PARIS COLLABORATIVE ON GREEN BUDGETING

INTRODUCTORY NOTE ON INTEGRATING CLIMATE INTO MACROECONOMIC MODELLING

DRAWING ON THE DANISH EXPERIENCE

OECD
BETTER POLICIES FOR BETTER LIVES

The Coalition of Finance Ministers for Climate Action

Organisation for Economic Co-operation and Development

GOV/PGC/SBO(2021)9

Unclassified | English - Or. English

Introductory note on integrating climate into macroeconomic modelling:

Drawing on the Danish experience

This note summarises insights from a Paris Collaborative on Green Budgeting and a Coalition of Finance Ministers for Climate Action workshop with the Danish Ministry of Finance on integrating climate into economic modelling held in February 2021. It provides a description of the ongoing GreenREFORM project carried out by the Danish Ministry of Finance and the Danish Research Institute for Economic Analysis and Modelling (DREAM). It also provides country examples and summarises the key elements of the discussion at the workshop, where countries shared their experiences and perspectives on integrating climate into economic modelling. The workshop's insights are to inform future economic modelling work, the design of the green recovery and the structural change towards a low-carbon transition in the wake of COVID-19.

Contact:
Thomas Braendle (thomas.braendle@oecd.org)

Table of contents

Tables

Figures

Boxes

1. Introduction[1]

A key priority for the decades to come is to reduce greenhouse gas emissions, with an objective of net zero emissions by the middle of the century, to limit climate change. Taxation and public expenditures play a key role in supporting the attainment of climate targets and addressing environmental challenges. Taxing emissions and polluting activities reduces these activities. On the spending side, support for research and investment in green technologies is argued to support the green transition (OECD, 2020[1]). Such economic policy challenges are addressed within international initiatives such as the OECD Paris Collaborative on Green Budgeting and the Coalition of Finance Ministers for Climate Action.

The OECD Paris Collaborative on Green Budgeting was launched at the One Planet Summit in December 2017 to provide a platform to share experiences and good practices on how best to integrate climate and broader environmental goals with the budget process. This includes evaluating environmental impacts of budgetary policies and assessing their coherence towards national and international commitments (OECD, 2020[2]).

The Coalition of Finance Ministers for Climate Action, established in April 2019, works towards mainstreaming climate change in economic and financial policies, and supports global collective actions to address climate change. The Coalition shares best practices, develops knowledge and seeks analytical expertise to support work of Finance Ministries towards low-carbon climate resilient growth. At the Fourth Ministerial Meeting of the Coalition in October 2020, Ministers tasked the Coalition to explore ways to integrate climate in economic modelling (Coalition of Finance Ministers for Climate Action, 2020[3]). According to the work programme of the Coalition, the objective is to identify current approaches, develop new ideas, support countries in their efforts to integrate climate into modelling, and prepare a report to Ministers accordingly. Moreover, it has been recognised that the regular work and long-term effort with the institutional partners is required to make progress, reflecting the importance of economic modelling in order to mainstream climate change considerations in economic policies.

The OECD is one of the Coalition's leading institutional partners with the World Bank, the International Monetary Fund, the European Commission, the Inter-American Development Bank, the United Nations Development Programme. The OECD Paris Collaborative on Green Budgeting acts as one of the main implementation platforms for Helsinki Principle Four on Macroeconomic Management and Public Finance (Box 1).

In February 2021, the Paris Collaborative on Green Budgeting & Coalition of Finance Ministers for Climate Action organised a workshop with the Danish Ministry of Finance on integrating climate into economic modelling. As there is increasing demand and interesting developments at national and international level, this virtual workshop was the first event in a new work stream under Helsinki Principle Four dedicated to economic modelling. The workshop gave an introduction to the state of play with regard to modelling and experiences of Coalition Members. The workshop focused on the GreenREFORM project aimed at developing a climate-economic model for the Danish economy. This model is an analytical tool that aims to provide an integrated assessment of the environmental and climate effects of economic policies, as well as economic effects of environmental and climate policies.

---

[1] This note was written by Thomas Braendle (Senior Policy Analyst, Public Management and Budgeting Division, OECD). The section on the Danish experience was contributed by Mads Dalum Libergren and Jesper Svejgaard (both Danish Ministry of Finance) and Jens Sand Kirk (DREAM). Andrew Burns (World Bank) contributed a paragraph on the World Bank's economic modelling work. Discussions and suggestions from the workshop are gratefully acknowledged, particularly from Ken Clery (Department of Public Expenditure and Reform, Ireland, Chair of the Paris Collaborative on Green Budgeting), and Pierre-Alain Bruchez (Federal Department of Finance, Switzerland) and Germán Romero (Ministry of Finance, Colombia) who served as discussants. The note benefitted from comments by Jon Blondal, Andrew Blazey, Scherie Nicol, Andrew Park, Rob Dellink and Elisa Lanzi, and Pekka Moren.

Economic modelling work as presented by the Danish Research Institute for Economic Analysis and Modelling (DREAM) associated with the Danish Ministry of Finance helps to assess the economic effects of climate policies and, at the same time, serves as a helpful tool to inform the discussion about how economic policies affect climate change. Such analytical tools strengthen evidence-based policy making, inform the design of climate-related policies and are likely to prove particularly useful for key functions carried out in ministries of finance, including regular budgetary planning and policy costing.

Box 1. Helsinki Principle Four

The Helsinki Principle Four 'Take climate change into account in macroeconomic policy, fiscal planning, budgeting, public investment management, and procurement practices' and could, inter alia, include:

- '**Macroeconomic policy'** – consideration of climate change targets, risks, vulnerabilities and policy objectives in economic forecasts, debt sustainability analyses, fiscal risk assessments and other macroeconomic policy instruments; tracking of tax expenditures on fossil fuels and tax incentives for the consumption and production of fossil fuels, feed-in tariffs, investments in low-carbon technologies, and other relevant incentive measures;
- '**Fiscal planning'**– consideration of climate change targets, risks, vulnerabilities and policy objectives in the formulation and implementation of fiscal plans and frameworks and when undertaking expenditure reviews and program evaluations used to inform fiscal policies;
- '**Budgeting'** – integration of climate change policy considerations in budget guidelines, pre-budget statements and budget documents and the tagging of climate-related expenditures, including those that have either a positive or adverse impact on climate outcomes, such as fossil fuel subsidies;
- '**Public investment management**' – integration of climate change considerations and policies in the guidance, procedures and methodologies used for program and project selection and appraisal, including the use of a shadow price of carbon in economic analysis and appropriate assessment of climate change risks and vulnerabilities; and
- '**Procurement'**– integration of climate change considerations in the guidance, procedures and methodologies for public procurement, including appropriate measures to improve energy-efficiency and favor low-carbon solutions.

Source: Coalition of Finance Ministers for Climate Action (2020[4]).

This introductory note summarises the insights of this workshop on integrating climate into macroeconomic modelling held in February 2021. It first provides a concise description of the ongoing GreenREFORM project on integrating climate into economic modelling carried out by the Danish Ministry of Finance and DREAM. In particular, it discusses the policy context in Denmark, the project background, the key elements of the economic model and stylised examples of use cases as well as preliminary key learnings. The note also describes further examples of ongoing economic modelling work by countries and international institutions. Finally, the note provides a summary of the key elements of the discussion at the workshop, where countries shared their experiences and perspectives on integrating climate into macroeconomic modelling. The discussion focused on differences across countries, the importance of cooperation and model transparency and the political acceptability of green reforms and the respective contribution of economic modelling. The workshop's insights will inform modelling work, be considered under all Helsinki Principles, and substantiate the debate about the design of the green recovery and the structural change towards the low-carbon transition in the wake of COVID-19.

2. Danish experience: The Green REFORM project

Policy context in Denmark

Climate is a political top priority for Denmark. In 2020, the Danish Parliament passed a climate law with a clear commitment to reduce greenhouse gas emissions by 70% in 2030 compared to 1990 levels. At the same time, the law states that the target should be met in a cost-efficient manner while taking into account the long-term green transition, healthy public finances and employment while avoiding carbon leakage and maintaining competitiveness, and ensuring social balance.

The Danish Minister of Finance, Nikolaj Wammen, has set out that the green transition should become a central part of the Finance Ministry's core business. As part of this, Denmark is developing a new macro-economic model, GreenREFORM, designed to assess the economic and fiscal impact of climate and environmental policies, as well as the climate and environmental impact of economic policies.

Before new policies are proposed in Denmark, an analysis is undertaken to estimate and weigh possible effects. Traditionally, however, climate and environmental effects have been difficult to estimate in a way that allows for consistent evaluation. The ambition of the GreenREFORM project is to make this possible.

Project background and set up

GreenREFORM is an environmental and climate-economic model for the Danish economy currently in development in collaboration between the Danish Research Institute for Economic Analysis and Modelling (DREAM) and the University of Copenhagen and Aarhus University. DREAM is an independent governmental research institution. GreenREFORM began as a research project at the University of Copenhagen and Aarhus University in 2017. In 2019, the project received funding from the Danish Ministry of Finance. The project goal is to develop an analytical tool that allows for an integrated assessment of the environmental and climate effects of economic policies, as well as the socio-economic effects of energy and climate policies.

An important premise is that the model projections of the economy should provide a comprehensive assessment of how future economic development is expected to affect the environment and climate. Further, the model projections should assess whether this development lives up to the political goals within these policy areas. The ambition is that GreenREFORM could be integrated with the analytical tool set of public authorities, think tanks, interest groups and other relevant organisations, and that the model as well as the underlying data will be publicly available to the extent possible.

The project group is composed of four economists and four research assistants on the project at DREAM. At the University of Copenhagen and Aarhus University, Professor Peter Birch Sørensen leads a research group of six doctoral-students and an adjunct professor, who work on sector specific sub-models. The research project has an advisory board, a board of directors and a large expert group of stakeholders.

The Danish Ministry of Finance has dedicated significant in-house resources to work on the GreenREFORM project to build capacity for integrating the model as an instrument for policy assessment available to both the Ministry of Finance and other ministries. Work that involves a broad set of government departments and stakeholders in the process is currently ongoing. The ambition is that the model will enable a more consistent assessment of the climate impacts of economic policies along with traditional budgetary and fiscal objectives and enable more rigorous evaluations of different climate policy options.

Key elements of the model

The GreenREFORM model consists of a main dynamic computable general equilibrium model (CGE-model) (see Box 2) and several sub-models that describe sectors in the economy that are particularly important in terms of climate and environmental impact (for instance, transport and agriculture). The model describes the total economic activity in Denmark and combines the results of the sub-models. Green-REFORM is designed as a fully integrated model system where all sub-models and the main model are linked and solved simultaneously.

Box 2. Computable General Equilibrium Models

Computable general equilibrium (CGE) models describe entire economies — national or global — and the interactions and mutual dependencies between the sectors within or across economies. They are the dominant tool in energy-economy-environment modelling to *ex ante* assess the impact of climate and climate policies on the economy.

CGE models principally follow the neoclassical theory assumptions of rational choice, utility and profit maximisation, and full information. The models make these assumptions for simplification purposes and reduce it to a tractable state. They seek to explain the behaviour of supply, demand and relative prices across an entire economy with competitive markets.

The models principally consist of agents in an economy, with enterprises maximising profits and households maximising utility depending on commodity prices, until all resources are efficiently allocated and the economy is in general equilibrium. The behaviour of households and enterprises in the model are represented by equations to systematically analyse the effects of policy changes.

CGE models are widely used to simulate the economic effects of climate policies, most commonly carbon taxes. The analysis usually begins with the simulated economy in a general equilibrium condition, based on real-world data. A policy change is then introduced, such as an increase in the carbon price or tax, which causes further changes in the prices of other commodities. Neoclassical theory asserts that the households and enterprises will adjust their consumption and production to maximise their utility and profit under new prices, and that over time supply and demand will converge to another general equilibrium.

There are two main components in a CGE model: its structure and its database. The standard structure is characterised by a relationship between all sectors and subsectors in terms of supply and demand of goods and services. Capital, labour and intermediate resources are inputs for producing a service or good. When the economy is at equilibrium, households, governments, investors and enterprises purchase these goods and services. The database consists of two parts: the flow of spending and income in an economy and the parameter values. The money flows are based on input-output tables.

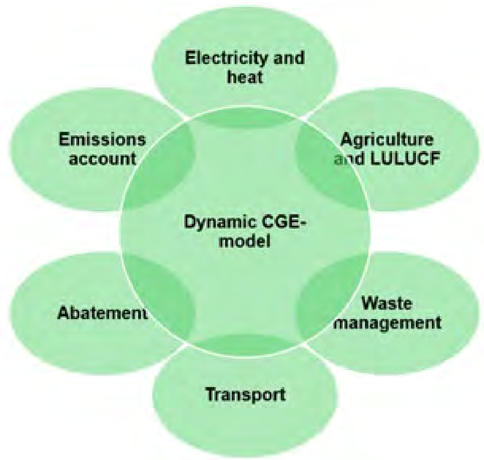
There are many categories of CGE models, including static and dynamic CGE models. Static models look at ‘before and after’ equilibria of the economy after a policy change. Dynamic models have time-variant capital stocks whose availability depends on investment in the previous year. In many cases, CGE models, which are typically set up as top-down models, have been further developed into hybrid models. Hybrid models aim to capture both the representation of economic behaviour found in CGE models and the detailed description within energy system models (so-called bottom-up models). From a policy perspective, this has the advantage of addressing complex energy and climate policy issues by including detailed representation of the energy system and the economic interactions.

Source: (Babatunde, Begum and Said, 2017[5]).

To assess the future impact of climate policy on greenhouse gas emissions and other environmental effects, a model must have a particularly high level of detail in the sectors where the impact is greatest.

The development of GreenREFORM is therefore focused on developing sub-models for sectors such as energy, transportation, waste management as well as agriculture and land use. As the model is designed in a modular fashion, each of the sub-models can be run independently for analysis in contexts that do not demand the full model (Figure.1).

Figure.1. Illustration of the GreenREFORM model and sub-models



Note: LULUCF stands for land use, land-use change and forestry.
Source: Danish Research Institute for Economic Analysis and Modelling (2021[6]).

The model depends crucially on two main data inputs. The first is the national accounts data made available by Statistics Denmark (Statistics Denmark, 2021[7]). The data describes the Danish economy in national accounts terms and provides input-output tables for all relevant sectors (Table 1). Statistics Denmark also supplies the Environmental-Economic Accounts. It complements the traditional national accounts and provides a more comprehensive picture of the economic and environmental development. The Environmental-Economic Accounts are based on internationally agreed guidelines and standards. Environmental-Economic Accounts can highlight the relationship between the economy and the emissions to the environment in a logical manner, based on activity of industries and households. For example, it is possible to compare industry production values or value added to the physical energy and water consumption used in production as well as highlight the resulting waste generation and air emissions.

Table 1. Example of input-output table

	Agriculture	Industry	Construction	Service	Private Consump.	Govt. Consump.	Investment	Export	Total
Agriculture	21	54	1	21	39	1	3	44	184
Industry	17	98	39	45	41	1	59	407	707
Construction	5	3	2	54	4	8	146	10	233
Service	35	93	63	567	636	508	104	415	2422
Import	28	181	39	318	100	5	5	232	982
Factor input and utilisation	107	429	144	1006	821	523	391	1109	4529
Gross value added	78	278	89	1416					1860
Production value	184	707	233	2422					3546

Source: Danish Research Institute for Economic Analysis and Modelling (2021[6]).

The second important input is the catalogues of technology data for energy industries developed and provided by the Danish Energy Agency and the Danish Transmission System Operator Energinet. The catalogues provide information about technology, economy and environmental measures for a number of energy installations (Danish Energy Agency, 2021[8]). They are essential for the GreenREFORM model as they describe the energy alternatives and abatement options available for industries and households and thus are necessary to model the future energy mix and how the agents in the economy will react to, for example, a tax or a subsidy. This, along with the Green-REFORM's description on the production of and investment in new technologies, enables the model to describe how new and cleaner technologies displace existing ones over time, depending on the policies in place (Beck, 2020[9]).

GreenREFORM will be able to describe the emission of pollutants in the Air Emissions Account produced by Statistics Denmark from all Danish businesses, households and the public sector. Furthermore, the model will describe the effect on emissions from environmental taxes, subsidies and command-and-control regulation. This implies a comprehensive description of the taxation and subsidy system.

The model can produce yearly forecasts for each year 2015-2100. The longer into the future the predictions reaches, the more uncertain they are. The data describes 142 different sectors in the economy which are then aggregated to 59 sectors in GreenREFORM to minimise the computational powers required to run the model, but maintain a high level of granularity in the important sectors. The model includes 27 different energy products, for example, oil, gas, and biomass, aggregated from 52 different products in the data. The energy usage in the model is separated into five purposes linked to specific rules of taxation, i.e. emissions covered by the EU Emissions Trading System (ETS), two categories of industrial processes outside the scope of the ETS, transport, and heating. The primary factors of production in the model are labour, machinery, buildings, and vehicles.

Furthermore, the model has a number of key characteristics. Firstly, it is a structural model, but it allows for future addition of business cycle features. For example, a Phillips curve will be implemented to describe the labour market. Secondly, households are partly forward looking and partly myopic – this imposes forward-looking behaviour in technology choice and, for example, makes agents opt for new technology if this will be beneficial to them in the future. Thirdly, companies have perfect foresight but adjust investments and implement new technology sluggishly over time.

Stylised examples and use cases

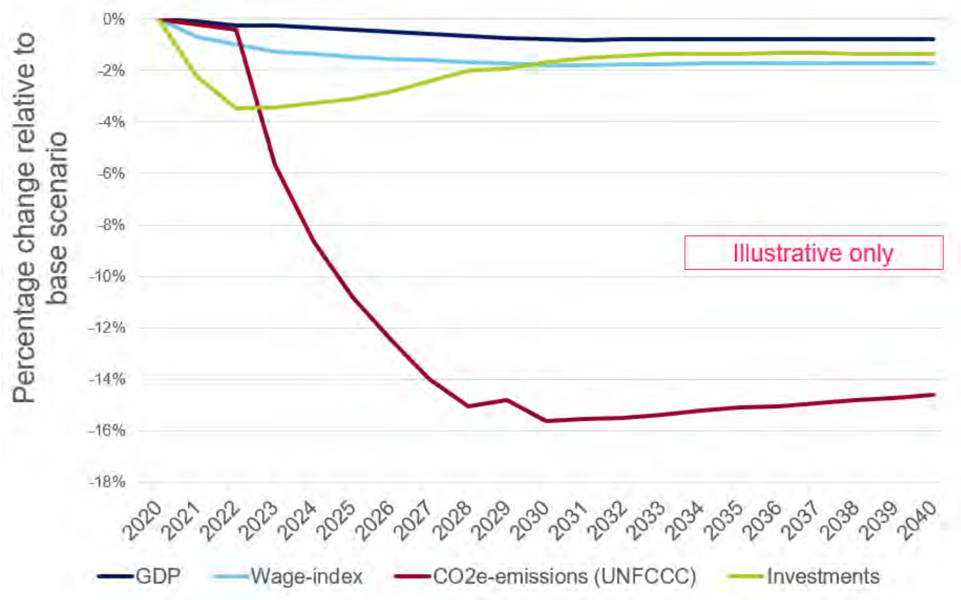
GreenREFORM is being developed with the aim of providing analysis to inform political decisions regarding Denmark's target of reducing green-house gas emissions by 70% in 2030. As GreenREFORM can forecast economic, climate and environment terms until the year 2100, it can also provide analytical insights into long-term strategies for reaching climate neutrality by 2050. When the development of the GreenREFORM model is finished, it will allow both forecasting economic and environmental terms such as GDP, employment, and CO_2 emissions in a no-policy change scenario, as well as simulating effects of policy changes, including taxes and subsidies. Below are examples of questions the model will be able to analyse:

- What happens if a uniform CO_2e tax is introduced?
- What happens if we double the tax on fossil fuels in the heat sector and reduce the tax on electricity by half?
- How much should the subsidy for organic agriculture per hectare be increased to double the area of organic agriculture?
- How will liberalising the waste management sector impact waste import?
- How will different scenarios for rolling out Power-to-X technologies impact the supply of electricity and the electricity price?

- What happens to emissions and the economy if we take out 150.000 hectares of high carbon agricultural land?

Using the model in a policy context will typically include estimating economic as well as climate and environmental effects of a potential policy. The Danish Parliament in 2020 agreed on the first steps towards a green tax reform and commissioned an expert group to develop policy options for introducing a uniform CO_2e tax. As an illustrative example, Figure 2 shows possible effects of introducing a uniform CO_2e tax. As the model is still under development, the figure is purely illustrative of the expected direction of effects and does not represent actual results. It is illustrated that introducing such a tax will impact macro-economic variables such as GDP, wages, and investments negatively. In the short term, investments will be impacted the most since agents are forward looking. The tax will also cause a significant drop in CO_2e emissions.

Figure 2. Illustration of impact of uniform CO_2e tax on macroeconomic variables



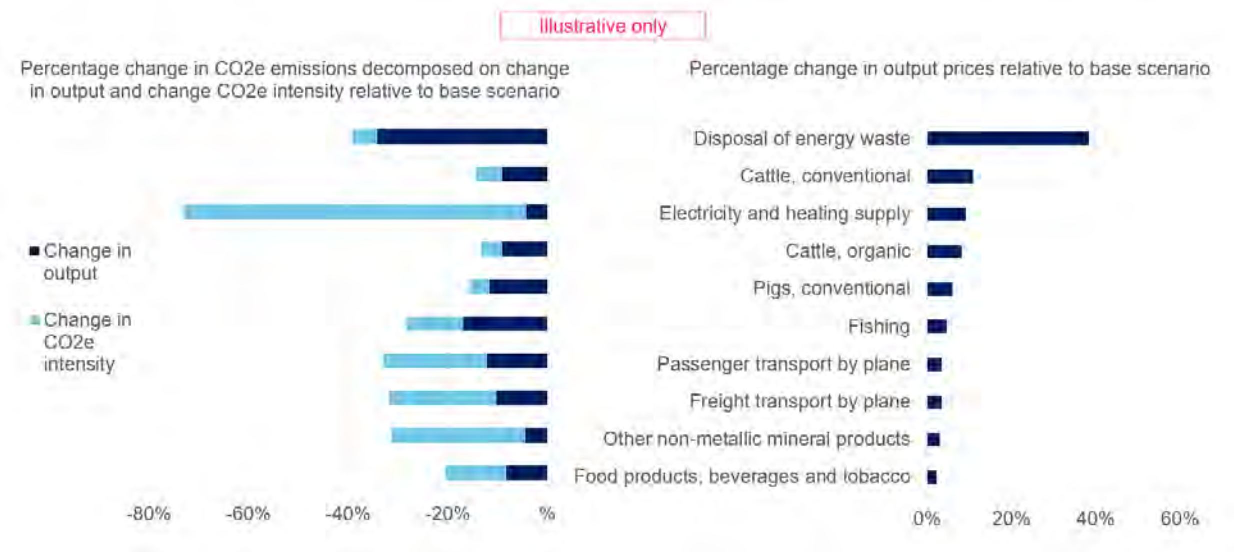
Note: Illustrative only – not actual results, 2021.
Source: Danish Research Institute for Economic Analysis and Modelling (2021[6]).

The GreenREFORM model will be able to estimate the effects of such a tax on different industries. This enables evaluation of which sectors would be most affected by such a tax in terms of loss of output as well as increased energy efficiency expressed as a lower CO_2e intensity.

Figure 3 illustrates the impact on the output prices by sectors (top 10 sectors shown) and the changes in emissions driven by changes in output and changes in CO_2e intensity, respectively. The figure is illustrative only and does not represent actual results, but shows the logic in such an analysis for the model under development. For example, the figure indicates that it could be easier to reduce CO_2e intensity in some sectors, e.g. in the electricity and heating supply, than in other sectors, e.g. agricultural cattle production. This could be caused by better options for substituting to less CO_2e-intensive inputs or better technological abatement options being available in one sector compared to the other. Some sectors will also see higher shifts in output prices than others as exemplified with the disposal of energy waste sector in Figure 3, which, for instance, can be caused by different conditions for competition across sectors. If a given sector sees a large increase in output price (right-hand side of the figure), this is – all else being equal – expected to translate into higher changes in output (left-hand side of the figure) caused by decreased demand. This, however, also depends on other circumstances such as competition and options for substitution in the given sector.

A CO_2e tax will also have different effects on different energy products. For example, while the tax is expected to push up the prices of both electricity and heating, the effect on the electricity price is expected to be much smaller than the effect on the heating price as electricity can easily be imported and the price is therefore to a large degree determined internationally.

Figure 3. Effects of CO_2e tax on CO_2e intensity, output, and output prices by sectors (top 10)



Note: Illustrative only – not actual results, 2021.
Source: Danish Research Institute for Economic Analysis and Modelling (2021[6]).

Learnings from an early stage

GreenREFORM is an ambitious project. While there is still much work to be done before the model is ready to be put to full use within the Danish government, the project has progressed enough to provide initial learnings. First, getting access to the necessary input data and expert knowledge is essential. The GreenREFORM project has approached this challenge by setting up the project around key principles of openness, transparency, and cooperation. For example, it is the ambition to make as much of the model's input data, methodology and code publicly available. Furthermore, the project integrates expert knowledge, for instance, by having frequent meetings with key stakeholders.

Another type of challenge is stemming from modelling technological change, combining descriptions of sectors in economic and energy terms, and integrating several sub-models that describe different sectors. Solving these issues has required new approaches. For example, one or few CO_2-intensive companies can be relatively small in terms of revenue, while they, at the same time, dominate some sectors in the economy in terms of emissions. In such sectors, it is difficult to attain accurate estimates of what effects a CO_2e-tax will have. In GreenREFORM, the approach has been to give the modelling team enough independence, time, and resources to rethink traditional modelling solutions. For example, for the first year of the project, the modelling group was working on providing such solutions and a proof-of-concept. This has been possible owing partly to the high political support for innovation within the field. Another crucial element for successful innovation has been to establish close ties between the modelling group and academia. The GreenREFORM project has close connections to several research projects that have provided ground-breaking modelling work to the project. In addition, the modelling team at DREAM has worked closely together with both the experts at Statistics Denmark, the Danish Energy Agency, and multiple other ministries, agencies, and institutions to ensure data structures and technology catalogues are are compatible with the model and that the data and modelling are generally reliable and accurate.

Looking ahead, a third challenge will be to continually ensure support for the economic model, i.e., that politicians, experts, stakeholders, and other opinion makers accept and consider the model accurate and adequate. Here, it is important to remain open to input from experts and make sure channels are in place for receiving such input, for instance, hearings with experts in which modelling decisions are presented and experts can provide feedback. In addition, it is important to make sure that the model will be able to provide answers to the questions faced by decision makers. For example, the emissions account in the model should follow international standards, and the model should have the capacity to evaluate carbon leakage, competitiveness of the economy, and welfare consequences. The challenges of proper accounting, carbon leakage and maintaining competitiveness and social balance are important in the green transition of the economy.

Adhering to the principles of openness and cooperation, the solutions developed in GreenREFORM as well as other learnings are shared through the project website and through national and international partnerships like the Coalition of Finance Ministers for Climate Action. The Danish Ministry of Finance will engage with Country Members and Institutional Partners of the Coalition as well as with the Paris Collaborative for Green Budgeting to share lessons learnt from the project and engage in work on how to develop modelling capacity and contribute to a stronger evidence base for cost-effective climate action.

3. Other international developments

Several governments and international organisations are working on integrating climate into economic modelling to support decision-making and inform the design of policies. This section briefly describes selected recent efforts at national and international level.

Models at national level

Ireland

The Economic and Social Research Institute developed a dynamic computable general equilibrium (CGE) model – called I3E - for the Irish economy. It is similar in its principle structure to other CGE models, such as the GreenREFORM model or the the ENV-Linkages model developed by the OECD (see below).

In addition to monetary flows between enterprises, households and the government, energy flows and carbon emissions are modelled. This allows the emission reduction due to a particular policy to be assessed. A set of carbon commodities is explicitly included, such as peat, coal and natural gas. The various sectors of the Irish economy are represented by production activities that choose the cheapest way to produce, from their options for capital, labour, energy and other production inputs. The EU Emissions Trading Scheme is also represented.

Production is comprised of 32 representative enterprises that produce multiple products. The ten representative households are distinguished by income level - making it possible to analyse the distributional impacts of policies on households. Moreover, there are three labour types, based on skill level, allowing investigation of distributional effects across labour types. However, the labour supply is exogenous and there is no representation of unemployment. In the case of labour demand is reduced in a certain sector, it is assumed the affected employees find employment in another sector with higher demand. Economic growth comes from the growth of employment driven by population growth and the growth of technology. These variables are obtained from a separate economic model, named COSMO (National Economic and Social Council, 2020[10]).

There are two studies by the Economic and Social Research Institute applying this model to investigate the economic effects of increasing the Irish carbon tax towards 2030 (de Bruin and Yakut (2019[11]), de Bruin, Monaghan and Yakut (2019[12])). The first study analyses two carbon tax scenarios while the second study is concerned with the distributional impacts of an increased carbon tax depending on different revenue recycling schemes. Further research by the Economic and Social Research Institute using this model involved investigating the regional labour impacts of the transition to a low-carbon economy and the effects of eliminating Irish government fossil-fuel subsidies on the economy.

Norway

Statistics Norway uses a CGE model ("SNoW") to analyse energy and climate policies. This CGE model features a detailed emissions module and can model climate policy instruments, including uniform or differentiated taxes, national or international (EU ETS) quota markets, prohibitions, technical standards, subsidies, funds, and border carbon adjustments. Abatement of energy-related emissions take place by fuel switching, substitution of other goods for energy, or by scaling down production and/or consumption.

The main underlying data are the input-output tables in the Norwegian National Accounts. The dataset includes up to 46 industries and up to 25 final consumption goods. The CGE model computes annual levels for supply and demand as well as domestic prices for a number of goods, services and production factors (labour, capital, energy) as well as emissions of greenhouse gases and welfare costs.

There is one representative household in the CGE model. The representative producer in each sector maximises profits. The energy goods comprise coal, crude oil, natural gas, refined oil products and electricity (Oslo Centre for Research on Environmentally Friendly Energy, 2021[13]). SnoW has been recently used, for instance, to quantify the marginal cost curves for EU-non quota emissions, i.e., what levels of uniform CO_2 prices are compatible with various emission targets for 2030 to assess the economic costs of linking the Norwegian climate policy for the non-quota sector to the EU (Bye and Rosnes, 2019[14]). Statistics Norway plans to enrich the CGE to better incorporate technologies and distributional impacts by splitting up the representative household into income groups. In line with the Norwegian Climate Act, there is also a broader effort to improve methods to assess the socio-economic and budget effects of climate policies, including the economic modelling that take into account climate and climate policies, within the mandate of the Technical Committee for Climate (Technical Committee for Climate, 2020[15]).

Switzerland

Under the Paris Agreement on Climate Change, Switzerland has committed to halve its GHG emissions by 2030 compared with 1990 levels. The Federal Council aims for net zero emissions by 2050, as defined in its long-term climate strategy to 2050.

In Switzerland, an economic consultancy firm, in cooperation with academia, developed a CGE model that is often used to assess the impact of climate and energy policies, the so-called SWISSGEM-E (Böhringer and Müller, 2014[16]). It builds upon general equilibrium theory that combines assumptions regarding the optimising behaviour of economic agents: enterprises combine primary factors and intermediate inputs at the least cost subject to technological constraints; given preferences, households maximise their well-being subject to budget constraints. The simultaneous explanation of the origin and spending of the agents' incomes makes allows studying economy-wide efficiency and distributional impacts of economic policies.

SWISSGEM-E emphasises features that are central to the debate on environmental and energy policy reforms. The model includes a description of the tax system to capture initial tax distortions. Technologies for generating electricity which determine the adjustment costs to CO_2 emission constraints are described in a detailed bottom-up fashion based on discrete activity analysis. To assess the incidence of green reforms, the household sector is decomposed into multiple types of households based on socio-economic criteria such as standard of living, work situation, and family status (Böhringer and Müller, 2014[16]).

For instance, this model has been used to assess the impact of a green tax reform proposal containing alternative revenue recycling strategies which go beyond lump-sum transfers, such as cutbacks in value-added taxes, corporate profit taxes, payroll taxes, and income taxes.[2] Revenue recycling plays an important role in the alleviation of adverse distributional impacts triggered by policy reforms. The analysis shows that compliance with ambitious CO_2 targets requires high CO_2 taxes. With a green tax reform, economic adjustment cost to a low carbon economy without nuclear energy remains modest and can be markedly reduced through revenue-neutral cuts of initial distortionary taxes. This model also supports work around the Energy Perspectives 2050+ that analyse the target of net zero greenhouse gas emissions.

United Kingdom

The UK became the first major economy to implement a legally binding net zero target in 2019. In this context, innovative initiatives have recently been taken to better account for climate change in decision-making. For instance, in December 2020, the first "Net Zero Review" (interim) report was published (HM Treasury, 2020[17]).

The Climate Change Committee noted that "if policies are not sufficiently funded or their costs are seen as unfair, then they will fail" and recommended that the Treasury undertake a review to consider:

- "how the costs of achieving net zero emissions are distributed and the benefits returned[…] the fiscal impacts, risks of competitiveness effects and the impacts of decarbonisation across the whole economy"; and
- "the full range of policy levers, including carbon pricing, taxes, financial incentives, public spending, regulation and information provision."

The interim report finds that the transition to net zero will create new opportunities for economic growth and job creation across the country. The demand for low-carbon goods and services will encourage new industries to emerge, with the potential to boost investment levels and productivity growth. Co-benefits from decarbonisation, such as improved air quality, can also be economically significant. However, reaching net zero will also involve costs and lead to significant structural change.

Government needs to use a mix of policy levers to address multiple market failures and support decarbonisation. In this context, well-designed policies can reduce costs and risk for investors, support innovation and the deployment of new technologies. Moreover, the report underlines that the risk of carbon leakage will increase with efforts to reduce emissions. Finally, the report emphasises that households are exposed to the transition through their consumption, labour market participation and asset holdings. Government needs to consider these patterns of exposure in designing policies for the transition. The final report will be published in spring 2021. This will build on the interim report, including by looking at innovation and growth, competitiveness, impacts on households. The final report will also detail how HM Treasury could incorporate climate considerations into spending reviews and fiscal events and how the principles of the Net Zero Review could be embedded into policy-making across government.[3]

---

[2] For an overview, see the official project web page of the Federal Finance Administration (2021[29]).

[3] Closely related, the UK Office for Budget Responsibility (OBR) included a discussion of climate-related fiscal risks in their fiscal risk report for the first time in 2019. While the assessment is qualitative, the OBR plans collaboration with the Bank of England to see how financial stability stress-testing scenarios can be adapted. Further collaboration is envisaged with the OECD Network of Parliamentary Budget Offices and Independent Fiscal Institutions and the OECD Network for Greening the Financial System (Office for Budget Responsibility, 2019[30]).

Models by international institutions

European Commission

The General Equilibrium Model for Economy-Energy-Environment (GEM-E3) is a multinational collaboration project partly funded by the European Commission. It is regularly used to provide support to European Commission services, especially on the economics of climate change (Capros et al., 2013[18]). The GEM-E3 represents 38 regions and 31 sectors linked through endogenous bilateral trade flows. The economic agents in the model maximise profit or utility, while the prices, derived from supply and demand interactions, guarantee global equilibrium. The model has a bottom-up representation of power-producing technologies, learning-by-doing effects, equilibrium unemployment, and options to introduce energy efficiency standards and emission permits and pollutants. There is also a variety of emission abatement policy instruments modelled, including different allocation schemes (for instance, grandfathering and auctioning), user-defined bubbles for traders, and various exemptions and revenue-recycling systems.

The model emphasises the analysis of market instruments for environmental policy and supports the analysis of distributional effects, both among countries and among social and economic groups in each country. The GEM-E3 has been recently combined with the Household Budget Survey to assess the distributional impacts of climate policy in the context of the European Green Deal (Temursho, Weitzel and Vandyck, 2020[19]). Further examples of analyses that GEM-E3 has undertaken include contributing to the EU's 2030 Climate and Energy Framework and the EU's preparation of the international climate negotiations at COP21 in Paris in 2015.

International Monetary Fund

The World Economic Outlook (IMF, 2020[20]) examines the combinations of climate change mitigation policies needed to bring net carbon emissions to zero by 2050 and how they may impact the macroeconomy. To this end, they use a CGE model to simulate the effects of mitigation policies, given that these affect the economy through various channels and come with both negative and positive effects on output as some sectors contract and others expand.

Policy simulations use the G-Cubed global macroeconomic model (McKibbin, and Wilcoxen, 2013[21]). This model features ten countries/regions, 20 detailed energy sectors, real and nominal rigidities, and fiscal and monetary policies. It incorporates different types of households and enterprises. Enterprises are modelled separately within each sector. There is a mixture of two types of households and two types of enterprises within each sector: one group bases their decisions on forward-looking expectations and the other group follows simpler rules of thumb which are optimal in the long run, but not necessarily in the short run. The model is suited to examining the effects of mitigation policies on carbon emissions and on the macroeconomic dynamics in the short, medium, and long term. The International Monetary Fund presents several policy scenarios, including an increase of carbon taxes to reach the net zero emission target in 2050, enhanced green public investment and green subsidies, and combinations thereof. The goal of such simulations is to illustrate the main causal mechanisms at work and provide some order of quantification. The exact magnitudes in these long-term projections are unavoidably subject to substantial uncertainty.

OECD

The OECD deploys a global dynamic general equilibrium model ("ENV-Linkages") to assist governments with decision-making and study the medium-to-long-term impacts on macroeconomic variables such as GDP from a range of climate-change mitigation and environmental policies.

Economic activity is aggregated into 50 sectors, while eight distinct electricity production technologies are specified, each with its own carbon emission parameter, determined from the International Energy Agency. Households are included as a representative consumer that allocate their disposable income according to preferences on commodities. A representative electricity producer maximises profit by using the available energy technologies – fossil fuels, hydro and geothermal, solar and wind, and renewable combustibles and waste. Emissions from sources other than the combustion of fossil fuels, including process emissions of CO2 and emissions of other greenhouse gases, are linked to sectoral activity. The governments collect taxes and can also provide subsidies and transfers to households (Chateau, Dellink and Lanzi, 2014[22]).

The ENV-Linkages model has been used to analyse competitiveness and carbon leakage in the face of climate policies (Lanzi et al., 2013[23]), the impact on emissions of reducing fossil-fuel subsidies (Burniaux and Chateau, 2010[24]), the damages from climate change on the economy (OECD, 2015[25]) and – particularly relevant to identifying vulnerable sectors of the economy during a transition – the labour-market effects of mitigation policies (Chateau, Bibas and Lanzi, 2018[26]). The results of this research suggest that the impact of climate and energy policies is generally small and overall positive, provided that the emission reduction targets are not too ambitious and carbon-tax revenues are recycled to lower income households. Low-skilled workers are found to be more affected by the policies than other workers.

World Bank

Several World Bank models are focused on detailed modelling of specific aspects of climate change, including poverty impacts, supply-chain effects of disasters, and agriculture impacts. A second set of tools use global databases to do quick diagnostics, including first-order approximation of impacts of carbon pricing on emissions, pollution and health. A third set are focused on providing central economic ministries with tools that fit into their daily work flow, but which also incorporates emissions, mitigation policies, climate economic damages and adaptation policy. The objective here is to bring climate outcomes into the mainstream alongside other policy priorities such as unemployment, inflation, growth and fiscal sustainability. The modelling platforms used for this third strategy include macrostructural models using the Bank's MacroFiscalModel framework (MFMod) and dynamic recursive CGE models using the MANAGE (Mitigation, Adaptation and New Technologies Applied General Equilibrium) and ENVISAGE (Environmental Impact and Sustainability Applied General Equilibrium) frameworks with more structural detail, including more than 50 sectors (Burns, Zebaze and Prihardini, 2018[27]).

4. Discussion

The current state of energy-economy-environment models appears sophisticated and the Danish project represents an advanced practice example. The workshop's discussion highlighted several critical dimensions relevant for integrating climate into economic modelling work itself as well as challenges economic modelling work faces when informing the policy debate and policy design.

Differences across countries matter for economic modelling work

In terms of integrating climate into economic modelling, it was highlighted that different national contexts regarding the energy supply structure, the sectoral structure and the state of development imply different policy challenges and priorities. For instance, while the primary climate policy challenge in high income countries is to de-carbonise, in developing countries, the primary challenge is not to carbonise. These differences lead to differing approaches to integrating climate into economic modelling across countries. Approaches also differ across government departments and agencies within countries. While ministries of finance or ministries of economy demand economic models that analyse effects on the macro economy and public finances (often by means of CGE models), ministries of energy and environment demand technically more challenging bottom-up models that represent the various sectors in greater detail.

In the discussion, it was underlined that economic models that integrate climate to inform policy-making should be easy to use, incorporate optimising behaviour by economic agents, accurately reflect climate and energy processes (for instance, emissions generation and technology adoption) and address key policy issues, including distributional consequences and competitiveness concern.

The importance of cooperation and model transparency

Countries, such as Chile and Colombia, reported that modellers in research institutes and universities should closely cooperate with policy officials across government departments and key stakeholders when setting up an economic modelling framework to integrate their respective expertise. This strategy also helps promote the understanding of the modelling work, including its benefits and limitations and may provide practical guidance on how an easy-to-use economic model that integrates climate could look like.

Transparency in model development and application is important for informing public policy. Consistent with the Danish experience, country experience suggests that a transparent approach to modelling is key. It should include articulating the underlying assumptions and data as well as communicating the limitations of and uncertainty surrounding economic modelling. By making model source codes publicly available, third parties can principally reproduce model results, an essential quality in science.

At the same time, economic modellers, policy officials and decision-makers should be aware of the fact that such models are not suited to address all kinds of policy questions related to climate. Policy-makers should recognise that economic modelling is a tool for debate rather than a comprehensive answer to complex and multi-faceted questions. To properly evaluate the results from economic modelling work, policy-makers should have an understanding of the economic models, including the models' purpose and its strengths and weaknesses.[4] Without such understanding, model results are likely to be misinterpreted.

Political acceptability of green reforms and the contribution of economic modelling

Building acceptance is a key condition for successful introduction of green reforms. The discussion highlighted experiences and learnings from green reform efforts that centre on the political acceptability of green reforms. These experiences, in turn, are highly relevant to the question of what elements should be considered as a pre-requisite when integrating climate into economic modelling to inform the policy debate.

Drawing from experiences on green reforms debates, it was first emphasised that insights from economic modelling may run the risk of overly emphasising the strengths of a specific economic modelling approach, for example, an innovative approach to technology adoption, while neglecting potential weaknesses of the economic modelling approach that may become important in the political debate, such as the modelling of distributional consequences of green reforms.

Second, while many stakeholders may abstain from commenting on the modelling work, they may still criticise weaknesses and seriously put into question its key results in the public debate. In this context, it is important to underline that the model results have to be understood as insights on how policy measures impact key economic outcomes based on certain assumptions rather than interpreting the quantitative results as predictions. This latter insight also involves emphasising the substantial uncertainty surrounding the assessments of the long-term effects of climate and climate policies by means of economic modelling.

Another experience from the national level is that attention should be paid to the baseline scenario and its underlying key assumptions and socioeconomic drivers to comprehensively assess the impact of climate effects in policy scenarios (Dellink, Van der Mensbrugghe, and Saveyn, 2020[28]).

---

[4] For instance, a collaborative review by researchers across the UK discussed key considerations when using modelling to support decision-making, including understanding of different models' use and its underlying critical assumptions by key stakeholders, model construction in close cooperation with key stakeholders, and awareness among modellers and users of the opportunities that could transform policy-making (Calder et al., 2018[31]).

The discussion also highlighted that the economic modelling approach should feature sufficient granularity to identify key policy dimensions, such as the distributional consequences and the impacts on international competitiveness. For instance, environmentally-related taxes, particularly energy taxes, can have a regressive impact on the income distribution of households. Therefore, it is critical to assess how different modes of revenue recycling, for instance, reductions in other taxes and social security contributions or lump-sum transfers impact the income distribution across households and may alleviate the regressive impacts of green taxes. Another obstacle to the implementation of green reforms, and particular climate-related taxes is often the fear of reduced international competitiveness in the most polluting and energy-intensive sectors. Therefore, a key question is how the decision of companies opening or relocating their production sites is affected by domestic climate-related policies and how this, in turn, may lead to carbon leakage. This issue requires a political decision on the exemption rule for energy intensive sectors (for instance, cement industry) defining the relative burden of non-exempted sectors and private households. More generally, this issue requires balancing environmental goals with competitiveness concerns.[5]

Finally, economic modelling work that integrates climate presupposes the political buy-in by key political decision-makers and senior officials, for instance, the support of the finance ministry or a key line ministry. To increase political buy-in, coordination efforts across government departments and agencies to compellingly communicate and showcase the value of the economic modelling work can prove helpful, for instance by means of applying pilots for specific policy areas.

5. Concluding remarks

This introductory note summarised key insights and discussions from a Paris Collaborative on Green Budgeting & Coalition of Finance Ministers for Climate Action workshop with the Danish Ministry of Finance on integrating climate into economic modelling held in February 2021.

The workshop's insights are to inform future economic modelling work and benefit the debate on the design of the green recovery and the speed up of a cost-effective structural change towards the low-carbon transition in the wake of COVID-19. More concretely, it contributes to the work undertaken within the Paris Collaborative on Green Budgeting and under the Helsinki Principle Four, including efforts in advanced economies as well as in emerging and developing countries.

The Danish experience underlines the importance of political leadership and the need to invest in technical work and expertise to achieve progress with climate goals. As the Danish experience also shows, economic models that integrate climate can be used on different scales when the modelling framework contains separate modular sub-model blocks, for instance, for specific energy sectors that then can be integrated into a more general modelling framework step-by-step. Countries have already benefitted from modelling efforts by Denmark. Countries such as Indonesia, Mexico and Vietnam have developed their own energy technology catalogues building on the approach developed by the Danish Energy Agency. In close cooperation with the Danes and country experts, building capacity to develop technology catalogues adapted to country-specific conditions and data was key to ensure climate-related dynamics are better modelled in each of the respective economies. Such initiatives could become building blocks for integrating climate into new economic models as has been the case with the Danish GreenREFORM project.

A relatively small number of countries are using macro-economic models that incorporate climate aspects. The role of academia and institutional partners collectively, as well as engagement of Coalition Members to experiment these models, is necessary to make progress. The economic models need to be adjusted to the country-specific circumstances, and therefore, training and education will also play an important role moving forward, requiring a collective long-term effort.

[5] For a discussion of the political economy of environmentally-related taxes, see (OECD, 2006[32]).

In light of ambitious climate targets and a green recovery in the aftermath of COVID-19, it will be important to use robust economic modelling to assess both the economic impact of climate policies and the climate effects of economic policies. Economic modelling that integrates climate is likely to become a critical function to be delivered by ministries of finance – often in coordination with line ministries. Therefore, it will be crucial to integrate economic modelling work that takes into account climate into the workflow of ministries of finance, including for regular budgetary planning and policy costing.

References

Babatunde, K., R. Begum and A. Said (2017), “Application of computable general equilibrium (CGE) to climate change mitigation policy: a systematic review.”, *Renewable and Sustainable Energy Reviews* 78, pp. 61-71. [5]

Beck, U. (2020), *Technology catalogs in GreenREFORM*, Danish Research Instiute for Economic Analysis and Modelling, https://dreamgroup.dk/media/11408/technology-catalogs-in-greenreform.pdf. [9]

Böhringer, C. and A. Müller (2014), “Environmental Tax Reforms in Switzerland: A Computable General Equilibrium Impact Analysis”, *Swiss Journal of Economics and Statstics*, Vol. 150/1, pp. 1-21. [16]

Burniaux, J. and J. Chateau (2010), *Mitigation potential of removing fossil fuel subsidies: a general equilibrium assessmentine.*, OECD Publishing, Paris, https://doi.org/10.1787/5kgdx1jr2plp-en. [24]

Burns, A., C. Zebaze and D. Prihardini (2018), *Good Practice Note 7: Modeling Macroeconomic Impacts and Global externalities*, World Bank, Washington DC, http://documents1.worldbank.org/curated/en/815971530883640016/pdf/ESRAF-note-7-Modeling-Macroeconomic-Impacts-and-Global-externalities.pdf. [27]

Bye, B. and O. Rosnes (2019), *Marginal Abatement Costs under EU Regulation*, Statistics Norway, Reports 10/19. [14]

Calder, M. et al. (2018), “Computational modelling for decision-making: where, why, what, who and how.”, *Royal Society Open Science*, Vol. 5: 172096., http://dx.doi.org/10.1098/rsos.172096. [31]

Capros, P. et al. (2013), *GEM-E3 model documentation*, Joint Research Centre, Scientific and Policy Reports, EUR 26034 EN. [18]

Chateau, J., R. Bibas and E. Lanzi (2018), *Impacts of Green Growth Policies on Labour Markets and Wage Income Distribution*, OECD Publishing, Paris, https://doi.org/10.1787/19970900. [26]

Chateau, J., R. Dellink and E. Lanzi (2014), *An Overview of the OECD ENV-Linkages Model: Version 3*, OECD Environment Working Papers No 65, OECD Publishing, Paris, https://dx.doi.org/10.1787/5jz2qck2b2vd-en. [22]

Coalition of Finance Ministers for Climate Action (2020), *Explanatory Notes to the Helsinki Principles*, https://www.cape4financeministry.org/sites/cape/files/inline-files/Explanatory%20Note%20-final.pdf. [4]

Coalition of Finance Ministers for Climate Action (2020), *The Coalition of Finance Ministers for Climate Action: An Overview*, https://www.financeministersforclimate.org/sites/cape/files/inline-files/FM%20Coalition%20-%20Brochure%20April%2022%20update.pdf. [3]

Danish Energy Agency (2021), *Technology Data*, https://ens.dk/en/our-services/projections-and-models/technology-data. [8]

Danish Research Institute for Economic Analysis and Modelling (2021), *GreenREFORM*, https://dreamgroup.dk/greenreform/. [6]

de Bruin,, K. and A. Yakut (2019), *The effects of an incremental increase in the Irish carbon tax towards 2030*, Economic and Social Research Institute (ESRI). [11]

de Bruin, K., E. Monaghan and A. Yakut, (2019), *The economic and distributional impacts of an increased carbon tax with different revenue recycling schemes*, Economic and Social Research Institute (ESRI), Research Series. [12]

Dellink, R., D. Van der Mensbrugghe, and B. Saveyn (2020), “Shaping Baseline Scenarios of Economic Activity with CGE Models: Introduction to the Special Issue”, *Journal of Global Economic Analysis*, Vol. 5/1, pp. 1-27, http://dx.doi.org/10.21642/JGEA.050101AF. [28]

Federal Finance Administration (2021), *Incentive system for climate and energy policy*, https://www.efv.admin.ch/efv/en/home/themen/projekte/lenkungssys_klima_energieb/uebersicht.html. [29]

HM Treasury (2020), *Net Zero Review: Interim Report*, Policy Paper, HM Treasury, London, https://www.gov.uk/government/publications/net-zero-review-interim-report. [17]

IMF (2020), *World Economic Outlook, October 2020: A Long and Difficult Ascent*, International Monetary Fund, Washington DC, https://www.imf.org/en/Publications/WEO/Issues/2020/09/30/world-economic-outlook-october-2020#Full Report and Executive Summary. [20]

Lanzi, E. et al. (2013), *Addressing Competitiveness and Carbon Leakage Impacts Arising from Multiple Carbon Markets: A Modelling Assessment*, OECD Publishing, Paris, http://dx.doi.org/ttps://dx.doi.org/10.1787/5k40ggjj7z8v-en. [23]

McKibbin,, W. and P. Wilcoxen (2013), *A Global Approach to Energy and the Environment: The G-Cubed Model*, Chapter 17 in Handbook of Computable General Equilibrium Modelling, 995–1068. North Holland: Elsevier. [21]

National Economic and Social Council (2020), *Modelling the Zero-Carbon Transition: International Approaches and Lessons for Ireland*. [10]

OECD (2020), *Green budgeting and tax policy tools to support a green recovery*, http://www.oecd.org/coronavirus/policy-responses/green-budgeting-and-tax-policy-tools-to-support-a-green-recovery-bd02ea23/. [1]

OECD (2020), *OECD Green Budgeting Framework: Highlights,*, OECD Publishing, Paris, http://www.oecd.org/environment/green-budgeting/OECD-Green-Budgeting-Framework-Highlights.pdf. [2]

OECD (2015), *The Economic Consequences of Climate Change*, OECD Publishing, Paris, [25] https://dx.doi.org/10.1787/9789264235410-en.

OECD (2006), *The Political Economy of Environmentally Related Taxes*, OECD Publishing, Paris, https://doi.org/10.1787/9789264025530-en. [32]

Office for Budget Responsibility (2019), *Fiscal Risks Report*, UK Office for Budget Responsibility, London, https://obr.uk/frr/fiscal-risks-report-july-2019/. [30]

Oslo Centre for Research on Environmentally Friendly Energy (2021), *SNoW-NO Statistics Norway's World model for Norway official webpage*, https://www.cree.uio.no/models/snow/. [13]

Statistics Denmark (2021), *Environmental-Economic Accounting*, https://www.dst.dk/en/Statistik/dokumentation/groent-nationalregnskab. [7]

Technical Committee for Climate (2020), *Rapport fra Teknisk beregningsutvalg for klima 2020*, Government of Norway, Technical Committee for Climate, https://www.regjeringen.no/no/dokumenter/rapport-fra-teknisk-beregningsutvalg-for-klima-2020/id2721888/. [15]

Temursho, U., M. Weitzel and T. Vandyck (2020), *Distributional impacts of reaching ambitious near-term climate targets across households with heterogeneous consumption patterns*, European Commission, Joint Research Center, http://dx.doi.org/doi:10.2760/89463. [19]