld, Head of Sector Model-based Economic Analysis
European Commission, DG ECFIN	Stephanie Pamies, Deputy Head of Unit

European Commission, DG ECFIN	Nicola Gagliardi, Economist
European Commission, Joint Research Centre	Matthias Weitzel
Inter-American Development Bank	Adrien Vogt-Schilb, Senior Climate Change Economist
ETLA Economic Research, Finland	Tero Kuusi, Research director
The Finnish Environment Institute SYKE	Johanna Pohjola, Senior Research Scientist
New Zealand Climate Change Commission	Anita King, Principal Analyst
New Zealand Climate Change Commission	Christopher Holland, Principal Analyst

Ministry	Expert
Danish Ministry of Finance	Mads Dalum Libergren, Senior Advisor
Danish Ministry of Finance	Malene Lauridsen, Deputy Head of Division
Spanish Ministry of Economy	Maria Covadonga Gomez Gonzalez
HM Treasury (UK)	Jainicca Chandrasekaram, Head of Fiscal Sustainability and Structural Analysis
HM Treasury (UK)	Ignacio Arguelles Martinez, Junior Economist
HM Treasury (UK)	Emmanuelle Dot, Policy Advisor
Swiss Federal Finance Administration	Pierre-Alain Bruchez, Economist
Department of Finance Canada	Scott Legree, Economist
Department of Finance Canada	Edgar Cudmore, Economist
Department of Finance Canada	Farhan Hameed, Senior Economist
Ministry of Environment of the Slovak Republic	Marek Engel, Policy Advisor

Interview Questions for Modelling Experts

1. Existing work and models

Are you familiar with or have you done any studies assessing climate strategies' impacts on fiscal balance? What methods were used?

How would you recommend analyzing the topic in general?

What models exist that could quantify the impact of climate change policies and structural changes on fiscal balance?

Could you please list the models and/or the type of the models (CGE, IAM, hybrid, microsimulation, etc)?

More detailed questions for specific models mentioned:

- Is the model open source, or is a license required?
- Who is responsible for the R&D work of the model?
- Which sectors the model can cover?
- Can you explain more in detail how the public sector is constructed in the model (coverage of regional/subregional entities, coverage of revenue and expenditure streams etc.)
- Is the model able to cover sectorial linkages? How is this done?
- In your opinion, is the model able to address disruptive changes in the society? If so, how?

2. Constraints of the existing models and key development needs

What are the major barriers, hindrances, or constraints related to the analyses of climate strategies' fiscal impacts in general?

What are the key constraints of existing models and assessment techniques for assessing fiscal impacts of climate measures? Or more in detail related such as to:

- Excel tools
- Sectoral models (such as energy, land-use, transport)
- Microsimulation
- CGE (computable general equilibrium models)
- IAMs in combination with economy or sectoral models
- Other:

How could these be addressed?

In your opinion, what development work should take place to obtain even better tools for the task? Would we need more detailed sectorial models which could potentially be linked with each other?

3. Practical advice on conducting studies on the impacts of climate strategies on fiscal balance

Assume that Government X would like to implement a research project on the impacts of climate change policies on fiscal balance.

- What do you think are the key issues that should be included in the Terms of Reference (TOR)?
- What are the key capabilities required from the research team? The project management team from the government side?
- What information and data are needed to conduct the study?
- If the country X does not have a country-specific model, which general models could be used to conduct the study?

Interview questions for Ministries

Part I: Current state

1. Has your country/ministry conducted assessments of the fiscal impacts of long-term climate strategies? If yes:

- What studies have you done/commissioned and how were they done?
- What lessons were learned that could you share with other countries about the process?
- How were the results received?
- Did the results feed into any policy process or result in any policy changes?

2. Do you see a need to conduct (further) analyses of the fiscal impacts of overall climate strategies?

3. In your opinion, do you have adequate assessment tools (such as energy and economy models covering your country adequately) and data to analyze the fiscal impacts of climate strategies?

4. In your opinion, do you have adequate human and financial resources to conduct such analysis where needed?

5. How has the stakeholder process been managed/is planned to be managed with relevant academic, other public, private, and NGO stakeholders?

6. Have you benchmarked how other countries conduct such analysis?

Part II: Future developments

1. In your opinion, what are the major barriers, hindrances, or constraints related to the analyses of climate strategies' fiscal impacts in general?

2. In your opinion, what development work should take place to obtain even better tools for the task? Are you involved in such development work already?

3. What institutional/resource changes do you find important to improve analysis on the topic?

The Coalition of Finance Ministers for Climate Action

Appendix 2: Model Categories

Table A2.1 Possible model types to be used in long-term climate strategies fiscal impact assessments including some of their common strengths and weaknesses

Model category	Short description	What kind of questions can be covered?	Ease of use (easy/medium /demanding) and time horizon	Some common strengths	Some common weaknesses
Computable general equilibrium models (CGE), E.g. GTAP, GEM-E3, OECD ENV-Linkages	Analyze direct and indirect interactions between all economic agents and sectors based on Social Accounting Matrixes. Model agents' behavior based on micro-theories with some parameters (e.g. elasticities) taken exogenously from other literature and some calibrated from historical data Both static and dynamic (recursive) models available	- What kind of direct, indirect and general equilibrium effects the policies or changes might have? - What kind of structural changes can results from the policies or changes? - What can happen to trade patterns in the scenarios? - What kind of fiscal impacts the policies can have in the long-run?	Ease of use: Medium—Demanding Time horizon: Short to long term	- Can analyze large structural changes in the economy over a long time period - Cover direct, indirect and general equilibrium effects - Can cover government taxes and expenditures in detail at regional, product and sectoral levels - Can cover many sectors and regions in detail (depending on data) - Trade linkages included - Compare different policy scenarios easily	- High complexity which complicates communication of results - Modelling process resource and time consuming - Many models don't model financial system or include physical quantities of inputs or outputs - Assume markets will balance (over long-term) - Representative agents - Do not analyze optimal timing of policies unless modified - Standards and regulations harder to model in many cases
Macro-econometric models, E.g. E3ME, NiGEM	Macro-econometric models are similar to CGE models, but their parameters are based on (time series) econometric analyses with past data within the model	- What kind of short and medium run impacts the policies can have if we consider market imperfections?	Ease of use: Medium—Demanding Time horizon: Short to	- Can model real and financial markets - Markets not assumed to balance	- High complexity which complicates communication of results - Modelling process resource and time consuming

Model category	Short description	What kind of questions can be covered?	Ease of use (easy/medium /demanding) and time horizon	Some common strengths	Some common weaknesses
	They often model less sectors than CGE models but replicate the fluctuations in the global or national macroeconomy in more detail and model the financial markets	- What kind of financial or macroeconomic impacts are possible?	Medium (occasionally also long-term)	- Economic agents are not able to optimize their decision making and base behavior on limited knowledge - Imperfect competition and sticky prices - Cover direct, indirect and general equilibrium effects - Can cover government taxes and expenditures in detail - Trade linkages included - Good for modelling short-medium term economic fluctuations	- Do not include physical quantities of inputs or outputs - Standards and regulations hard to model - Behavioral parameters based on econometric analysis of historic data - Structural changes in the economy harder to analyze - Typically less sectors and products than in CGE
Dynamic Stochastic General Equilibrium models (DSGE), E.g E-QUEST	Use modern macroeconomic theory and microeconomic principles to explain and forecast comovements of aggregate time series over the business cycle and to perform (monetary) policy analysis Model seeks to optimize the economic behavior of rational agents, with forward-looking dynamics	- What are the macroeconomic impacts of the policy or market shock? - What kind of economic growth levels can be expected for next years? - What would be optimal interest rate?	Ease of use: Demanding Time horizon: Short to medium (occasionally also long-term)	- Models financial system and monetary policies in detail - Typically assumption of imperfect competition in markets - Good for modelling short-medium term economic fluctuations and monetary markets	- High complexity which complicates communication of results - Modelling process resource and time consuming - Few sectors or regions, high aggregation levels - Standard models cannot account for long-term structural changes (doesn’t apply to E-QUEST)

Model category	Short description	What kind of questions can be covered?	Ease of use (easy/medium /demanding) and time horizon	Some common strengths	Some common weaknesses
					- Do not model links between different industries through input-output structures
Spreadsheet models, e.g. IMF-WB CPAT, excel calculations at tax instrument level	Analyze selected indicators or sectors based on few key assumptions (e.g. elasticities, energy efficiency assumptions) and projections of key drivers (e.g. GDP, international energy prices). Models can be run in Excel	- What is the (short term) impact of carbon pricing on specific fuel consumption and fiscal balance? -How different carbon and fuel t axes compare to emission trading scheme in CO_2 and energy price impacts?	Ease of use: Easy Time horizon: Short to medium term	- Results more transparent and easier to communicate - Can model roughly both taxes' and regulations' impacts - Can be used for numerous different types of countries easily	- Do not cover general equilibrium effects - Limited modelling of behavioral or technological changes - No international trade - Parameter values often similar for all countries
Microsimulat ion models, E.g. MIMOSI (for the Netherlands)	Microsimulation models are used to estimate how demographic, behavioral, and policy changes might affect individual outcomes, and to better understand the microlevel (household or firm) effects of current policies	- What kind of distributional effects the transition or climate policies might have? - What kind of firms would be most affected by the policy change?	Ease of use: Easy–Demanding Time horizon: Short to medium term	- Model microlevel and distributional impacts of policies - Capture interactions between multiple programs or policies -Tabulate results by a wide variety of socioeconomic characteristics	- Require substantial time to develop and maintain - Do not cover general equilibrium effects - Cannot account for long-term structural changes - Do not model links between different industries through input-output structures
Overlapping generations (OLG), E.g. FOG (Finland)	An OLG model is a simplified theoretical representation of economic processes through a set of identities and equations that describe the behavior of various	- Impact of population aging on public budget? - Effect of tax policies on different generations?	Ease of use: Medium - Demanding Time horizon: Long term	- Highlights intergenerational redistribution	- Does not consider endogenous systemic risks (climate change or transition) - Assume often that individuals have perfect

The Coalition of Finance Ministers for Climate Action

Model category	Short description	What kind of questions can be covered?	Ease of use (easy/medium /demanding) and time horizon	Some common strengths	Some common weaknesses
	agents interacting with each other The most distinguishing feature of an OLG model lies in the way it captures the changing behavior of consumers over different phases of their lives In many cases OLG dynamics are included in a CGE model (see e.g. Zodrow and Diamond (2013) for an overview on OLG-CGE models)	- Sustainability of the pensions system		- Incorporates life-cycle investment decisions	foresight about future prices and economic conditions - Difficult to model detailed environmental taxes or policies
Agent based models	In an agent-based model the actions and interactions of autonomous agents are simulated to understand the behavior of a system The goal of ABM is to search for explanatory insight into the collective behavior of agents obeying simple rules ABMs are used to study complex systems, e.g.: ecosystems, pandemics, markets, energy generation and distribution, urbanization, traffic flows and migration	- How consumers or firms change their behavior due to herding or panic? - How excessive levels of leverage in financial markets can lead to a systemic crash?	Ease of use: Demanding Time horizon: Short to medium term	- Model heterogeneous agents - Do not assume market equilibrium balancing - Can model discrete changes, big fluctuations and even crashes in markets - Allow feedback mechanisms that can amplify small effects, such as the herding and panic that generate bubbles and crashes	- High complexity which complicates communication of results - Modelling process resource and time consuming - Each model can typically cover only a small topic area (e.g. banking system)

Model category	Short description	What kind of questions can be covered?	Ease of use (easy/medium /demanding) and time horizon	Some common strengths	Some common weaknesses
Input-output models	Simple economic models that track interdependencies between different sectors through input-output structures Typically do not model behavior of economic agents	- How dependent each sector (or industry) is on the other sector? - What direct impacts a positive or a negative economic shock can have if nobody changes their behavior and what are the ripple effects throughout an economy?	Ease of use: Easy - Medium Time horizon: Short to medium term	- Cover both direct and indirect effects - Model short-medium term economic impacts	- Fixed prices - Do not model behavior of economic agents - Assume fully flexible supply of labor and intermediate inputs - No substitution effects - No general equilibrium effects
Stock-Flow-Consistent (SFC) Models e.g., EIRIN (Monasterolo and Raberto 2018), DEFINE (Dafermos et al. 2017), Bovari et al. 2018 model	SFC models represent heterogeneous agents and sectors as a network of interconnected balance sheets items This helps tracing financial and economic flows and stocks adjustments Agents can be characterized by adaptive behaviors and expectations Model output is usually determined by aggregate demand Supply-side constraints may arise primarily due to expectations, environmental or financial issues	- How shocks (e.g., climate physical or transition risk) transmit through the balance sheet of economy and financial agents? - What are the drivers of shocks' amplification? What their implications for the economy and finance (e.g., business cycles, expansionary vs contractionary periods, hysteresis)? - What are direct and indirect impacts of compounding shocks (e.g., COVID-19 and climate risks), and how do they affect socio-economic and financial stability?	Ease of use: Medium - Demanding Time horizon: short to medium term	- Rigorous accounting framework replaces equilibrium conditions and ensures that overall budget and adding-up constraints cannot be violated - Quantitatively assess the richness of risk transmission channels, feedbacks and amplification effects between the economy and finance - Endogenize the role of finance and its complexity, and connects it to economic decisions - Embed heterogeneity, heuristics and behavioral patterns that contribute to emerging phenomena and	- Modelling process resource and time consuming - Usually, few regions and high aggregation levels of sectors - High model dimensionality and complexity limits analytical model solutions - High dependency on the value of parameters

The Coalition of Finance Ministers for Climate Action

Model category	Short description	What kind of questions can be covered?	Ease of use (easy/medium /demanding) and time horizon	Some common strengths	Some common weaknesses
				out-of-equilibrium states of the economy -Shows path dependency (short-term impacts affecting long-run output)	
Energy system models, e.g.PRIMES; POLES, TIMES	Bottom-up model generator, which uses linear-programming to produce, for example, a least-cost energy system, optimized according to a number of user constraints	- What kind of technological and behavioral changes can limit emissions at required speed? - How can energy system develop in the future? - How future energy needs can be met under certain constraints, such as simultaneously achieving climate neutrality? - What is the cost-optimal pathway for energy transition?	Ease of use: Demanding Time horizon: Short to long term	- Technologies and sectors modeled in detail - Can cover standard and regulation driven technological and behavioral changes	- High complexity - Sectoral interlinkages not covered - Do not model entire government sector, even if some taxes or expenditures could be covered
Integrated Assessment Models (IAM), e.g. DICE, IMAGE, REMIND-MAgPIE, AIM/CGE	IAMs cover various different types of technology-climate-economy models Simple IAMs compare the costs and benefits of avoiding different levels of warming Typically, these are run in a spreadsheet using highly simplified equations	- (Complex models) What kind of technological and behavioral changes can limit emissions at required speed? - How high carbon price would be needed to reach the emission target? - (Simple models) What is the social cost of carbon or the marginal cost of emitting one	Ease of use: Medium–Demanding Time horizon: Short to long term	- Captures feedback between socioeconomic and climate systems effectively -Projections are internally consistent -Models accommodate alternative assumptions and policies	- Highly aggregated (simple models) - High complexity (complex models) - Typically relies on limited damage function, which may not effectively incorporate risks of extreme weather events

Model category	Short description	What kind of questions can be covered?	Ease of use (easy/medium /demanding) and time horizon	Some common strengths	Some common weaknesses
	Complex IAM models link detailed energy system, land use and climate modelling to a (simple) economic growth model	more ton of carbon into the atmosphere at any point in time?			-L acks resiliency to imperfect information and unforeseen endogenous events, such as technology or policy change - Most IAMs do not model money, finance, or banking - Do not model fiscal system or interactions between economic sectors in detail
Sector-specific model, e.g. transport system model, global oil sector model	Model an individual sector (e.g. transport, agriculture, forestry, coal, oil) at national or global level based on technical details and market dynamics	- How vehicle fleet and transport sector tax revenues could change due to additional climate policies? - How carbon taxes can affect oil demand and production? - How forest carbon sinks might develop under current or additional climate policies?	Ease of use: Easy–Medium Time horizon: Short to medium term	- Model individual sectors at great detail - Can often model both taxes and regulations effects at the sector	- Model only the particular sector with little interaction to other sectors - Do not account for general equilibrium effects

Sources: Interviews, BIS 2021, NGFS (2020), Encyclopedia.com, various individual model manuscripts.

Appendix 3: Previous Literature

Table A3.1 Long-term climate strategies assessments including some more detailed economic impact assessments

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
European Commission (2018b). In-depth analysis in support on the COM(2018) 773: A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy	2015–2050	Joint Research Centre, European Commission, Cambridge Econometrics	- 4 different energy models (e.g. POLES-JRC & PRIMES) - 3 agriculture and land use models - model for non-CO_2 gases and air pollution - 3 economic models (JRC-GEM-E3 (CGE model) QUEST (DSGE model), E3ME (macro-econometric model)	8 scenarios	All	Large number of different mitigation policy options In fiscal side e.g. carbon pricing in the ETS and non-ETS sectors and the use of carbon-based revenues	All revenue recycled by assumption Fiscal impacts not analyzed in detail

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
Groves et al. (2020). The Benefits and Costs Of Decarbonizing Costa Rica's Economy: Informing the Implementation of Costa Rica's National Decarbonization Plan under Uncertainty	2020–2050	University of Costa Rica, the RAND Corporation, the Costa Rica Climate Change Directorate, the Inter-American Development Bank (IDB)	Integrated sector-specific assessments. Energy and transport system model for Costa Rica (OSeMOSYS-CR) New aggregated model for other sectors to a OSeMOSYS-CR estimates emissions from the transportation and energy sectors based on demands for transport, specifications of the technologies and fuels used to meet those demands, emission factors, and energy demands from other sectors For other sectors, new Python-based models that project emissions, benefits, and costs based on specified activities, applications of technologies or methods, and emission rates Integrated Economic-Environment Modelling (IEEP) CGE model to devide 3 scenarios of underlying economic activity	Repeated emissions and benefit and cost calculations for 3,003 plausible futures, reflecting different assumptions over 300 uncertainties	Energy and transport in detail	Did not assess what specific policy instruments or institutional changes would be required to implement the NDP; instead, assessed directly the impact of the sectoral transformation listed in the NDP	No

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
Benavides et al. (2021). Options to Achieve Carbon Neutrality in Chile: An Assessment Under Uncertainty	2020–2050	Government of Chile, Inter-American Development Bank (IDB), Ponticia Universidad Católica de Chile, Universidad de Chile, RAND Corporación, Tecnológico de Monterrey	- Sectoral models were implemented for all sectors of the GHG Inventory. All models were integrated into a computational platform to simulate hundreds and thousands of scenarios at national level in limited simulation times, in order to apply the robust decision-making method - MEMO dynamic stochastic general equilibrium model	NDC and NDC+ scenarios both analyzed for 1,000 possible futures Macroeconomic impacts were analyzed with the MEMO model for a sample of 10 scenarios, representing a set of possible futures	All (electricity generation, transportation, commerce, public, residential, industry and mining, waste, industrial processes, forestry and agriculture)	Did not assess what specific policy instruments or institutional changes would be required to implement the NDP; instead, assessed directly the impact of the sectoral transformation listed in the NDP	Public spending analyzed at macro level
Koljonen et al. (2019). Long-term development of total emissions Aakkula et al. (2019). Development of emissions and sinks in the agricultural and LULUCF sectors until 2050 Koljonen et al. (2020). Carbon Neutral Finland 2035: Scenarios	2010–2050	VTT Technical Research Centre of Finland, Finnish Environment Institute SYKE, LUKE Natural Resources Institute Finland, Merit Economics	- TIMES-VTT model: energy production and energy systems, including production scenarios for harvested wood products - REMA model: energy consumption of the building stock - DREMFIA model: agriculture - MELA software: development of forest resources - FINAGE (CGE) model: economic impacts	4 different pathways	All	Some climate policies modeled in addition to tax revenue recycling with lump sum payments	Yes

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
and Impact assessments							
Government of Indonesia (2021). INDONESIA: Long-Term Strategy for Low Carbon and Climate Resilience 2050	2010–2050	Government of Indonesia	AFOLU Dashboard (a spreadsheet model), energy sector AIM-EndUse and the AIM-ExSS (Extended Snapshoot) In the second stage, the economic and economic impact of both AFOLU and energy sector mitigation are analyzed by utilizing the Asia Pacific Integrated Model/Computable General Equilibrium (AIM/CGE)	3 main scenarios, where one is a "current policies scenario"	All	Some policies identified in the strategy but required fiscal policies and regulations not modeled in detail	No
HM Treasury (2021). Net-zero Review: Analysis exploring the key issues	2000–2051	HM Treasury	- Assessments by tax and spending category with spreadsheet models	Uses different sector-specific scenarios from other work (e.g. future power generation, road traffic forecasts)	All	Economy-wide carbon pricing. Projections of the change in tax revenues over time, calculated as the difference between projected revenue as a share of GDP in each year, and revenue as a share of GDP in 2025-26 for Fuel Duty, Vehicle Excise Duty	Yes

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
						Landfill Tax, the Emissions Trading Scheme, and the Carbon Price Floor	
Office for Budget Responsibility (OBR) (2021). Fiscal risks report	2020–2050	Office for Budget Responsibility (OBR)	Analysis based on 1) long-term scenarios produced by the Climate Change Committee (CCC) including economic costs and savings analyses, and 2) work by the Bank of England regarding the price of carbon necessary to achieve net-zero and its economic implications	Impact on public sector debt: BoE's 'Early Action' scenario as reference scenario + eight alternative scenarios Scenarios to look at cost of public debt: Baseline + five alternative scenarios	All	Discussion on mitigation policy instruments (taxes, emissions trading schemes, other tax incentives, public spending, regulation, and other non-fiscal policies)	Yes
De Rosa et al. (2019). A Low-Carbon Growth Study for Slovakia: Implementing the EU 2030 Climate and Energy Policy Framework	2015–2050	World Bank in partnership with the Government of Slovakia and E3 Modelling	Compact-PRIMES Energy model for Slovakia, ENVISAGE-Slovakia Applied General Equilibrium Model (CGE)	BAU and 4 decarbonization scenarios	All	All scenarios include Slovakia's participation in the ETS, while each scenario differs in their targets for renewable energy and energy efficiency	Yes, but the government is assumed to increase taxes or reduce transfers to ensure sustainability of the government

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
							budget during the transition to a low carbon economy

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
Government of Canada (2016). Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy	2005–2050	Government of Canada	DDPP: - Bottom-up energy and economic model to forecast demand for GHG-intensive goods and services, energy balances, technology and ultimately emissions (CIMS model) - Computable General Equilibrium model (GEEM) to forecast GDP, employment, economic structure, and trade TEFP: the North American TIMES Energy Model (NATEM) and CanESS models ECCC: - Global Change Assessment Model (GCAM), a dynamic-recursive model with technology-rich representations of the economy, energy sector, land use and water linked to a climate model. GCAM is a Representative Concentration Pathway class model that can be used to simulate scenarios, policies, and emission targets from various sources - Computable General Equilibrium Model (CGE), a multi-sector, multi-regional open-economy recursive-dynamic computable general	Five scenarios from three different modelling projects (Deep Decarbonization Pathways Project, Environment and Climate Change Canada, Trottier Energy Futures Project)	ECCC: energy, industrial processes, agriculture, and waste (+ improved land sector sequestration and internationally transferred credits) TEFP: energy sector, industrial processes, agriculture and waste DDPP: all sectors of the economy except agriculture	ECCC: A common price on greenhouse gas emissions across sectors	No

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
			equilibrium model of the global economy				

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
Environment and Climate Change Canada (2020). A Healthy Environment and a Healthy Economy: Canada's strengthened climate plan to create jobs and support people, communities and the planet	2020–2030	Environment and Climate Change Canada	Two ECCC models were used: E3MC—a modelling framework that combines Energy 2020 and a macroeconomic model working in tandem. ENERGY 2020 is a 10-province and three-territory, bottom-up, energy technology simulation model. Its granularity allows for the analysis of a wide range of complementary measures and targeted performance standards and regulations. EC-Pro is a 10-province and three-territory multi-sector, multi-region, computable general equilibrium model. The model has more than 25 sectors with focus on energy and energy-intensive industries	Assessment of the Plan's impact versus a baseline scenario + sensitivity scenarios around different assumptions regarding oil and gas prices	Eight sectors	Carbon pricing, complementary sectoral measures (e.g. Emissions regulations for LDVs and heavy-duty vehicles (HDVs), retrofits, energy efficiency improvements in industry), clean fuel standard	No
CPB Netherlands Bureau for Economic Policy Analysis (2019). Evaluation of the Climate Agreement	2021–2030	CPB, Netherlands Bureau for Economic Policy Analysis, in cooperation with PBL (Netherlands Environmental Assessment Agency)	- MIMOSI: micro-simulation model for taxation, social security, wage costs and purchasing power - Excel based estimations for projections of the size of the budgetary impact and the financial burden - Worldscan CGE model for macroeconomic effects	Two analyses carried out in parallel: CPB and PBL used differing baseline scenarios, and accordingly the low-carbon scenarios were defined differently	Five sectors (electricity, built environment, industry, agriculture and land use, mobility and transport)	122 measures included in the Climate Agreement (covering various regulations, spending increases and tax changes)	Yes

Reference and name of publication(s)	Timeframe	Organization(s)	Methods and models used	Number of decarbonization scenarios analyzed	Sectors covered	Policies covered	Fiscal impacts analyzed?
Basque Centre for Climate Change (BC3), Spanish Ministry for Ecological Transition (MITECO) (2020). Integrated National Energy and Climate Plan 2021–2030	2021–2030	Basque Centre for Climate Change (BC3) with the Spanish Ministry for Ecological Transition (MITECO) (Large taskforce)	- Sinergia-TIMES energy model - DENIO (dynamic neoclassical econometric input-output model) - Electricity sector model, ROM - Health impact model TM5-FASST - SEI-model for non-energy emissions	The study, following the Governance Regulation, differentiates between a Baseline Scenario (with no additional measures) and a Target Scenario (with additional measures)	74 sectors	Policies and measures in the Plan grouped to five dimensions: decarbonization, energy efficiency, energy security, internal energy market, and research, innovation and competitiveness	Yes

Table A3.2 Sector level assessments and policy option assessments (especially environmental tax reforms [ETRs])

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
Varga et al. (2021). E-QUEST—A Multi-Region Sectoral Dynamic General Equilibrium Model with Energy: Model Description and Applications to Reach the EU Climate Targets	2020–2050	European Commission	E-QUEST, Energy-extended DSGE model	6 different policy scenarios that all reach EU 2050 climate target	Energy sector modeled in most detail, in total just 7 sectors in the E-QUEST model Analysis includes two regions: EU and the rest of the world	Regulations vs. carbon taxes with 5 ways to recycle the carbon tax revenue	Yes, but all revenue recycled
Huxham et al. (2019). Understanding the impact of a low carbon transition on South Africa	2018–2035	Climate Policy Initiative	Global coal and oil model, spreadsheet calculations	BAU and one global 2 degrees scenario	Quantitative analysis of thermal coal exports and oil imports. Qualitative reviews of platinum, manganese, iron ore, automotive industries. South Africa	Analyzing mostly 'external' policies and the impact of global markets. Two national policies covered: a) an accelerated shut-down of the country's coal-fired power fleet in line with the implications of the SDS 2017 for South African coal-fired power generation; and b) an early closure of the Secunda coal-to-liquids synthetic fuel refiner	Yes, but only from the covered energy-intensive sector related risks
Huxham et al. (2020). Understanding the impact of a low carbon transition on Uganda's planned oil industry	2020–2040	Climate Policy Initiative	Global oil model	BAU and one global 2 degrees scenario	Oil sector Uganda	Analyzing mostly external policies and the impact of global markets.	Yes, but only from the oil sector

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
							related risks
Solano-Rodriguez et al. (2019). Implications of Climate Targets on Oil Production and Fiscal Revenues in Latin America and the Caribbean	2016–2035	University College London and Inter-American Development Bank	BUEGO (Bottom-Up Economic and Geological Oil field production) model to simulate field development and production decisions globally	480 combinations of different uncertain variables	Oil sector. Nine countries examined individually and other countries bundled together	Global and national policies related to oil production and demand modeled	Yes, but only from the oil sector related risks
Welsby et al. (2021). High and Dry: Stranded Natural Gas Reserves and Fiscal Revenues in Latin America and the Caribbean	2017–2035	Inter-American Development Bank and researchers from University College London	Combine three models: - Future natural gas demand is taken from TIAM-UCL integrated assessment model - Bottom-Up Geological and Economic Oil field model (BUEGO) to inform country-level production	Use robust decision making method with 450 individual sensitivity combinations across nine climate policy-demand pathway scenarios from TIAM-UCL	Natural gas sector Whole Latin American and Caribbean region, with individual country level results presented for up to eight countries	Global and national policies (in particular tax rates) related to natural gas production and demand modeled	Yes, but only from the natural gas sector

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
			of associated natural gas (gas co-produced with oil). -The Global GAs Production, Trade and Annual Pricing Model (GAPTAP), geological-economic model of global natural gas resources at field-level				
Tamminen et al. (2019). How to Implement a Larger Environmental Tax Reform in Finland? Potential instruments and impacts	2019–2030	The Finnish Innovation Fund Sitra, Cambridge Econometrics, The Ex'tax Project, Institute for European Environmental Policy, Merit Economics	Two dynamic general equilibrium models used: FINAGE (applied, dynamic general equilibrium model for Finland) and E3ME macroeconomic model	three different types of ETR scenarios are formed and their impacts on the economy and emissions are analyzed	All sectors Finland	The policy scenarios studied introduce distinct environmental tax packages and consider alternative ways of using the revenue to implement an environmental tax reform	Yes
Barron et al. (2018). Policy Insights from the EMF 32 Study on U.S. Carbon Tax Scenarios	2015–2030	Academic article from The Stanford Energy Modelling Forum exercise, authors from	11 different models used to assess emissions, energy, and economic	Reference case and four core carbon tax trajectories	Five sectors (electricity, transportation, industry, residential,	Economy-wide carbon pricing (the scenarios apply the carbon tax to all fossil fuel CO_2 emissions, which represent	Direct carbon tax revenues estimated

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
		different organization	outcomes from a plausible range of economy-wide carbon price policies to reduce carbon dioxide (CO_2) emissions in the United States		commercial) United States	roughly 77% of overall gross US GHG emissions)	
Böhringer et al. (2021). Climate policies after Paris: Pledge, Trade and Recycle: Insights from the 36th Energy Modelling Forum Study (EMF36)	2011–2030	University of Oldenburg, Germany; Kiel Institute for the World Economy, University of Wisconsin	Analysis is based on a systematic cross-comparison of results from 17 energy-economy models (15 multi-region models and two single-country models) which simulate pre-defined policy scenarios with harmonized assumptions	15 core scenarios (as the cross-product of two scenario dimensions for three NDC variants and five emissions trading variants)	Five energy sub-sectors and five other sectors (or aggregates) Eight individual countries and six aggregated regions (e.g. Middle East, Africa, Europe)	Domestic emissions pricing and international emissions trading	Carbon tax revenues recycled back to households through revenue-neutral lump-sum transfers

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
Timilsina, Pang, and Xi (2021). Enhancing the quality of climate policy analysis in China	2005–2030	World Bank, Renmin University, China, China Petroleum University	The study first uses a national CGE model to estimate the economic costs of meeting China's NDCs through a carbon tax. The CGE model is then linked to the bottom-up TIMES model to produce a revised baseline	One (the study investigates the case of meeting China's Nationally Determined Contributions (NDCs) under the Paris Agreement)	CGE model: 16 sectors The TIMES model has five demand sectors: agriculture, industry, commercial, residential, and transportation China	Carbon tax	Yes
OECD and ITF (2019). Tax Revenue Implications of Decarbonizing Road Transport: Scenarios for Slovenia	2017–2050	OECD & ITF	Vehicle stock model	BAU and one main 2 degrees consistent transport scenario with different tax changes	Transport sector Slovenia	Different proposals for a transport sector tax reform in Slovenia	Yes
Jenn et al. (2015). How will we fund our roads? A case of decreasing revenue from electric vehicles	2015–2025	Academic article	Using forecasts of EV adoption the study calculates aggregate funding deficits, and examines policy options to tackle the revenue decreases	Baseline + AEO 2013 forecast + sensitivity analyses	Transport sector United States	Two policy options to cover for the revenue decrease due to EV uptake: annual registration fee and use tax (per mile)	Yes

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
Victor-Gallardo et al. (forthcoming). Policy options to mitigate the fiscal impact of road transport decarbonization: the case of Costa Rica	2019–2050	University of Costa Rica, Central Bank of Costa Rica, 2050 Pathways Platform, Inter-American Development Bank	OSeMOSYS-CR, long-term energy system optimization model and National Household Survey ENIGH to model transport expenses in detail	BAU and National Decarbonization Plan scenario	Transport sector Costa Rica	Analysis on tax options to abolish the tax revenue decrease from transport sector decarbonization. Analysis of 1000 different combinations of 10 main tax policy options	Yes, but only from the transport sector related risks and policies
Chateau and Mavroeidi (2020). The jobs potential of a transition toward a resource efficient and circular economy.	2018–2040	OECD	OECD ENV-Linkages CGE model	BAU and Material fiscal reform scenario	60 materials linked to 55 sectors and 43 commodities are considered. 21 regions covering the world economy	Analysis on material fiscal reform that aims to promote resource-efficient and circular economy (RE-CE) sectors	Yes, but all additional government revenue recycled
Bibas, Chateau, and Lanzi (2021). Policy scenarios for a transition to a more resource efficient and circular economy	2017–2040	OECD	OECD ENV-Linkages CGE model	BAU, Material fiscal reform scenario, Energy Transition scenario and Combined energy and material transition scenario	60 materials linked to 55 sectors and 43 commodities are considered. Results presented for 25 countries/regions covering the world economy	Tax on primary metals and non-metallic minerals, subsidies to recycling and secondary metal production	Yes, but all additional tax revenue recycled
Jaumotte, Liu, and McKibbin (2021). Mitigating Climate	2020–2050	IMF	G-CUBED macromodel with energy	2 main scenarios, but results	Global analysis, with the globe divided to 10	Comparing analyses on effect of carbon pricing, fiscal support for	Yes

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
Change Growth-Friendly Policies to Achieve Net-zero Emissions by 2050 IMF (2020) World Economic Outlook. A Long and Difficult Ascent Chapter 3			sector emissions modeled in detail	presented with 6 different layers.	regions. 20 sectors modeled. Other sources of greenhouse gas emissions beyond domestic fossil fuel CO_2 emissions are not covered	renewables and energy efficiency and green infrastructure investment requiring public debt increase, and cash transfers to households. Analysis on individual policy effects and the effect of aggregate policy package including all elements	
Weitzel et al. (forthcoming). A comprehensive socio-economic assessment of EU climate policy pathways	2020–2030	European Commission, Joint Research Center and Iopedia	Computable general equilibrium (CGE) model JRC-GEM-E3 The model receives inputs from energy system models PRIMES and POLES-JRC Distributional and labor market impacts analyzed with less aggregated and micro-data	Three main policy scenarios, but with various different specifications	All, except LULUCF emissions. Results reported for all EU countries in total	Regulatory measures that increase ambition on energy efficiency, renewables, and transport Strengthening of the carbon pricing and the EU ETS Mix of the policies Different assumption options on carbon tax revenue recycling options and EU ETS free allowances	Not reported

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
			based simulations				
Böhringer and Müller (2014). Environmental Tax Reforms in Switzerland—A Computable General Equilibrium Impact Analysis	2008–2050	Swiss Society of Economics and Statistics	SWISSGEM-E, a computable general equilibrium (CGE) model for Switzerland, used to assess two alternative policy packages	Two policy scenarios—POM (“Politische Massnahmen Bundesrat”) and NEP (“Neue Energiepolitik”)—which differ in their stringency of reduction targets for long-term CO_2 emissions and electricity demand	The model contains a disaggregate representation of 62 industries, whereby the electricity sector is modeled in explicit technological detail. Switzerland	To comply with the reduction targets for CO_2 and electricity demand we impose respective quotas where the equilibrium shadow prices indicate the level of CO_2 and electricity taxes consistent with the reduction targets	The model includes a detailed representa tion of the Swiss tax system to capture initial tax distortions and thereby the scope for a "second dividend" from revenue recycling of additional

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
							environmental tax income
Sawyer et al. (2021). 2020 Expert Assessment of Carbon Pricing Systems. Canadian Institute for Climate Choices	2005–2030	Environment and Climate Change Canada	The report assesses the carbon pricing systems in 13 Canadian regions as implemented in 2020	To show the distributional range of carbon costs, we explore the implications of three alternative cost pass-through scenarios	Nine broad sectors of large emitters (covering 41 percent of national emissions and 87 percent of all large emitter emissions)	Price- and quantity-based carbon pricing systems	Not reported

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
Winter et al. (2021). Carbon pricing costs for households and the progressivity of revenue recycling options in Canada	Not reported	Smart Prosperity Institute	Statistics Canada's Social Policy Simulation Database and Model (SPSD/M) used to quantify the direct and indirect costs of carbon pricing for households in Canadian regions and across the income distribution, and to identify the net cost to households	Two policy scenarios Four potential revenue-recycling approaches	29 production sectors and 13 regions Canada	Existing output-based pricing system (OBPS) for large emitters and an alternative scenario without output-based allocations of free permits	First order estimates of government carbon pricing revenues derived from households

The Coalition of Finance Ministers for Climate Action

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
He Pou a Rangi Climate Change Commission (2021). Ināia tonu nei: a low emissions future for Aotearoa. Advice to the New Zealand Government on its first three emissions budgets and direction for its emissions reduction plan 2022–2025	2019–2035 (emissions budgets compatible with 2050 target)	He Pou a Rangi Climate Change Commission, New Zealand	Four models used: - ENZ for interactions within the energy system and between different sectors. - Climate Policy Analysis (C-PLAN) model (CGE model) - Distributional Impacts Microsimulation for Employment (DIM-E) - EMarket and I-Gen models to validate electricity modelling in ENZ	4 scenarios for ENZ modelling, and 4 additional scenarios for C-PLAN/DIM-E modelling	ENZ: Energy, industry, and buildings, Transport, Land, Waste and F-gases C-PLAN: All sectors New Zealand	Policies discussed influencing all sectors (e.g. carbon pricing), and also policy directions for each sector discussed	Yes (brief qualitative assessment)
Gourdel et al. (2022). Assessing the double materiality of climate-financial risks in the euro area economy and banking sector. ECB Working Paper Series. Accepted and forthcoming	2020–2050	Vienna University of Economics and Business (WU), EDHEC Business School, EDHEC-Risk Institute, Ca' Foscari University of Venice, World	EIRIN Stock-Flow Consistent model, an open economy model composed by a limited number of heterogeneous and interacting	Four NGFS (2020) scenarios analyzed enhanced with physical risk impacts as in Alogoskoufis et al. (2021):	Whole economy disaggregated into 5 macro sectors: the non-financial sector, the financial sector, households, the government and the foreign sector.	A carbon tax Monetary- and non-monetary renewable energy incentives by the government	Yes (e.g. budget, public debt), but focus on financial stability implications

Reference and name of publication	Timeframe	Organization(s)	Methods and models used	Number of scenarios analyzed	Sectors and countries covered	Policies covered	Fiscal impacts analyzed?
		Bank, European Central Bank	agents of the real economy and financial system. Agents are heterogeneous in terms of source of income and wealth, embedded with bounded rationality and adaptive expectations Banks and firms have “climate sentiments” i.e. introduce climate scenarios’ impact in their investment decisions. EIRIN is adapted to Euro-area specific characteristics in this study	Orderly, disorderly (limited and high physical damages) hot-house world In addition, scenarios of firms’ climate sentiments	The non-financial sector is divided into high- and low-carbon energy and electricity firms, mining firm, labor- and capital-intensive consumption good producers, high- and low- carbon capital good producers, service sector The financial sector is divided into a commercial banking sector, a central bank (conventional and unconventional monetary policy), and a financial market (stocks, bonds) Euro area calibration		

[1] Precision fermentation refers to producing genuine animal proteins through fermentation in laboratories. In this process, encoding genetic material for the desired animal protein is integrated into an efficient host organism (which may be a strain of yeast, other fungi, or bacteria). This host is then cultivated in fermentation tanks where it produces the desired protein in large amounts. The protein is subsequently separated from the host cells and purified. The resulting protein is the same protein as in the original animal-derived product and will exhibit substantially equivalent sensory and functional characteristics in foods (Good Food Institute: gfi.org).

[2] See also the old publications of Joseph Schumpeter on creative destruction.

[3] See the following news articles: The Wall Street Journal (2021); CNBC (2021).

[4] System model refers here in general to a model and the parameters in it that can describe the properties and functioning of the underlying system in question.

[5] See also analyses on climate stress tests such as Battiston et al. (2017), Vermeulen et al. (2018), Alogoskoufis et al. (2021), and Reinders et al. (2021).

[6] https://carbonpricingdashboard.worldbank.org/map_data.

[7] The main results of the analyses are also available at EC (2020[a]).

[8] The IMF-ENV model has been operational for a few months at the IMF, but some aspects are still under development including the draft of documentation. Meanwhile, readers interested in the model can consult the documentation of the two models the current model is built on: the ENVISAGE model (van der Mensbrugghe 2019) and the OECD ENV-Linkages Model (Château, Dellink, and Lanzi 2014).

[9] See www.greenREFORM.dk for more information.

[10] In SFC models, a rigorous accounting framework replaces equilibrium conditions and ensures that overall budget and adding-up constraints cannot be violated.

[11] Calibration refers to the procedure for selecting free parameters to fit the algebraic equation system of the model to the base year or to historical data. See Dixon et al. (2013), *Handbook of Computable General Equilibrium Modelling*, for more information on calibration of CGE models.

[12] https://www.climatecommission.govt.nz/our-work/advice-to-government-topic/inaia-tonu-nei-a-low-emissions-future-for-aotearoa/modelling/.

[13] Database including all SSPs quantifications can be obtained from: https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about.

[14] https://www.ngfs.net/ngfs-scenarios-portal/.

[15] With "processes of change in the economy" Grubb et al. (2021) refer to innovations, diffusion, growth, contraction, reorganisation, or replacement of one or more sets of economic resources, assets, or structures, with another.

[16] www.dreamgroup.dk.

[17] https://www.gtap.agecon.purdue.edu/databases/default.asp.

[18] https://www.worldmrio.com/.

[19] http://www.wiod.org/home.

[20] https://www.exiobase.eu/index.php/about-exiobase.

[21] https://iea-etsap.org/.

[22] For more information on weak signals, please visit: https://www.sitra.fi/en/articles/what-is-a-weak-signal/.