Framework Convention on
Climate Change

Katowice Committee of Experts on the Impacts of the Implementation of Response Measures

Impacts of the implementation of domestic and global response measures

Case study on Maldives

Abbreviations and acronyms

CES	constant elasticity of substitution
CGE	Computable General Equilibrium
CO_2	carbon dioxide
CO_2 eq	carbon dioxide equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
GAMS	General Algebraic Modeling System
GDP	gross domestic product
GHG	greenhouse gas
GTAP	Global Trade Analysis Project
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
MIRO	Model Interface with Rapid Orchestration
NDC	nationally determined contribution
PV	photovoltaic(s)
Q	quintile
SACU	South African Customs Union
SAM	social accounting matrix
SDG	Sustainable Development Goal
SIDS	small island developing State(s)
SSP	Shared Socioeconomic Pathway
UNFCCC	United Nations Framework Convention on Climate Change

Contents

Page

I. Introduction

A. Background and motivation

Global warming, caused mostly by human activities, threatens natural ecosystems as well as human and economic systems. Global warming is arguably the largest environmental externality facing economies, international organizations, citizens and the world's ecosystems and addressing this global crisis requires a reorientation of economic systems (Carney, 2020). Climate is a global public good. As such, remedying existing effects of global climate change and preventing future effects requires the implementation of coordinated response measures[1] as well as action to address their (potentially negative) impacts.

There is a compelling need within the international climate regime to better understand the impacts of the implementation of climate policies and actions in order to spur ambitious mitigation and adaptation action. The regime stands to benefit from the sharing of national and subnational experience, examples and case studies of the impacts of the implementation of response measures across developing country and small island regions.

The aim of this case study is to support informed policymaking by providing insights into the impacts of the implementation of global and domestic response measures and identifying possible unintended spillover effects thereof. The study makes use of a toolkit based on two CGE models, which are quantitative assessment tools that are widely used within international organizations such as the United Nations, the World Bank and the European Commission. The selection of the CGE models was guided by a report by Cambridge Econometrics (2015) and workshop in 2018, under the UNFCCC forum on the impact of the implementation of response measures, on the use of economic modelling tools for understanding the assessment of the impacts of the implementation of response measures. The findings from CGE impact assessments complement insights obtained from other quantitative and qualitative tools to inform the policy process aimed at maximizing the positive and minimizing the negative impacts of the implementation of response measures.

Maldives, like many SIDS, is a low-lying island that faces a double threat from climate change despite contributing only 0.003% of total global emissions: first, its infrastructure and natural resources are directly affected by increased extreme weather events and adverse climate trends, such as rising sea levels and biodiversity loss; second, its location, reliance on fossil fuels for energy, and narrow economic base with a strong reliance on tourism make it vulnerable to the impacts of climate policies on import prices, export demand and demand for tourism, which many island economies rely upon, via the impact on oil prices and transport costs.

Maldives has pledged to reduce its emissions by 26% by 2030[2] and to strive to reach net zero emissions by 2030. Since its emissions in 2030 are projected to be 3,284.92 Gg CO_2 eq under a reference scenario (Ministry of Environment, 2020), this means reducing them by 854.08 Gg CO_2 eq. The implementation plan (Ministry of Environment, 2018) that accompanies the NDC puts forward several options for reducing emissions, including increasing the share of renewables in the energy mix, which is considered in this case study alongside global response measures.

Mitigating climate change is costly. Communicating the costs is difficult because mitigation requires action now and causes costs in the short and medium term, while the costs of climate change, such as sea level rise, will be felt mainly in the long term. However, extreme events that SIDS experience today, such as storms, tropical cyclones, floods, drought and marine heat waves, demonstrate the vulnerability of small islands' ecosystems and human and economic systems to climate change.

Despite contributing only a small proportion of global emissions, SIDS are especially vulnerable to climate change: they face particularly high costs of adaptation to adverse climate trends and extreme weather events; and their economic structure and location, such as reliance on fossil fuels for energy and transport and reliance on tourism for income, make them vulnerable to the impacts of the implementation of climate policies.

[1] Defined as policy responses to climate change in the form of mitigation policies, programmes and actions implemented by Parties under the Convention, the Kyoto Protocol and the Paris Agreement.

[2] Target is given relative to the projected emissions to 2030 under a Business As Usual scenario with 2011 as the base year of emissions.

To inform the policy process towards maximizing the positive and minimizing the negative impacts of the implementation of response measures, it is key to analyse the impacts and identify possible unintended spillover effects of the implementation of response measures. This case study considers a set of global and domestic climate policies: A uniform carbon tax, strategies for reducing emissions from maritime and air transport, and expanding solar PV electricity generation capacity as part of achieving the NDC in Maldives, with the aim of identifying their socioeconomic and GHG emission impacts on the country.

The toolkit developed and applied for the analysis is described in chapter 1; chapter 2 presents the model results; policy implications are discussed in chapter 3; and chapter 4 shares challenges faced and lessons learned in conducting the case study.

The full report on the case study details models and scenario assumptions and data employed in the analysis (UNFCCC, 2024a). The UNFCCC-MIRO interface was designed based on the CGE models used in the study to provide a user-friendly access to the models to facilitate communication between modellers and policymakers (UNFCCC, 2024b). Model documentation detailing equations for both models, the global model and the model for Maldives, is available.

The whole package used for the case study is referred to herein as the toolkit, a set of analytical tools that can be customized to the needs of a country without the large fixed costs associated with the development of CGE-based analytical tools. As such, the case study may serve as a template for other Parties wishing to conduct a similar analysis.

B. Introduction to the toolkit

The toolkit developed for the case study has five components:

(a) **A global CGE model** to quantify the impacts of the implementation of three global response measures on the global economy, accompanied by a model technical specification document and user guide;

(b) **A single-country CGE model** to quantify the impacts of the implementation of three global response measures and two domestic response measures on the Maldivian economy, accompanied by a model technical specification document and user guide;

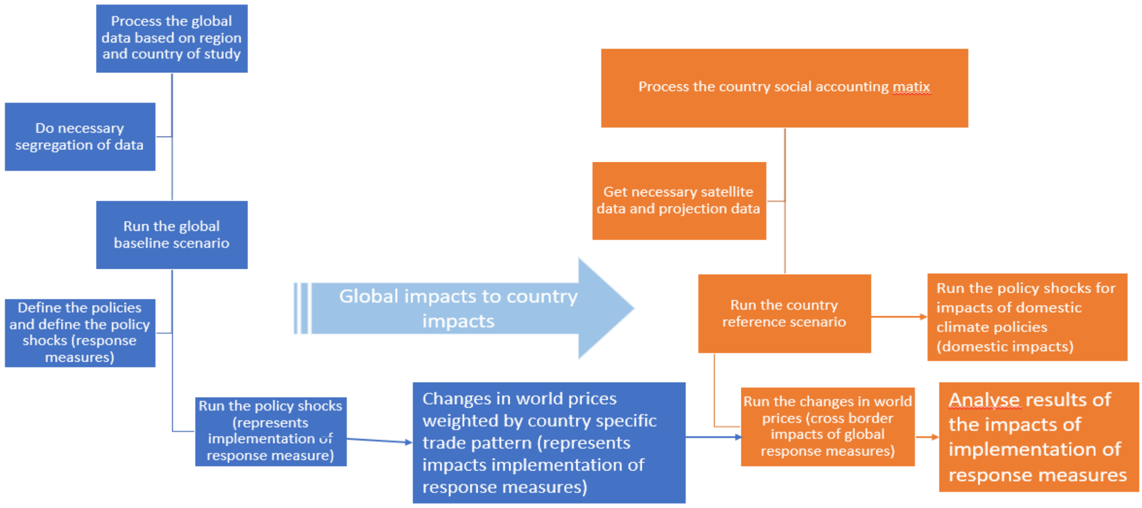
(c) **A SAM for Maldives**, which is consistent with its System of National Accounts, to serve as the database for the national CGE model;

(d) **A user-friendly modelling interface** (UNFCCC-MIRO) to enable stakeholders to interact with the global and national CGE models to further explore the impacts of the implementation of response measures and conduct their own analysis thereof;

(e) **Training** to enhance the capacity of Maldivian experts, including those at the Maldives Climate Change Department, to use the models in the future.

Figure 1 is a schematic representation of the process of using the toolkit to assess the impacts of the implementation of response measures.

Figure 1 Schematic representation of the modelling process for assessing the impacts of the implementation of response measures using the toolkit



2. Why a Computable General Equilibrium model?

A CGE model was chosen for assessing the impacts of the implementation of climate policies because of the comprehensive nature of its economic framework. With climate policies being multidimensional and impactful across various sectors, an analytical tool capable of capturing intricate interdependencies within and beyond national boundaries is required.

An economic model is a simplified framework for describing the workings of an economy or economies. Often a change in an economic system will have repercussions far beyond the sector in which the change occurs. Models are typically used for simulating changes in policies and/or economic trends to evaluate how the country or world would change after the introduction of a policy relative to in the absence of the policy; for example, what the world might look like in 2030 assuming certain future developments with and without the implementation of response measures. The strength of a CGE model is that it is based on linkages between sectors and captures both direct and indirect intersectoral, interregional and intertemporal effects induced by policy changes. CGE models are based on national accounts data and, thus, incorporate the unique features of an economic system. It requires the modeller to formally articulate assumptions and tease out relationships behind those assumptions. It is important to highlight that economic models provide projections; they are not designed to forecast, meaning they cannot predict the future.

A CGE model is a set of mathematical equations that describe a theory of economic behaviour. It is an economy-wide numerical model covering one or more countries. The model moves from one equilibrium to the next, where equilibrium is defined as the situation where the optimizing agents have found their best solutions subject to their budgetary constraints, quantities demanded equal quantities supplied in factor and commodity markets, and the decisions of all agents jointly satisfy the system constraints. As such, the model is best suited for medium- to long-term analysis in which markets have time to adjust, although alternative assumptions can be employed to simulate short-term events.

CGE models are viewed with suspicion by some in the economics and policy analysis communities as a ‘black box’, whose results cannot be meaningfully traced to any particular features of their database or input parameters, algebraic structure or method of solution (e.g. Sue Wing, 2004). Such criticism typically rests on the presumption that CGE models contain a large number of variables and parameters and are structurally complex, both of which allow questionable assumptions to be hidden within them that end up driving their results.

This critique reflects a misunderstanding of the simplicity of the algebraic foundation at the core of all CGE models, regardless of their size or apparent complexity, the key features of the data that these models use, and the numerical calibration methods by which models employ these data to imbue their algebraic framework with empirical substance (Sue Wing, 2004). The critique may also be based on incomplete communication of information in a manner that is not accessible to the broader economics or policy communities.

The results produced by CGE models are determined by four elements:

1. The linkages within the economy and between economies as captured in the SAM;
2. The 'behaviour' of the model as specified in the model's equations, determined by the functional forms and conditioned by parameter values, including elasticities;
3. The closure settings for the model, which depict the assumed functioning of the economy;
4. The location and magnitude of the response measure.

Together these assumptions determine how resources are reallocated as a result of the response measure and the consequences for growth, income distribution and sustainable development.

Thus, the selection of a CGE model for assessing the impacts of the implementation of climate policies is justified by its ability to analyse the multifaceted repercussions of such policies for the economy and beyond.

3. Description of global model, database and assumptions

The global CGE model used for the study is based on the GTAP-Power database version 10 (Chepeliev, 2020) in SAM format detailing 22 regions and 46 sectors. The database provides data on CO_2 emissions on the basis of extended energy balances compiled by the International Energy Agency. The emission data are distinguished by fuel and by user for each of the regions in the database. The model is implemented in its recursive dynamic mode. The model consists of a series of single-country CGE models that are linked through trade relationships. The model is linear homogeneous of degree zero in prices, and each region has its numeraire and an exchange rate that is defined relative to an exchange rate index for reference regions.

Production maximizes profits and is depicted by a nested mix of CES, assuming imperfect substitutability, and Leontief production functions, assuming consumption in fixed shares. CES technology is employed between aggregate primary inputs and aggregate intermediate inputs, with CES production functions over primary inputs and Leontief technology across intermediate inputs. Aggregate primary inputs are formed by labour, a composite of skilled and unskilled, land and a capital-energy composite. This capital-energy composite is formed from capital and an energy composite, which is depicted by nested CES functions.

Households receive income from factor (like labour and land) ownership and spend their income on consumption after paying income taxes and saving. Households maximize utility subject to preferences represented by a nested linear expenditure system, where subsistence consumption of households is selected from aggregate commodity groups – food, manufacturing, energy, construction and services – within which commodities are substitutable (CES) depending on relative price changes.

Domestic and foreign products, and those from different origins, are assumed imperfect substitutes. Domestic final demand chooses between aggregate imports and domestic supply based on relative prices employing CES technology. CES technology is further employed to form aggregate imports from different regions in two steps, allowing to differentiate imports sourced from low-, middle- and high-income regions and oil exporters. Exports and domestic supply are assumed to be homogeneous goods. The distribution of exports between regions is determined by the relative export prices.

The Government receives income from taxes that are mostly expressed as ad valorem and specific tax rates, while income taxes are average rates based on household incomes. Government expenditure consists of commodity demand, which is assumed to be in fixed proportions, and government saving is defined as a residual. Total savings come from the households, the internal balance on the government account and the external balance on the trade account. The external balance is defined as the difference between the value of total exports and total imports, converted into domestic currency units using the exchange rate. Expenditure by the capital account consists solely of commodity demand for investment.

The model includes regional tax instruments on emissions of greenhouse gases. The carbon tax is levied on the CO_2 emissions associated with inputs in the production process (scope 1) and CO_2 emissions associated with household consumption of fossil fuels. In addition, the model includes a carbon tax, levied as specific tax on exports and based on scope 1 emissions. This carbon tax on exports serves to model taxation of international traded goods and services, such as international water and air transport.

The climate policy instruments allow carbon tax revenues to be used partially or fully for investment purposes inside a region and/or fund transfers to other regions in the form of development aid. Two specifications are available for these aid flows, they can be bound for investment purposes or unbound.

Dynamic modelling requires the development of a reference scenario, a simulation of one possible future. Effects of scenarios, such as policy changes, are analysed relative to the future under the reference scenario. The reference scenario covers 2019–2045 and follows the narrative of a ‘middle of the road’ scenario with intermediate mitigation and adaptation challenges, SSP2, incorporating projections from the EconMap 3.1 database (Fontagné et al., 2021; Fouré et al., 2013), with the addition of carbon prices. The SSP2 projections provide forecasts of macroeconomic aggregates including GDP, capital, labour force, population and the share of the working age population with secondary and tertiary education. The projections are aggregated to the regions in this study using GDP or population weights as appropriate.

The model is solved for annual steps under the maintained assumption that agents make decisions about resource allocations at the start of the current period. These decisions are then revised on the basis of the outcomes, primarily prices, in the current period to determine the decisions about resource allocations at the start of the next period. Between each solution, the elasticity, shift and share parameters for all non-linear functions, and any parameters calibrated from current period data, are updated. This ensures that economic systems evolve as the behaviour of the agents, primarily producers and consumers, evolve.

Capital assets are assumed to be tied to activities once they are installed, that is buildings and activity-specific plants, such as gas-fired electricity generators. New capital stocks are allocated taking into account historic allocation of capital stock and a part of new capital is allocated taking into account changing rates of return across sectors. Noting the various factors influencing the trade balances, the model allows for partial adjustment of the trade balance and a reduction of global fossil demand will reduce the trade balance of net oil exporters.

4. Description of single-country model, social accounting matrix and assumptions

A single-country CGE model has the advantage that it can incorporate more detailed data that might not be available on a global scale, particularly relating to household groups, which can be used to assess distributional impacts. Therefore, a single-country CGE model was used to assess the impact of the implementation of both global response measures and domestic climate policies aimed at achieving Maldives’ NDC.

The model employed in the study belongs to the category of single-country CGE models that are successors to the CGE modelling approach described by Dervis et al. (1982). Specifically, the implementation of this model, using the GAMS software, is a direct evolution of models developed in the late 1980s and early 1990s, particularly those reported by Robinson et al. (1990), Kilkenny (1991) and Devarajan et al. (1994). The model operates in its recursive dynamic mode and is linear homogeneous of degree zero in prices, with the consumer price index serving as the benchmark against which price changes are measured.

The single-country model is a SAM-based CGE model, wherein the SAM serves to identify the agents in the economy and provides the transactions database with which the model is calibrated. The Maldives’ version of the single-country model is based on a 2019 SAM (Mainar-Causapé et al., 2023) with an explicit depiction of renewable energy sources. The representation of the economy includes 48 commodities (of which 37 are produced within Maldives), 38 production activities, 12 factors of production (labour and capital) and 10 household groups. Of the 12 factors included, there are 6 labour types grouped by location

(Malé or atoll[3]) and skill level, and 6 capital types grouped by location (non-resort or resort) and type of capital (other or energy capital by fuel input). Households are disaggregated into 10 representative groups by location and income quintile. The remaining accounts consist of enterprise (corporation) accounts, a margin account, the government account and six tax accounts, the capital account (savings and investments) and the rest of the world account. Key features of the Maldivian economy, including the importance of the fishing and tourism sectors, differences in Malé and atoll labour markets and households, and capital holdings differentiated by fuel type are captured both through the detail in the SAM and the behavioural relationships in the model.

The SAM reflects the narrow economic base of Maldives, relying on tourism as the mainstay of production and exports. Exports of services dominate the exports of goods in Maldives by a factor of nine. Construction is the second-largest production activity, and passenger transport and fish processing follow tourism as key exports. The economy is highly dependent on imports and ran a trade balance deficit in 2019. Maldives is wholly reliant on imports for diesel fuel, minerals (a key input to the construction industry) and machinery. Aside from fish, Maldives is highly dependent on imports for food, including dairy products. Maldives is linked to global energy markets through a high dependency on diesel imports. Almost all electricity was produced using imported fossil fuels in 2019, with limited use of renewables.

Producers' decisions regarding what to produce and which inputs to use, as well as consumers' decisions about which products to consume, follow the same processes as those in the global model. Products for the domestic and export market, and imports from different origins, are assumed to be imperfect substitutes. The exchange rate is fixed to reflect the managed nature of the rufiyaa exchange rate, with a varying external balance. It is assumed that Maldives operates as a price taker in global markets, resulting in fixed world prices.

Households receive income from capital rents and wages, plus payments from corporations and transfers from the Government. Households located in Malé have a higher average income per capita than those located on the atolls and possess a larger share of capital and skilled labour, which contributes to their higher income status. The Government receives income from taxation as in the global model, plus capital rents and transfers from outside Maldives. The economy is assumed to be investment driven, with savings of households and corporations adjusting to provide investable funds. Government borrowing is fixed as a share of GDP to prevent additional expenditure beyond the designated proportion being financed by government debt. Instead, additional government income comes from returns on government-owned capital and corporation income tax.

All factors are assumed to be fully employed, recognizing the role of labour in providing non-market services, including home and caring duties, which are not captured in the standard definition of the labour force. Some sectoral rigidities are introduced into the model; specifically, electricity generation capital by fuel type (generators, PV cells, etc.) is fixed into non-resort and resort use to prevent the movement of capital when investments are made in non-resorts and not resorts, or vice versa. This factor market specification results in economy-wide returns for labour and capital and sector-specific returns for electricity generation capital by fuel type. Technology is fixed at all production levels.

The model is configured to include a production system that captures changes in GHG emissions, measured in CO_2 eq. These GHGs are determined endogenously using CO_2 emission coefficients (emissions per unit) as patterns of production and consumption change due to climate policies. Emissions from industry change as their consumption of intermediate inputs changes. Emissions from households change in line with changes in consumption of final goods. Total emissions in the economy are the sum of industry- and household-generated emissions. The model contains an explicit modelling of renewables and emissions for investigating the impact of the implementation of domestic response measures. Maldives does not have, nor does it currently intend to have, a carbon tax in place.

The reference scenario for the national model is specified for the same period as the global model, 2019–2045, following the SSP2 narrative for Maldives (Fontagné et al., 2021; Fouré et al., 2013). The SSP2 database projects 0.5% annual average GDP growth over the period, driven by growth in investment of

[3] Islands other than the capital island of Malé.

0.2% per year, population and employment growth of 0.1% and 0.02% respectively, and technological change (derived as the residual growth when other growth factors are accounted for). The process of moving from one year to the next is the same as in the global model with the exception of the treatment of capital. Investment in each type of capital is converted into installed capital at the end of each period. Non-energy capital, which is not tied to specific sectors, can be reallocated to other sectors in response to changes in relative returns.

The model includes a set of selected SDG indicators covering SDG 1, no poverty; SDG 7, affordable and clean energy; SDG 8, decent work and economic growth; SDG 9, industry, innovation and infrastructure; and SDG 10, reduced inequalities.

5. Linking the global and national models

To understand the impacts of global response measures on the Maldives' economy, the global and national models are connected using a 'soft link' to transmit changes in world market prices to the national economy. Through this connection, the production and consumption decisions are aligned between the South Asia region of the global model, which Maldives is a part of, and the national CGE model. The product aggregation of the global model is chosen to resemble the product aggregation in the Maldives SAM and the assumptions of the functioning of the economy are the same (where appropriate).

Domestic impacts of global policies are evaluated by passing changes in world market prices arising from the implementation of global climate policies from the global to the national model. Price changes are weighted by the pattern of trade in Maldives to reflect differences in trade patterns between Maldives and the wider South Asia region. Response measures are introduced for 2020–2045 using recursive dynamic variants of both models.

6. UNFCCC-MIRO interface

UNFCCC-MIRO offers a user-friendly platform that empowers individuals without modelling expertise to conduct their own assessments. Through this interface, users can run policy scenarios and visualize results using the models used for detailed impact assessments within the core model. There is increasing demand to conduct assessments of the impacts of climate actions. Recognizing the significance of future consequences, climate change is progressively being incorporated into environmental impact assessments. Impact assessments are regularly conducted by international organizations and national Governments. However, the models used to assess these impacts are often complex and using them requires substantial training.

UNFCCC-MIRO, developed under this study and powered by GAMS MIRO (GAMS, 2023), enables stakeholders to interact with comparative static versions of the models to explore the impacts of the implementation of:

a) Global response measures at the global level with and without international transfer payments;
b) Global response measures at the national level;
c) Domestic response measures (including policies aimed at achieving NDCs) at the national level.

UNFCCC-MIRO **is intended to serve a complementary role in providing insights from the core model to policy advisors and stakeholders.** It should be noted that, while UNFCCC-MIRO uses complex impact assessment models, the interface itself does not replace the in-depth policy analysis conducted by policy analysts using the core models. In-depth analysis is needed ahead of any policy change being implemented. UNFCCC-MIRO serves as a supplementary tool rather than replacing the direct use of the core model that offers a wider range of options for policy analysis.

C. Description of scenarios

1. Global response measure scenarios

The case study considers three global scenarios of climate change response measures.

(a) Global scenario I: Uniform carbon tax towards achieving atmospheric carbon concentrations consistent with limiting global warming to 1.5 or 2.0 °C above pre-industrial levels (global temperature goal scenario)

The IPCC Sixth Assessment Report (IPCC, 2022) provides the most up-to-date information on global emission pathways related to specific global warming outcomes. Each emission pathway involves different likelihoods with respect to temperature and peak temperature, and these data were employed in the simulations for this study. The selected emission pathways are based on those identified in the Sixth Assessment Report aiming to limit warming to the respective temperature goal with a probability greater than 50%. Following the classification of emissions scenarios into warming levels (IPCC, 2022), three scenarios were run: limiting warming to 1.5 °C; returning to 1.5 °C after a temperature high; and limiting warming to 2 °C.

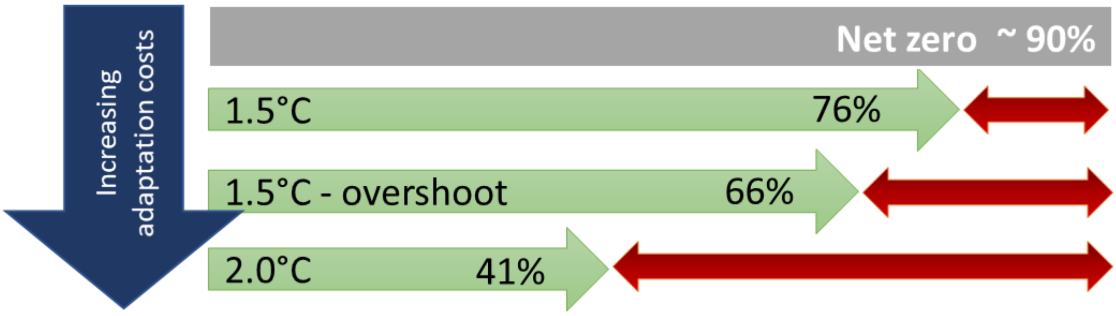
Each of the three temperature scenarios aimed at reaching a specific global warming threshold was simulated in three variations to understand the effects of transferring the received carbon tax revenue back to countries in different ways: (1) low-income regions are included in reducing emissions, in combination with transfer payments from high-income to low-income regions, used for green investment (the standard simulation presented in the results); (2) all regions are subject to the carbon tax, with no transfers; (3) low-income regions are exempt from reducing emissions.

In the scenarios, emission reductions are induced by a uniform tax on carbon emissions across all sectors and regions, aiming to achieve global emission pathways consistent with different thresholds of global warming. Thus, taxes are levied on the basis of actual emissions in each modelled year.

Limitations: The modelling exercise in this study covers up until 2045, which means that it covers only a part of the journey to net zero emissions. Because of the remaining gap, the full picture of results may not be reflected. Even though all scenarios report effects up to the same year, they vary in how close they get to the net zero target (see figure 2). On the more ambitious emission reduction pathways, stronger pressure will be imposed on the economy in the near future and thus costs will be more during this time. On **emission reduction pathways that are less ambitious, these costs will be transferred to a future period** that is not captured in this modelling exercise.

Therefore, less ambitious emission reduction pathways leave questions about intergenerational equity unanswered. They will also result in higher costs for adapting to the impacts of global warming, including environmental impacts that are hard to reverse, such as projected sea level rise and impacts on human health. Additionally, on ambitious emission reduction pathways, more and earlier mitigation action is required, which can also bring economic challenges, such as scrapping power plants earlier, reducing people’s living standards to fund accelerated investment programmes, etc.

Figure 2 Global temperature goal **s**cenario coverage to net zero emissions



Note: Green arrows depict emission reductions captured in simulations in 2045 (in % compared with 2019 levels); red arrows represent the remaining gap to net zero, assumed to equal a 90% reduction of fossil CO_2 emissions.

(b) Global scenario II: Impact of Initial International Maritime Organization Strategy on reduction of emissions from ships (global maritime transport scenario)

Emissions from international shipping are not subject to limitation or reduction commitments under the UNFCCC because they are not accounted for in national GHG inventory totals and are not covered by the latest submitted NDCs. IMO controls these emissions. The Initial IMO Strategy on reduction of emissions from ships (IMO, 2018) is aimed at achieving a peaking of global carbon emissions from international shipping as soon as possible and then reducing them by 50% compared with the 2008 level by 2050. Accounting for developments in the sector until 2019 (the base year of the database), this translates into an annual reduction of emissions of about 3% (International Energy Agency, 2022). Midterm measures, targeting 2023–2030, might include market-based approaches to incentivize emission reductions. In this global maritime transport scenario, a carbon tax is applied to emissions from water transport to ensure a 50% reduction of the sectoral emissions in each modelled region by 2050. Revenue from this tax is reinvested in the water transport sector to support technological advancements, and 5% of carbon tax revenue is transferred to low-income regions and SIDS to assist in their climate response efforts.

In July 2023, IMO adopted its 2023 IMO Strategy on Reduction of GHG Emissions from Ships, which outlines a goal to decrease the carbon intensity of international shipping (which means reducing CO_2 emissions per transport unit) by at least 40% compared to 2008 levels on average across international shipping by 2030. Another aim is to achieve a significant increase in the adoption of zero or near-zero GHG emission technologies, fuels and energy sources, which are to represent at least 5%, striving for 10%, of the energy used in international shipping by 2030.

(c) Global scenario III: Impact of Carbon Offsetting and Reduction Scheme for International Aviation (global air transport scenario)

Emissions from international flights in the aviation sector are not accounted for in national GHG inventory totals or covered by the latest submitted NDCs. ICAO controls these emissions. Under the ICAO agreement[4], the aim is to improve global fuel efficiency of planes by 2% annually and reach a point where the emissions from the air sector remain at the 2020 level; and to reduce air sectors' carbon emissions by 50% compared with the 2005 level by 2050, which can be translated into an annual reduction of emissions of 3%. In aviation, climate action goals are being pursued through a four-pillar strategy, a key element of which is CORSIA. The other three pillars are new, less carbon-intensive technology, more efficient operations and better infrastructure. CORSIA is a global offsetting scheme, which requires airlines and other aircraft operators to offset any growth in CO_2 emissions above the 2020 level and imposes a price on carbon that exceeds the 2020 level in international air transport. The global air transport scenario simulates the carbon offsetting price and path needed to achieve a 50% reduction in carbon emissions by 2050. The generated income is invested in environmental initiatives.

[4] The ICAO Assembly at its 41st Session in 2022 adopted Resolution A41-21 Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change.

2. Domestic response measure scenarios

The impact of the global response measures is examined for the world as a whole and for Maldives specifically using the linked models.

Increasing the share of renewable energy in Maldives' energy mix to 15% is a key part of achieving the NDC emission reduction goal by 2030 (Ministry of Environment, 2020). In 2019, diesel consumption accounted for around 80% of total emissions in Maldives (Ministry of Environment, 2018). The non-tourism and tourism sectors account for 18% and 8% of the demand for diesel respectively. Two scenarios of domestic response measures for contributing to meeting the NDC were considered using the national CGE model for Maldives.

(a) Increasing use of renewable energy in the non-tourism[5] sectors via solar photovoltaics

The components of this scenario are expanding PV energy production capacity to 112 GWh by 2045 to meet 15% of the demand for electricity of the non-tourism sectors; phasing out the subsidy on fossil-based electricity production (9% in 2019); and introducing a 9% subsidy on PV-based electricity. All three changes are implemented simultaneously in the scenario.

Assumptions: No substantial investments were made in non-resort PV before 2020 and the investment in PV is government financed, funded by increases in the general goods and services tax rate.

(b) Increasing use of renewable energy in the tourism sector via solar photovoltaics

In 2019, almost all resorts had their own diesel generators; thus, moving part of resort energy demand to PV will reduce emissions. The impact of expanding PV energy production capacity to 36 GWh by 2045 to meet 15% of the demand for electricity of the tourism sector is examined in this scenario.

Assumptions: No substantial investments were made in resort PV before 2020, the investment in resort PV is funded by private corporations, and the Government continues not to subsidize resort electricity use.

II. Discussion of model results

A. Costs of climate change[6] and climate action

Mitigation of climate change is costly. The communication of these costs is difficult, as mitigation requires immediate action and costs are incurred in the short and medium term, while the costs of climate change will be felt in the long term. However, extreme events experienced by SIDS today, such as storms, tropical cyclones, floods, drought and marine heat waves, clearly demonstrate the vulnerability of small island systems to climate change. The scientific evidence published by the IPCC (IPCC, 2021) about sea level rise is clear: in 1901–1990 the global mean sea level rose by 1.5 mm per year, accelerating to 3.6 mm per year in 2005–2015. Without mitigation efforts the global mean sea level is likely to rise by 0.6–1.1 m by 2100 and could even rise by more than 2 m.

Without ambitious adaptation actions, accelerating sea level rise will combine with storm surges, tides and waves to generate extreme sea level events causing shoreline changes and flooding, resulting in salination of soils and water resources. Ocean warming and acidification will combine and negatively affect marine ecosystems, decreasing species' abundance and distribution, and affect the ecosystem services benefiting human societies. Effects extend to risks to coral reefs and associated living resources, affecting recreational activities and tourism.

[5] Non-tourism sectors are all parts of the economy not related to resorts.

[6] Costs of climate change to SIDS are discussed in Oppenheimer et al. (2019) and Magnan et al. (2019), which also served as sources for data on costs of climate change for this section.

Coastal infrastructure and facilities, such as harbours and resorts, are at risk from storm waves and extreme weather events, with a negative impact on coastal tourism.

Coastal communities can in principle be protected against sea level rise through 'hard protection', like dikes and seawalls, and can thus effectively reduce risk. However, the magnitude and frequency of extreme weather events make hard protection difficult, and these protection measures will inevitably have limits. Retreat becomes inevitable for those unable to afford protection or to accommodate or advance measures, or when protection measures are no longer viable or effective. This will have an impact on distinctive cultures and could be devastating to the ways of life within those cultures.

Ambitious climate policy can lower these risks and restrict sea level rise to 1–2 m by 2300 under a future scenario where temperature rise is likely kept below 2 °C. However, with 80% of its islands lying below the average elevation of 1 m above sea level, sea level rise remains a threat to Maldives even in the context of ambitious climate goals.

B. Regional impacts of global response measures

Overall, response measures have significant distributed effects. The potential implications of mitigation policies are multifaceted. Even a market-based mitigation policy, such as a uniform carbon tax, will have substantively different implications for different countries and different households within those countries. This discrepancy is due partly to past emissions and energy tax policies and partly to the extent of structural adjustment required in countries with high emission intensities (emissions relative to GDP). The model results indicate how the cost of achieving a global temperature goal affects income distribution both between and within countries.

(a) How do different regions respond to a uniform carbon tax? Impacts of the global temperature goal scenario on regional emissions

The results of implementing a uniform carbon tax, aimed at curbing temperature rise via three distinct pathways, illustrate that emission reductions vary by region (see table 1). The pattern is similar across pathways, with the emission reductions and associated economic costs being highest on the most ambitious pathway as more of the adjustment costs are incorporated into the period under review, while on the least ambitious pathway these adjustment costs are transferred to the future and in addition adaptation costs are higher. In the global temperature goal scenario, all regions participate in the tax scheme and low-income and SIDS regions[7] receive transfers for investment in renewable energy. This happens because different regions have varying emission intensities of production.[8] When the carbon tax is levied per t CO_2, it generates different impacts on each region according to the emission intensity of their production and therefore changes the composition of the regional contributions to emissions. Thus, regions that currently contribute relatively large shares of global emissions achieve large absolute emission reductions.

Emission reductions are considerably below average and emissions partly increase on the 2 °C pathway to a higher temperature increase for the low-income SIDS regions Pacific Islands and West and East Africa, which receive transfers and thus experience a boost in economic growth. Emission reductions are low and even increase on the 2 °C pathway for India, which is predicted to experience strong growth and has emission-intensive production, making emission reductions relatively costly relative to the other regions. These increases in emissions are relatively low in absolute terms, except for India. In contrast, Australia and New Zealand, the United States of America and Canada, Eastern Europe and Central Asia, the Russian Federation, the Gulf States and SACU show the strongest reduction of emissions in relative terms. Most of the regions that currently contribute relatively large shares to global emissions, such as China, the United States and Canada, the European Union, the Gulf States, Russia, and Japan and South Korea, have large absolute reductions. Meanwhile, India, the rest of South Asia and South-East Asia are increasing their share in global emissions.

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[7] Pacific Islands, West and East Africa, Caribbean, rest of South Asia (South Asia excluding India) and the rest of the world (regions and countries not singled out in Table 1).

[8] Production is a measure of total output produced in an economy. It reflects the process of using intermediate inputs, labour capital and natural resources to produce output in form of goods and services.

Table 1 Model result for emission pathways under global temperature goal scenario: Reduction in emissions by 2045 relative to the 2019 level, by region

	relative			*absolute (Gt CO $_2$)*		
	1.5°	*1.5° overshoot*	*2.0°*	*1.5°*	*1.5° overshoot*	*2.0°*
Global reduction	**-76**	**-66**	**-41**	**-26.2**	**-22.8**	**-14.0**
Australia and New Zealand	-86	-81	-64	-0.4	-0.4	-0.3
Pacific Islands	-47	-24	33	0.0	0.0	0.0
China and Hong Kong	-75	-66	-41	-7.4	-6.5	-4.1
Japan and South Korea	-74	-66	-44	-1.2	-1.1	-0.7
Rest of the world	-64	-50	-13	-0.7	-0.6	-0.2
South-East Asia	-66	-53	-20	-1.0	-0.8	-0.3
Rest of South Asia	-63	-49	-14	-0.2	-0.1	0.0
India	-42	-16	48	-1.1	-0.4	1.2
United States and Canada	-87	-82	-67	-5.4	-5.1	-4.2
Central America	-78	-69	-44	-0.4	-0.4	-0.3
South America	-78	-70	-46	-0.6	-0.5	-0.3
Brazil	-82	-76	-55	-0.4	-0.4	-0.3
Caribbean Islands	-67	-57	-33	-0.1	-0.1	0.0
European Union	-76	-68	-47	-2.3	-2.1	-1.4
Rest of Europe	-73	-63	-39	-0.5	-0.4	-0.3
Eastern Eur. and C. Asia	-89	-81	-57	-0.7	-0.7	-0.5
Russian Federation	-90	-83	-63	-1.3	-1.2	-0.9
Gulf States	-98	-92	-69	-1.5	-1.4	-1.1
North Africa	-78	-67	-38	-0.4	-0.3	-0.2
West Africa	-30	-3	63	0.0	0.0	0.1
East Africa	-27	1	65	0.0	0.0	0.1
SACU	-94	-92	-83	-0.4	-0.4	-0.4
CO2 emitted in 2045				*-26.2*	*-22.8*	*-14.0*

(b) How is regional production affected by the uniform carbon tax in the global temperature goal scenario?

The uniform carbon tax was observed to have a negative effect on the production of goods and services across all regions but particularly emission-intensive regions. While the emission-intensive regions typically show a significant decrease in production, the impact on production is not directly proportional to their emission intensities (see table 2). The trading structure plays a crucial role in that regard. Regions where production is emission intensive and that rely heavily on fossil fuel exports, experience the strongest negative effects, namely the Gulf States, Russia, Eastern Europe and Central Asia, and North Africa. Regions with high emission intensities but where fossil fuel exports do not play a big role also face significant impacts, such as India, China and Hong Kong, and SACU. In these regions, carbon taxes affect domestic production. Regions with low emission intensities but high dependency on fossil exports also see significant impacts on production, such as West Africa, Australia and New Zealand, and South America.

In summary, regions where production is highly emission intensive experience significant production effects, especially if they rely heavily on fossil fuel exports. Similarly, regions where production is not emission intensive but there is a dependence on fossil fuel exports also experience impacts when a uniform carbon tax is implemented towards limiting global temperature rise.

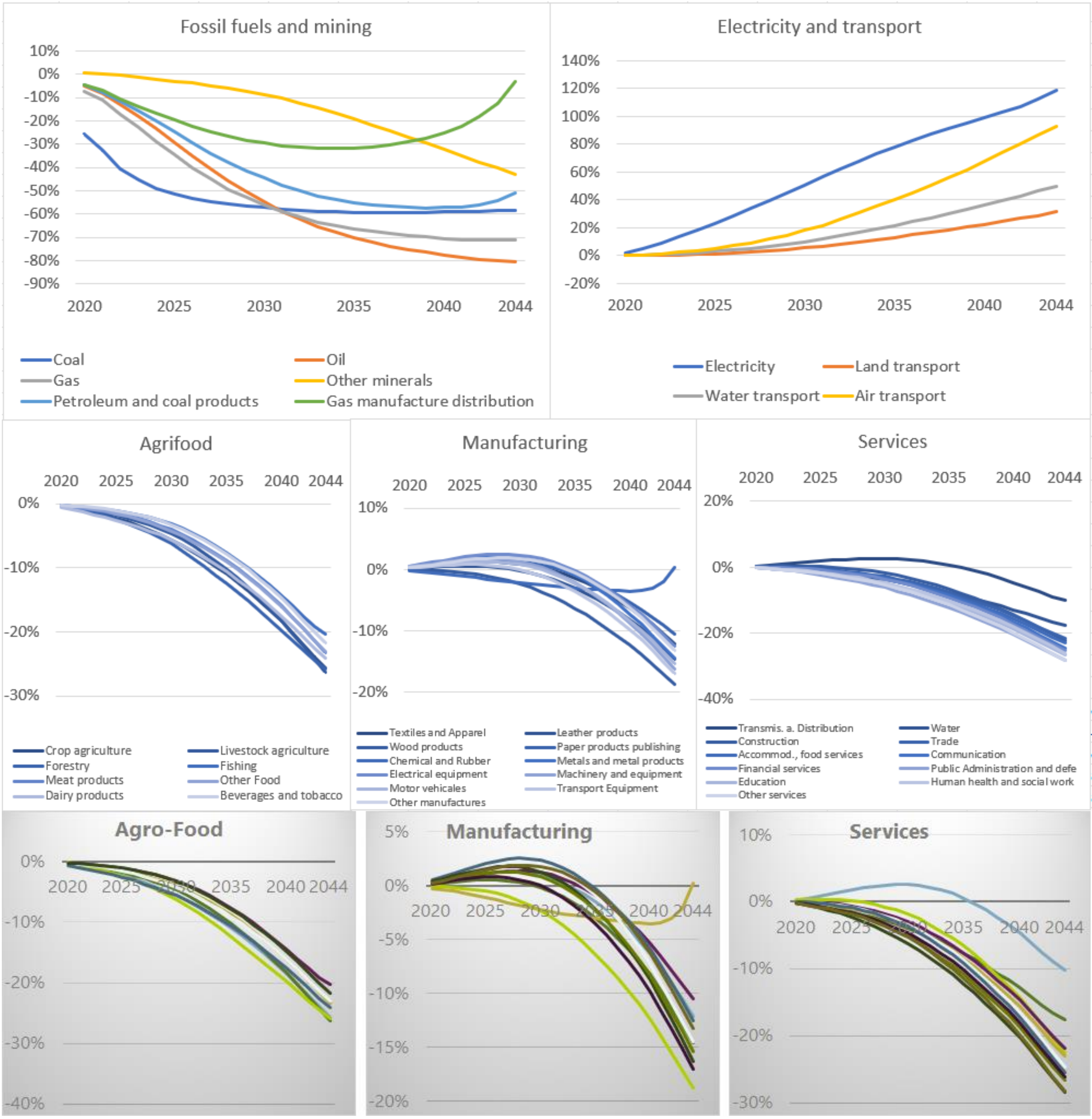
Table 2 Model result for emission pathways under global temperature goal scenario: Effect on production and emission intensity, by region

	Production % change from reference scenario in 2045			Emission intensity	
	1.5°	1.5° overshoot	2.0°	Fossil CO_2 emissions (t)/ GDP (million)	Fossil exports relative to total exports
Australia and New Zealand	-12	-10	-7	0.2	22%
Pacific Islands	-13	-10	-6	0.3	10%
China and Hong Kong	-16	-12	-7	0.8	1%
Japan and South Korea	-9	-6	-2	0.3	3%
Rest of the world	-12	-8	-1	0.4	21%
South-East Asia	-15	-11	-5	0.5	10%
Rest of South Asia	-4	-2	0	0.4	2%
India	-13	-9	-4	0.9	9%
United States and Canada	-11	-9	-5	0.3	11%
Central America	-13	-10	-5	0.3	10%
South America	-15	-12	-7	0.3	28%
Brazil	-13	-10	-6	0.2	9%
Caribbean Islands	-4	-1	2	0.3	19%
European Union	-7	-5	-2	0.2	3%
Rest of Europe	-5	-4	-1	0.1	9%
Eastern Eur. and C. Asia	-40	-31	-17	1.1	39%
Russian Federation	-44	-35	-19	0.7	54%
Gulf States	-66	-48	-25	0.7	74%
North Africa	-21	-16	-8	0.6	44%
West Africa	-12	-11	-7	0.2	65%
East Africa	-6	-4	-2	0.2	20%
SACU	-28	-22	-14	1.1	8%

(c) Impact of uniform carbon tax in global temperature goal scenario on sectoral prices and global trade

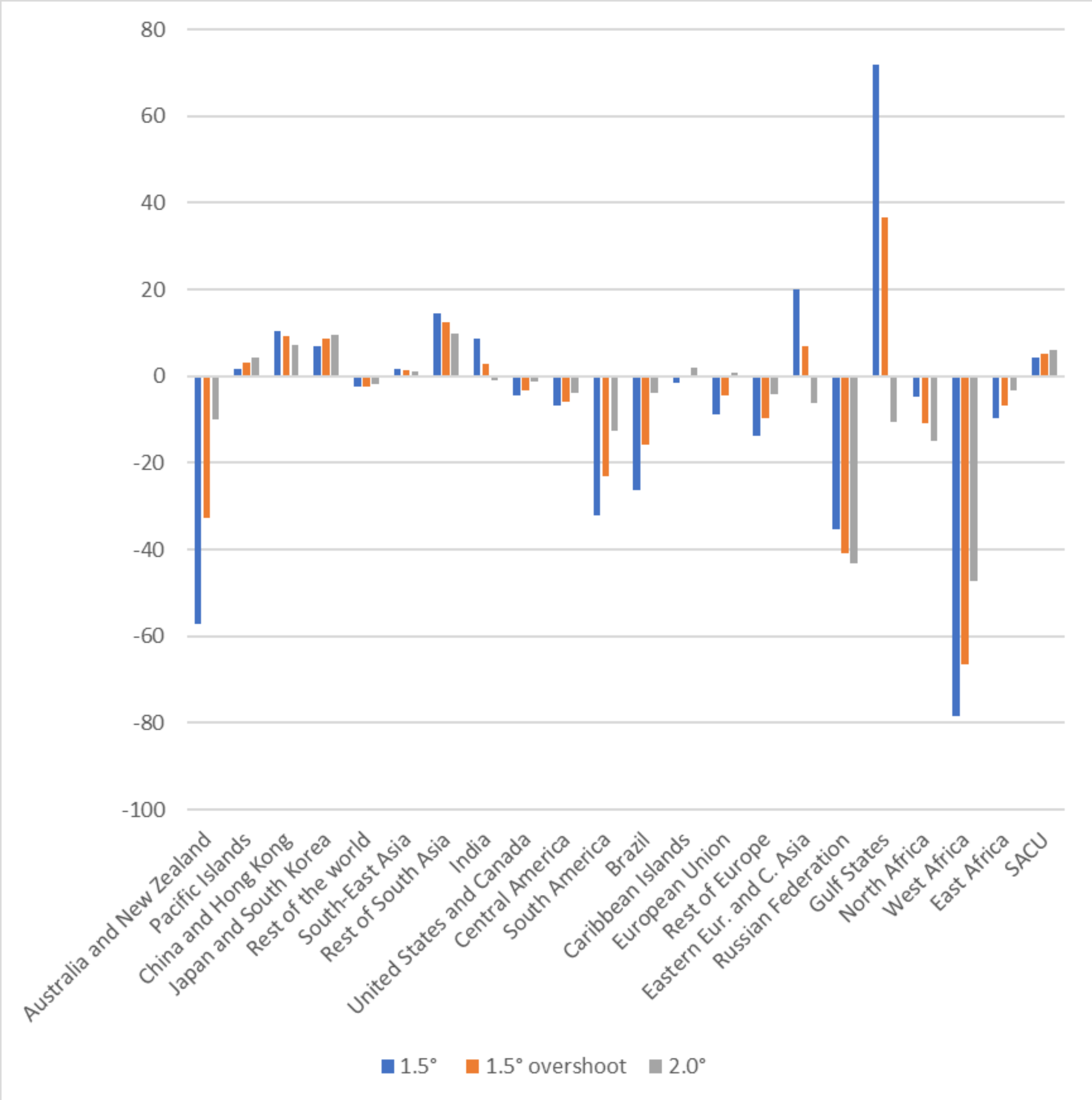
The uniform carbon tax affects sectors differently. A uniform carbon tax affects world market prices (see figure 3), which are mainly influenced by the emission intensity of the respective commodity and demand effects. On the 1.5 °C pathway, world market prices for electricity double, and transport service prices increase considerably. The price of coal, which contributes the highest share of emissions, experiences a sharp drop but stabilizes at around –60% after production adjusts to the carbon tax. Export prices of crude oil and gas decrease steadily over the period under review, while prices for processed oil and gas show a U-shaped curve, benefiting from increased substitution away from the raw products. Export prices for other commodities like agrifood, manufacturing and services are lower compared with the reference scenario, reflecting decreasing demand. This trend starts later for manufacturing, where prices increase due to higher input costs and start decreasing after 2035 when decreasing demand dominates the price effects. An outlier is the chemicals and rubber sector – subject to relatively high taxes – where prices increase with increasing taxes later in the period. These price changes lead to decreased global trade in all scenarios compared with the reference scenario.

Figure 3 Model result for global temperature goal scenario: Effects on world market prices on the 1.5 °C pathway (% change compared with reference scenario)



The exchange rate adjusts to keep the current account balanced (Figure 4). The change depends on changes in import prices, changes in import demand and export supply. Fossil fuel exporters face a drop in the demand for their exports, so their exchange rates depreciate (their currency becomes less valuable) to maintain the current account balance. The currency depreciation makes imports more expensive, which in turn reduces import demand. But it also makes exports more competitive by lowering prices for other regions and stimulates supply. The impact of the uniform carbon tax on **emission-intensive regions results in a relatively stronger increase in production prices, which reinforces the depreciation.** The currencies of those regions appreciate that have low emission intensities, that do not export fossil fuels and that do not participate in emission reduction efforts.

Figure 4 Model result for global temperature goal scenario: Exchange rate effects (% change compared with reference scenario, in 2045)



Note: A decreasing exchange rate represents a depreciation and vice versa.

(d) Impact of maritime and air transport emission reduction strategies on regional production and import prices

As for the global temperature goal scenario, the global maritime and air transport GHG reduction strategies also affect regions differently[9]. Examining the impacts on regional production, the increased transport costs resulting from the imposition of carbon taxes in the maritime and air transport sectors, as a consequence of the implementation of emission reduction strategies, exerts pressure on production in all regions. The effect on production is influenced by a complex interplay between trade structure, such as the amount of oil imported and exported, and import shares in general, and the specific production structure of a region (see table 3).

The increase in transport costs affects import prices of goods, and transport costs contribute up to 1 percentage point to the import price changes. The extent of change depends on factors such as relationship between commodity value and volume, the main mode of transportation and the distance travelled. Globally, the results show a decrease in average import prices for fossil fuels (about 3% for maritime transport and about 11% for air

[9] Results are described in detail in section B4 of the full report (UNFCCC, 2024a).

transport) and several service sectors, despite the increase in transport costs. The price of manufacturing commodities increases the most (by about 0–0.7%).

The strategies for reducing GHG emissions from maritime and air transport have three opposing effects: (1) as a direct effect, the import prices of goods increase due to the increase in costs of trading; (2) reduced demand for transport services reduces demand for oil products resulting in decreased oil prices, which is beneficial for sectors that are relatively oil intensive or less reliant on water or air transport as a transportation mode, and production costs in these sectors decrease; (3) increased import prices for manufacturing goods, which are used as intermediates in the production process, increase the cost of intermediate products and production costs increase, which disadvantages sectors that rely heavily on global value chains that rely on imported intermediates – this effect is particularly pronounced for maritime transport.

Results from additional simulations, that vary the model set-up with respect to the possibility to adapt production technologies, show that the magnitude of effects depends crucially on the availability of carbon-saving technologies and related implementation costs. Thus, when running the model with reduced adjustment possibilities in investment for the maritime sector, , i.e., when investment is stronger determined by historical investment patterns, transportation costs can increase by a factor of 5, resulting in stronger negative effects on production.

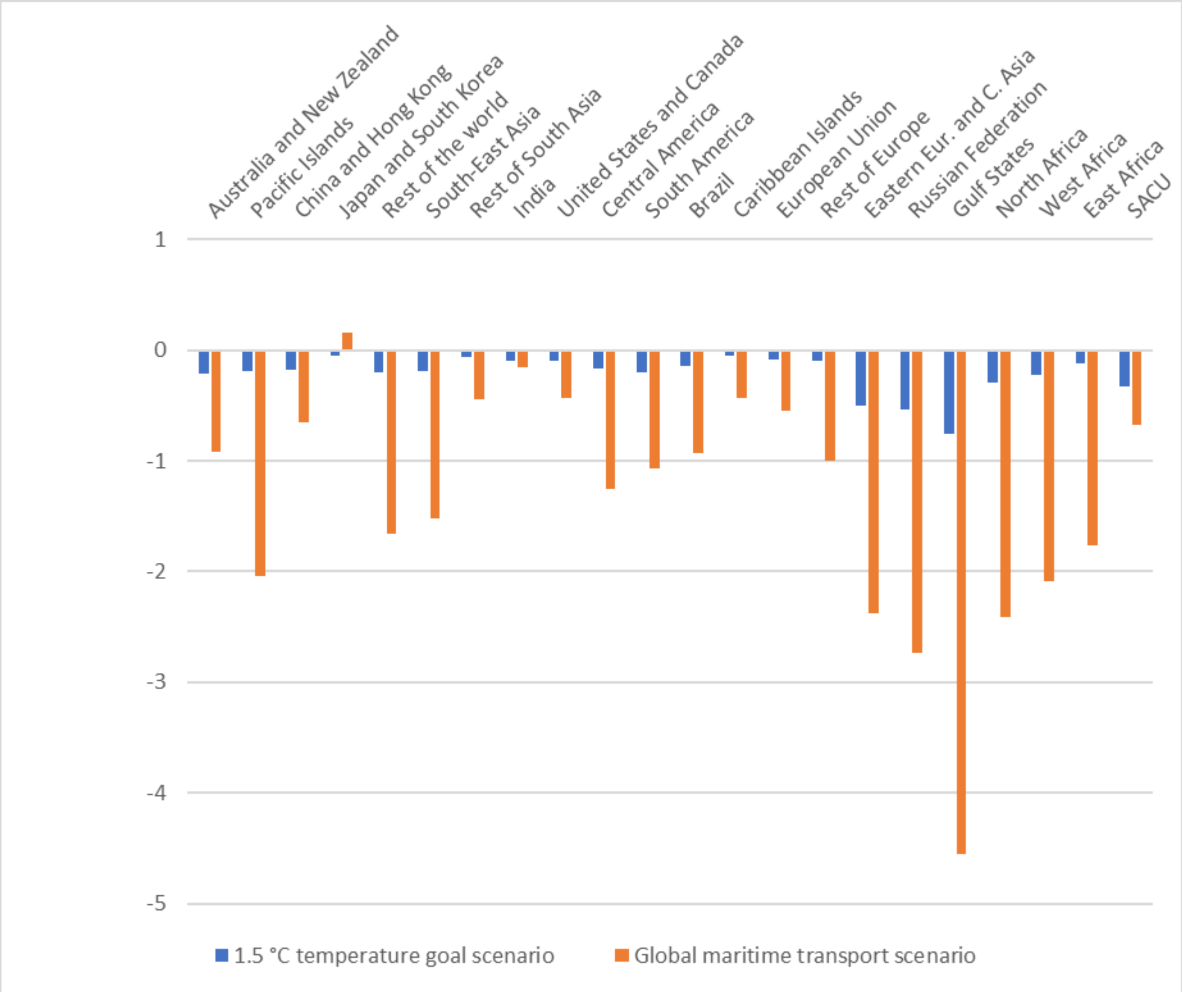
Table 3 Model results for global maritime and air transport scenarios: Effects on production by region and emissions by 2045 (% deviation from reference scenario)

	Scenario II		Scenario III	
	Production	*Emissions/ population*	*Production*	*Emissions/ population*
Australia and New Zealand	-0.1	-0.5	-0.2	-5.2
Pacific Islands	-0.1	-0.5	0.6	5.2
China and Hong Kong	0.0	0.1	-0.2	1.4
Japan and South Korea	-0.1	-1.5	0.3	-0.5
Rest of the world	-0.1	-1.8	0	-1.7
South-East Asia	-0.4	0.1	-0.6	-0.3
Rest of South Asia	-0.2	-0.1	0.7	4.6
India	-0.2	-1.0	0.3	3.1
United States and Canada	0.0	0.1	0.3	3.3
Central America	-0.4	-0.8	-0.1	0.9
South America	-0.4	-1.3	-0.2	3.7
Brazil	-0.2	-0.1	0.4	8.7
Caribbean Islands	-0.6	-2.2	-0.5	0.2
European Union	0.0	0.3	1.6	9.5
Rest of Europe	-0.4	-1.2	0.4	5.2
Eastern Eur. and C. Asia	-0.2	-0.1	0	2.2
Russian Federation	-0.1	-0.4	0.2	3.8
Gulf States	-0.4	-0.3	0.2	3.9
North Africa	-0.4	-0.4	-0.3	1.3
West Africa	-0.7	-0.8	-0.1	3.2
East Africa	-0.3	-0.3	0.7	6.6
SACU	-0.1	0.1	1	7.6

(e) Cost dynamics of leakage in different scenarios

Leakage is increasing the cost of combatting climate change. A comparison of the global maritime transport scenario with the global temperature goal scenario reveals insightful observations. Figure 5 shows welfare effects of the two scenarios: as the scenarios are targeting different levels of emission reduction, the results are depicted relative to a 1% decrease of emissions to allow a comparison of the effects. While efforts to reduce emissions within one sector can result in a decrease in global emissions in the maritime transport scenario, the accompanying leakage phenomenon leads to higher related costs compared with the ambitious 1.5 °C temperature goal scenario. Welfare is up to 1% lower than in the reference scenario for each 1% reduction in global emissions in the ambitious 1.5 °C temperature goal scenario and ranges between +0.2 and –4.5% in the maritime transport scenario. Indeed, leakage effects increase global emissions in the air transport scenario.

Figure 5 Comparison of effects of leakage on welfare (depicted by real household expenditure) between the global temperature goal and maritime transport scenarios in 2045



Note: The welfare costs of a 1% reduction in global emissions achieved by different policies, relative to the reference scenario in 2045.

Similarly, all regions are worse off if a single region does not participate in the global effort to implement a carbon tax, including SIDS and low-income economies. Table 4 shows that all participating regions are clearly worse off when specific regions do not participate in the uniform carbon tax scheme, as emission reductions are now contributed to by a smaller group of regions, and non-participating regions are increasing emissions as fossil fuel prices decline. In addition, all donor regions are better off when transferring part (5%) of their additional tax income compared with an exemption for certain regions.

As a result, increased intercountry **transfers from richer economies to smaller and poorer economies are better for both donors and recipients than exempting certain regions**. Unrequited transfers to SIDS and low-income economies, earmarked for investment in enhanced technologies, will benefit the donors. The magnitudes and distribution of these transfers are critical. The results indicate that an amount considerably more than USD 200 billion per year will be needed to offset the negative effects on SIDS and low-income economies.

The production and export responses of fossil fuel exporters to global mitigation policies will play a crucial role. The implications for SIDS and low-income economies, which depend heavily on fossil fuel imports, hinge on the extent to which fossil fuel exporters adjust their production and exports. Put simply, if fossil fuel output remains constant and fossil fuel prices fall, fuel exporters will see a fall in their income and the incentive to pursue mitigation efforts decreases for all countries. In the short term, reducing fossil fuel output raises prices and incomes for fossil fuel producers. However, higher fuel prices increase the motivation to mitigate emissions, which reduces the demand for oil – and income to fossil fuel producers – in the medium to long term as renewables become relatively cheaper. This dynamic highlights the intricate relationship between production decisions, market forces and the drive to address climate change, particularly for vulnerable economies reliant on fossil fuel imports.

Table 4 Global temperature goal scenario, 2 °C pathway: Effects on real household expenditure (% change from reference scenario)

		2.0 °C pathway		
		standard with transfers (Variant A)	all participate - no transfers (Variant B)	low income and SIDS are not participating (Variant C)
Donor regions (5% of carbon tax income)	Australia and New Zealand	-8	-8	-10
	Japan and South Korea	1	1	0
	United States and Canada	-5	-4	-5
	European Union	-2	-2	-3
	Rest of Europe	-4	-4	-5
Transfer receiving regions	Pacific Islands	-6	-7	-3
	Rest of the world	-6	-9	-4
	South Asia	2	-2	2
	Caribbean	2	-2	-1
	West Africa	-14	-14	-11
	East Africa	-5	-5	-3
Other regions – not involved in transfers	China and Hong Kong	-7	-7	-9
	South East Asia	-7	-7	-9
	India	-3	-3	-4
	Central America	-6	-6	-8
	South America	-8	-8	-10
	Brazil	-5	-5	-7
	Eastern Eur. and C. Asia	-22	-22	-26
	Russian Federation	-28	-28	-31
	Gulf States	-38	-39	-42
	North Africa	-15	-15	-16
	SACU	-13	-13	-16

C. Impacts of response measures on Maldives

1. Economic impacts of global response measures on Maldives

The impact analysis for Maldives highlights important considerations for SIDS when assessing the implications of global mitigation policies for them.

Cross-border effects are substantial and have important implications for economies, especially for small open economies with limited capacity to adapt to the changing global economic environment. The results are an illustration of the principle that multiple policy objectives typically require multiple policy instruments, meaning that ‘optimal’ policy instruments to reduce emissions may need to be accompanied by policy instruments that address distributional implications.

The impacts of global response measures reverberate through various aspects of Maldives' economy, even in the absence of direct participation in climate action. These measures influence the pattern of production, trade, consumption and welfare within the country. Global climate response measures, through their effect on international prices, directly influence the costs of imports and prices received for exports in Maldives. These changes in global market dynamics then transmit to the local economy, affecting terms of trade as well as real exchange rates. Consequently, these fluctuations cause domestic changes in production, consumption patterns, carbon emissions and ultimately household welfare.

As shown in figure 6, there is an increase in imports in Maldives on all pathways in the global temperature goal scenario, primarily driven by cheaper oil imports. Exports also increase, along with welfare, measured by domestic absorption (total consumption by households, government and in the production of capital). However, GDP experiences a decline as the growth in imports exceeds that of exports. These effects are stronger for the 2 °C pathway as the fall in oil prices persists until 2045. This demonstrates that, even if Maldives does not actively engage in climate action, the interconnectedness of the global economy ensures that the repercussions of such measures are felt locally, affecting various economic indicators and the well-being of households.

Additionally, the results for the global temperature goal scenario reveal that the terms of trade[10] for Maldives improve across all but the most stringent climate scenario by 2045, which is also driven by the fall in the world oil price, as illustrated in figure 7. This improvement in terms of trade results in a strong increase in imports, and expansion in production due to the influx of cheaper oil and other imports. Consequently, wages and capital returns experience an increase as production expands, leading to an overall increase in household expenditure across all income brackets, with the exception of the lowest income households. However, it is worth noting that the impact on production, factor returns and household expenditure is smaller on the 1.5 °C pathway. This is attributed to the recovery of the oil prices starting from 2038 onward, which mitigates the magnitude of changes observed compared with the more stringent climate scenarios. The global response measures aimed at limiting global temperature rise enhance the terms of trade in Maldives across all income groups except for the lowest income households.

Similarly, the implementation of the global maritime transport scenario has impacts on the Maldivian economy, leading to its contraction and a subsequent decrease in household expenditure. This shrinkage is predominantly attributed to the interaction between the response measure and import costs, particularly those associated with shipping. One aspect of this interaction is the relatively modest impact on oil prices induced by the global maritime transport scenario, amounting to a decrease of merely 6% in comparison with up to 43% achievable under a global carbon tax. However, despite this reduction in oil prices, the overall effect is not sufficient to offset the amplified import costs arising from escalated shipping expenses. This illuminates that **the implementation of the global maritime transport scenario results in a smaller Maldivian economy, accompanied by reduced household expenditure.**

Meanwhile, the global air transport scenario affects the Maldivian economy mainly through the tourism industry due to tourism demand reducing as a result of higher airfares. Unlike the global maritime transport scenario, the primary mechanism through which the global air transport policy influences the economy is by diminishing tourism demand due to the increased cost of air travel, rather than altering the price of oil imports. This substantial effect on tourism demand triggers a cascade of consequences, prompting a shift in economic activities towards alternative export-oriented sectors. This shift ripples through labour and capital markets, resulting in a tangible reduction in consumption for all but the richest households. Furthermore, the implementation of this policy correlates with a deterioration in relation to almost all SDG indicators, signalling broader socioeconomic ramifications (see figure 8). Therefore, it can be inferred that **the global air transport scenario has substantial impacts on Maldives' tourist industry and wider economy owing to higher airfares.**

[10] The ratio of world export prices to world import prices weighted by the pattern of trade for Maldives.

Figure 6 Macroeconomic impacts of the global temperature goal scenario in Maldives (% change from the reference scenario in 2045 (2044 for 1.5 °C simulation), real values adjusted for price changes, no domestic carbon tax)

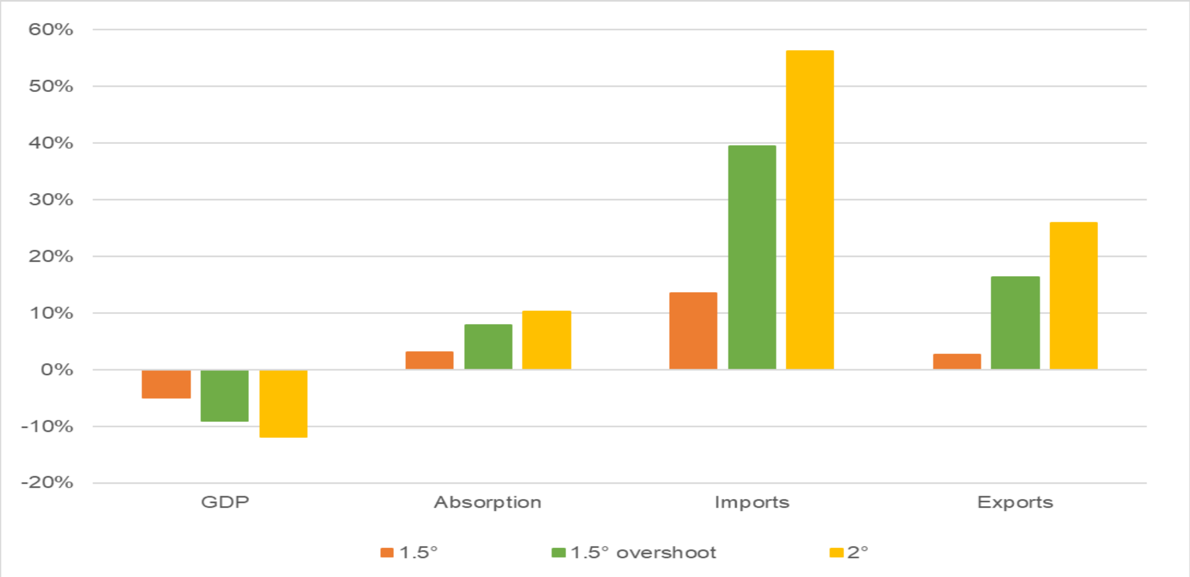
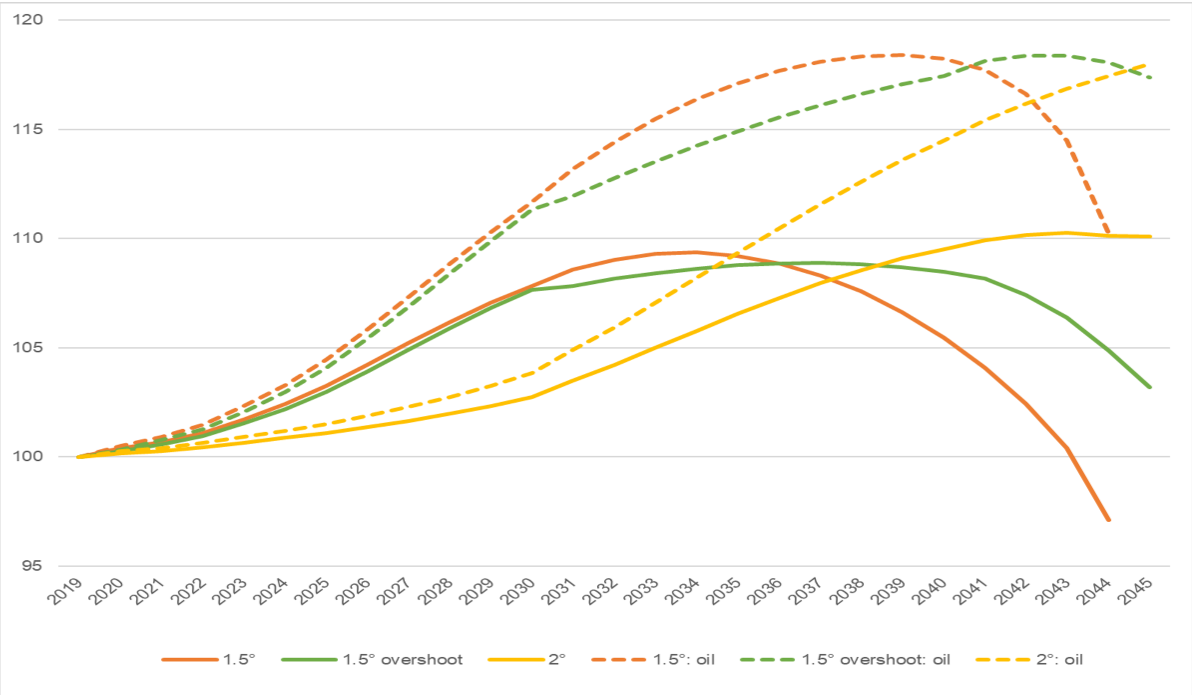
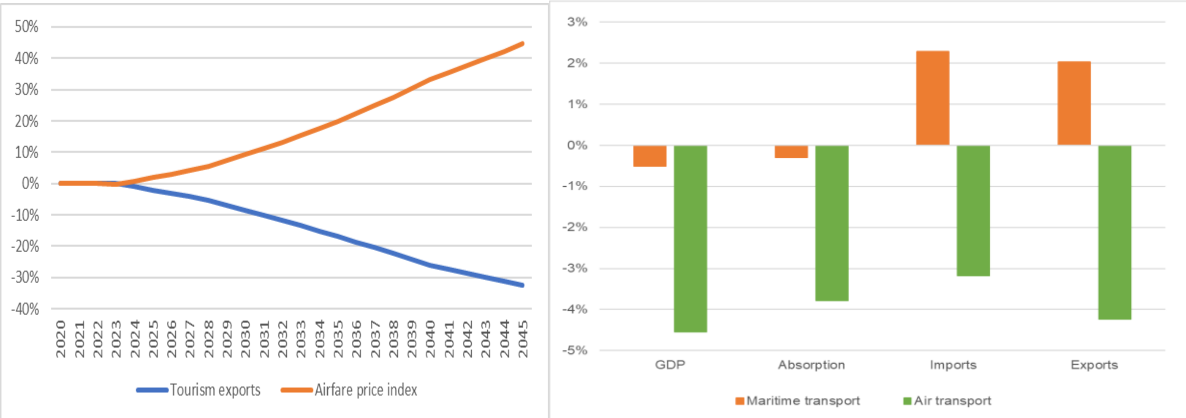


Figure 7 Terms of trade average for all products and oil alone under global uniform carbon tax (index relative to the reference scenario,)



Note: The index equals 100 when the terms of trade in the scenario and reference scenario are the same.

Figure 8 Global airfare price index and export of tourism services by Maldives tourism (% change from the reference scenario); and macroeconomic impacts of global maritime and air transport scenarios (% change from the reference scenario in 2045)



2. Employment dynamics and welfare implications of global response measures in Maldives

The impact of global response measures on jobs in Maldives is a crucial aspect to consider. Considering that the model assumes full employment at all times, the expansion of certain sectors necessitates the reallocation of labour from contracting sectors, reflecting changes in the job market according to changes in the structure of production. Figures 9 and 10 illustrate the effects of global response measures on jobs in Maldives.

Across the three variations of the global temperature goal scenario, the expansion of fish and fish processing exports, aimed at raising foreign currency and consequently higher imports, results in a notable influx of workers into the agriculture and fishing sector, and the food processing sector, which includes fish processing. Workers move from sectors that are less oil intensive and have less benefits from the falling oil price. However, on the 1.5 ºC pathway a different trend emerges. The expansion in manufacturing goods and transport services attracts workers into the industrial sector, diverting them from employment in other sectors. This shift underscores the dynamic nature of employment patterns in response to varying temperature goals, highlighting the need for adequate policy consideration to ensure equitable outcomes across sectors and income groups in Maldives.

The results for the maritime and air transport scenarios (see figure 10) reveal that the expansion of fish and fish processing exports will raise foreign currency, which is then used to purchase imports. This expansion draws workers into the agriculture and fishing sectors as well as the food processing sector, which includes fish processing. This effect is particularly notable under the CORSIA scenario where labour previously employed in the contracting tourism sector is redirected towards fish and fish processing, implying substantial changes in Maldives' labour market.

Global response measures have a progressive impact on household welfare in non-participating regions owing to the lower oil price. When analysing the impacts of the global temperature goal scenario on households, the results highlighted a key mechanism of global climate response measures with less than global participation, namely that countries that do not participate benefit from falling oil prices. The implementation of the carbon tax reduces the global demand for and price of fossil fuels. Countries, such as Maldives, that do not implement the carbon tax can import more oil at lower prices. This produces an 'externality effect', an indirect, unintended consequence in which global response measures lead to increases in emissions and reduced incentives to invest in renewables (although this may be partly offset by targeting transfers towards green investment).

As the main source of household income, changes in wages and capital and land payments drive changes in household income, expenditure and welfare. The impact of these changes on household consumption (welfare) in Maldives, compared with the initial wealth level of the household, is shown in figure 11. This analysis highlights the impacts of measures under the global temperature goal scenario across households and identifies vulnerable household groups that may be particularly negatively affected. In the case of global response measures that lead to falling oil import prices in an oil-dependent economy like Maldives, the overall impact on households is positive. All households are better off in all but the most stringent climate scenarios, with the poorest households seeing a large increase in welfare. Most households also benefit under the more stringent climate scenarios, but richer households in income quintiles 4 and 5, which derive a larger share of their income from capital, see a reduction in welfare on the 1.5 ºC and 1.5 ºC with overshoot pathways.

Figure 9 Jobs under the global uniform carbon tax (% change from the reference scenario in 2045 (2044 for 1.5 °C simulation))

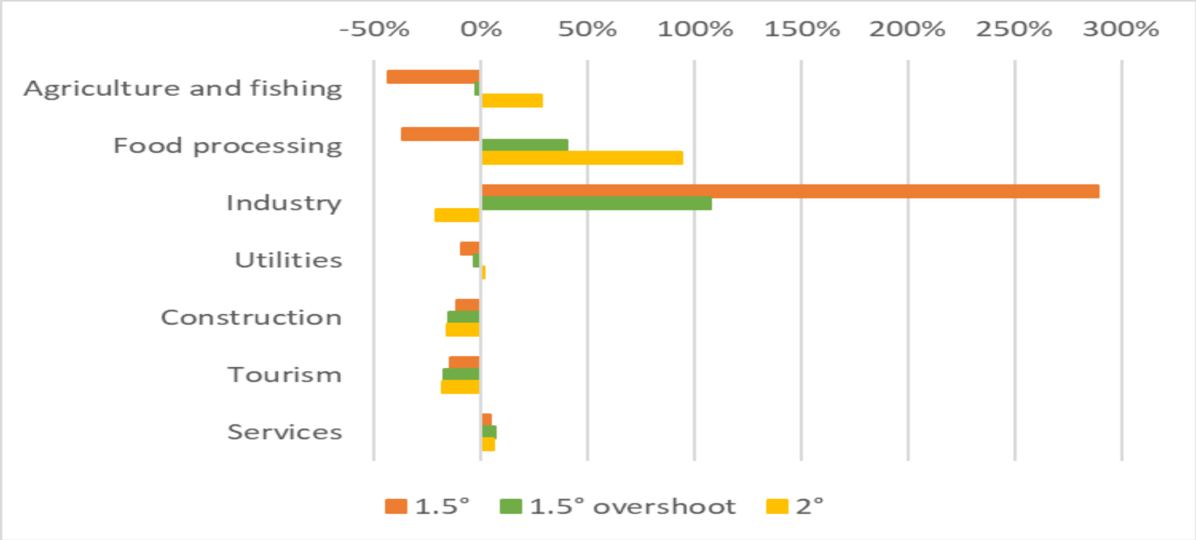
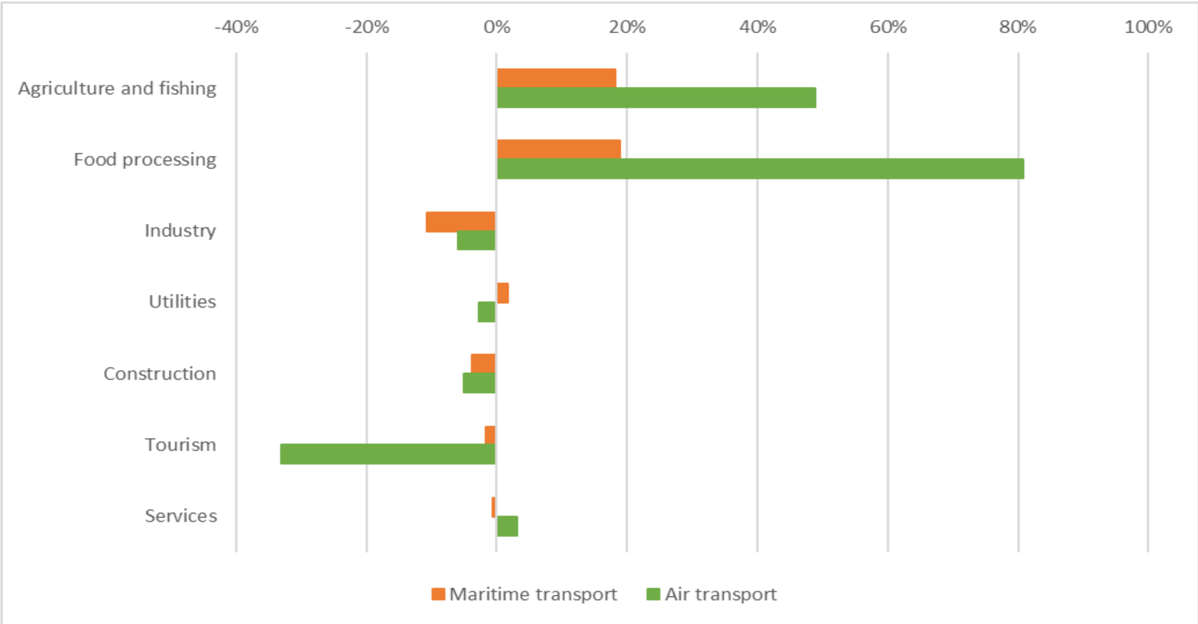


Figure 10 Jobs under the global maritime and air transport scenarios (% change from the reference scenario in 2045)



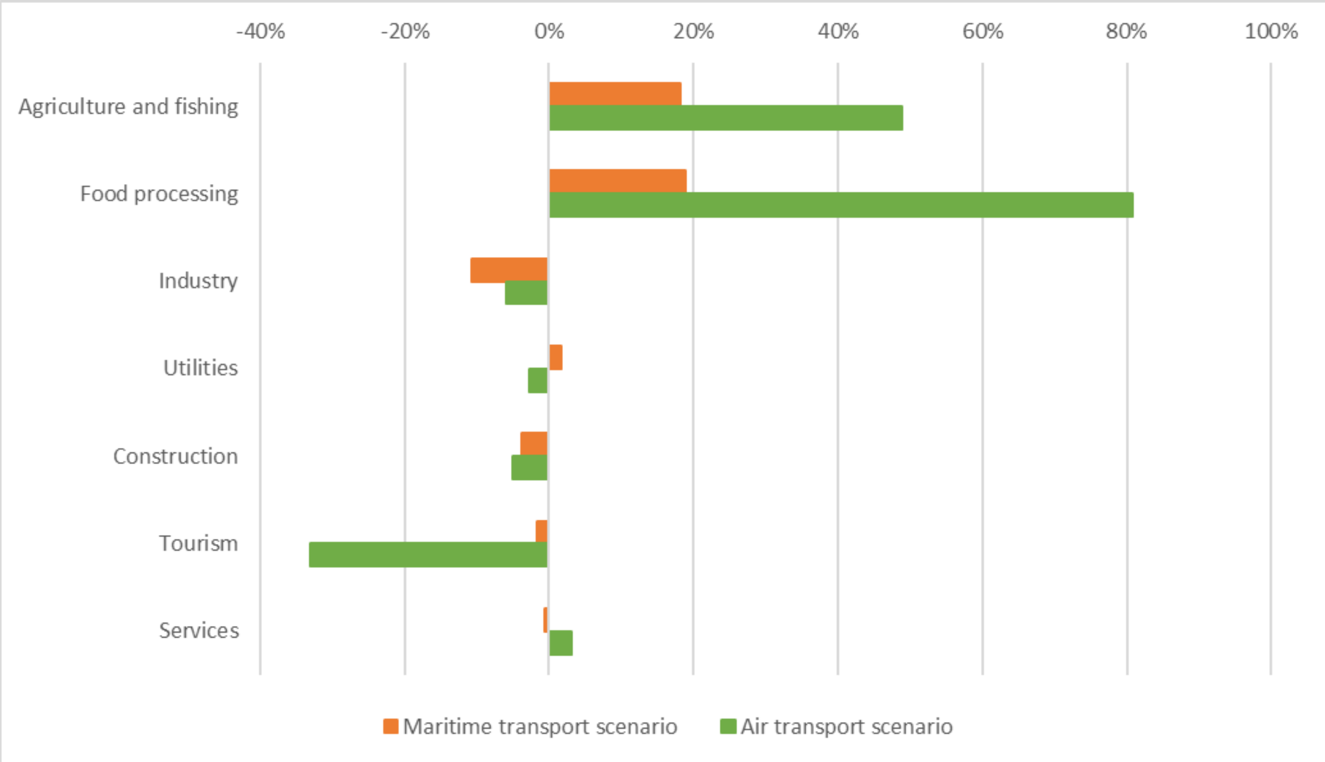
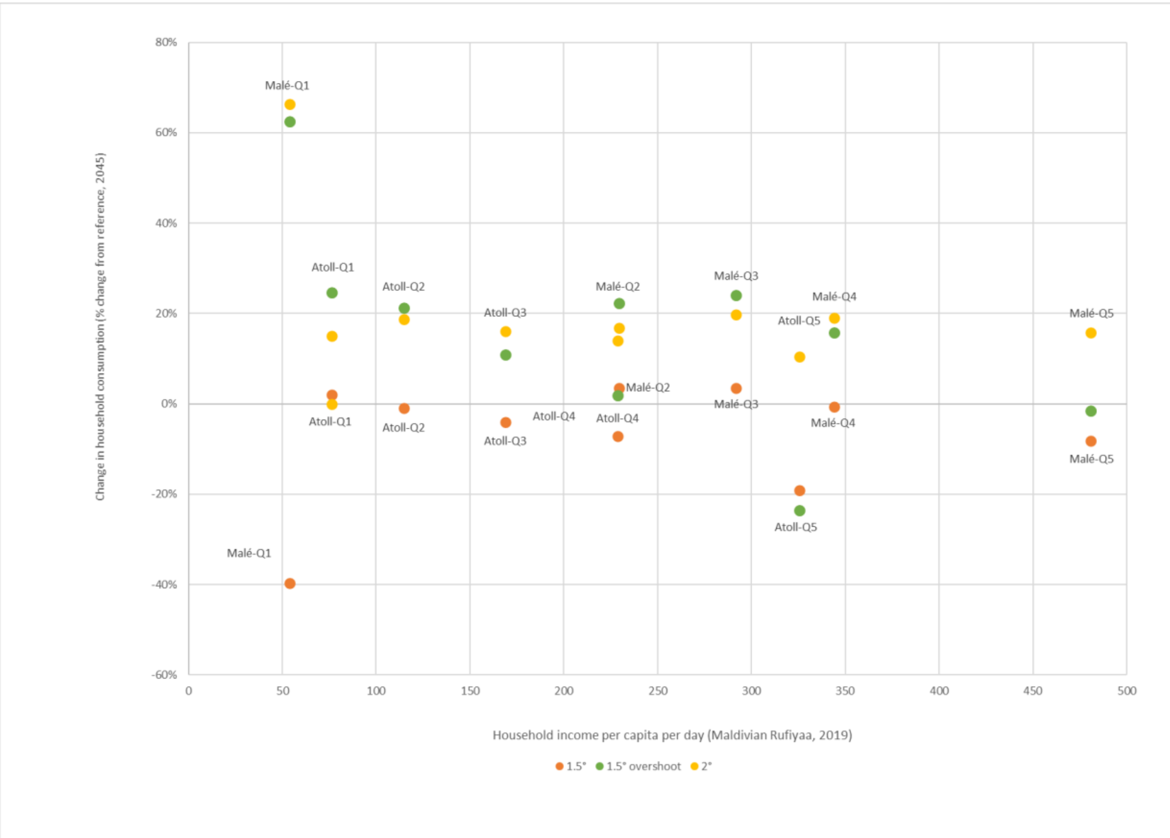


Figure 11 Impact on households of a uniform carbon tax as a response measure to achieve the global temperature goal



Note: Households are grouped by location and income quintile. The two locations are the capital island of Malé and other islands (atolls). There are five income quintiles, where quintile 1 (Q1) includes households with the lowest 20% of income and quintile 5 includes households with the highest 20% of income.

3. Navigating the interplay between global response measures and the Sustainable Development Goals

The interplay between lower oil prices and emissions is evident in all scenarios, where reduced fuel costs intersect with shifts in production, resulting in emissions surpassing reference scenario levels. However, the consequences extend beyond mere emission dynamics; lower oil prices also dampen the impetus for investment in renewable energy sources, complicating efforts to achieve NDC emission reduction targets.

Another consequence of global climate response measures for non-participating countries, particularly apparent in the case of Maldives as an oil-importing, import-dependent nation, is the additional hurdles encountered in meeting NDC targets when lower fossil fuel prices drive up emissions. This challenge is exacerbated for SIDS and low-income economies characterized by limited economic diversity and heightened exposure to international markets.

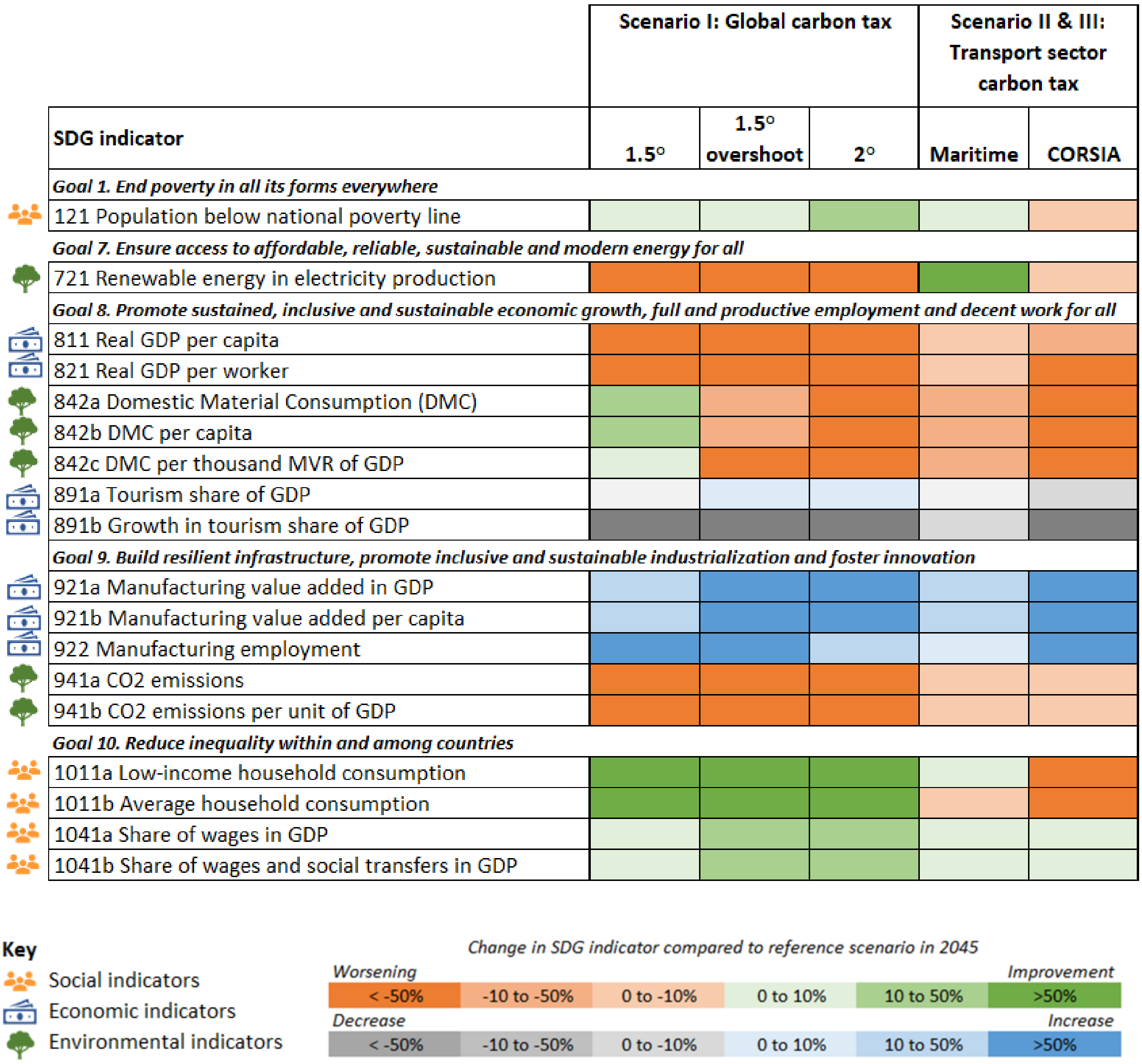
Given these circumstances, the capacity of such economies to adapt to shifts in global economic dynamics is significantly constrained. While global modelling exercises provide valuable insights, it is essential to recognize the unique circumstances and challenges faced by individual countries. Lower oil prices lead to higher emissions in both transport scenarios. Lower fuel costs combine with changes in production to increase emissions above reference scenario levels.

Lower oil prices reduce the incentive to invest in renewables and make reaching NDC emission reduction targets more difficult. A consequence of global climate response measures for non-participating countries is that it will take additional efforts to achieve their NDCs when lower fossil fuel prices lead to higher emissions. These effects are particularly clear for Maldives as an oil-importing, import-dependent country.

SIDS and low-income economies that are characterized by limited economic diversity and are highly exposed to international markets will have less capacity to adjust to changes in the global economic markets. The global modelling exercise was run with an aggregation specifically designed for SIDS. The nuances available to policymakers in individual countries will vary enormously but some general principles are clear. Nevertheless, overarching principles emerge, highlighting the vulnerability of Maldives, due to its high dependence on tourism, imported fossil fuels and international transport services, which exposes the country to cross-border impacts of global response measures.

Further, the findings reveal that the global response measures directed towards limiting global temperature rise inadvertently enable non-participating regions to advance towards the SDGs, albeit at the cost of environmental objectives. From the impacts of the global temperature goal scenario in Maldives, it becomes evident that the higher the targeted global temperature rise, the more regression is observed in environmental SDG indicators. At the same time, more progress is observed on social and economic indicators, as shown in figure 12. This progression and regression is driven by the fall in world oil prices resulting from the reduction in fossil fuel demand. Consequently, in the global temperature goal scenario, a strong expansion in production occurs in response to lower input costs. This expansion in production leads to significantly higher emissions, particularly in sectors heavily reliant on oil imports, as the reduced costs make expansion more economically viable. In essence, global response measures aimed at limiting global temperature rise allow non-participating regions or countries to make progress towards social and economic SDGs at a cost to environmental goals.

Figure 12 Impacts of global response measures on progress towards the Sustainable Development Goals in 2045 (2044 for 1.5 °C simulation)



Scenario I: Global carbon tax
Scenario II & III: Transport sector carbon tax
SDG indicator
1.5°
1.5° overshoot
2°
Maritime
CORSIA
Goal 1. End poverty in all its forms everywhere
121 Population below national poverty line
Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all
721 Renewable energy in electricity production
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
811 Real GDP per capita
821 Real GDP per worker
842a Domestic Material Consumption (DMC)
842b DMC per capita
842c DMC per thousand MVR of GDP
891a Tourism share of GDP
891b Growth in tourism share of GDP
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
921a Manufacturing value added in GDP
921b Manufacturing value added per capita
922 Manufacturing employment
941a CO2 emissions
941b CO2 emissions per unit of GDP
Goal 10. Reduce inequality within and among countries
1011a Low-income household consumption
1011b Average household consumption
1041a Share of wages in GDP
1041b Share of wages and social transfers in GDP
Key
Social indicators
Economic indicators
Environmental indicators
Change in SDG indicator compared to reference scenario in 2045
Worsening
Improvement
< -50%
-10 to -50%
0 to -10%
0 to 10%
10 to 50%
>50%
Decrease
Increase
< -50%
-10 to -50%
0 to -10%
0 to 10%
10 to 50%
>50%

4. **Socioeconomic impacts of domestic response measures**

The model results for the NDC scenarios show that expanding renewable energy sources has a positive effect on reducing emissions while having minimal impacts on the broader economy. Specifically, when domestic response measures are implemented to increase the share of renewables in the energy mix to 15% in both the tourism and non-tourism sectors, the resulting impacts on the economy are relatively minor (see figure 13) compared with the global climate change response measures discussed earlier. The smaller impact on the economy is due to the fact that the change in the energy mix primarily targets electricity production. As a result, the effects are more contained and do not have significant ripple effects across the entire economy.

Furthermore, it is observed that that scenario aligned with NDCs results in lower emissions compared with those under the broader global response measures. This indicates that domestic measures aimed at transitioning to renewable energy sources can contribute to emissions reduction goals outlined in international agreements like the Paris Agreement, in contrast to the potential increase in emissions resulting from global responses to climate change (see figure 14).

The comparison between the two NDC scenarios further highlights that scaling up use of renewable energy by increasing PV systems in non-tourism sectors (non-resort PV) results in a significant reduction in emissions (see figure 14) compared with PV installation in the tourism sector (resorts). This reduction is primarily driven by the abolition of the 9% subsidy on diesel-based electricity production. In essence, by eliminating the subsidy, there is less financial incentive to use fossil fuels for electricity generation and the adoption of cleaner energy sources like PV systems is encouraged.

Figure 13 Macroeconomic impacts of domestic response measures (% change from the reference scenario in 2030 and 2045)

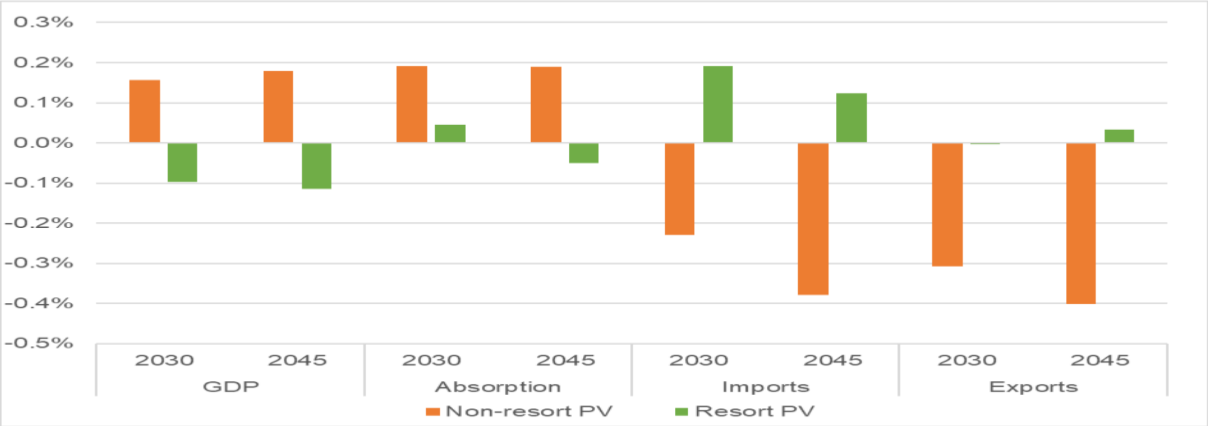


Figure 14 Emissions resulting from domestic response measures (% change from the reference scenario in 2030 and 2045)

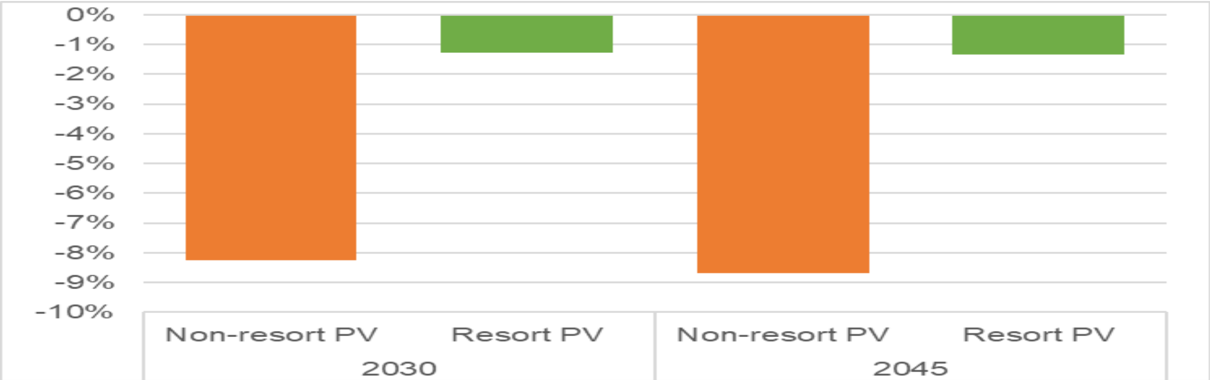
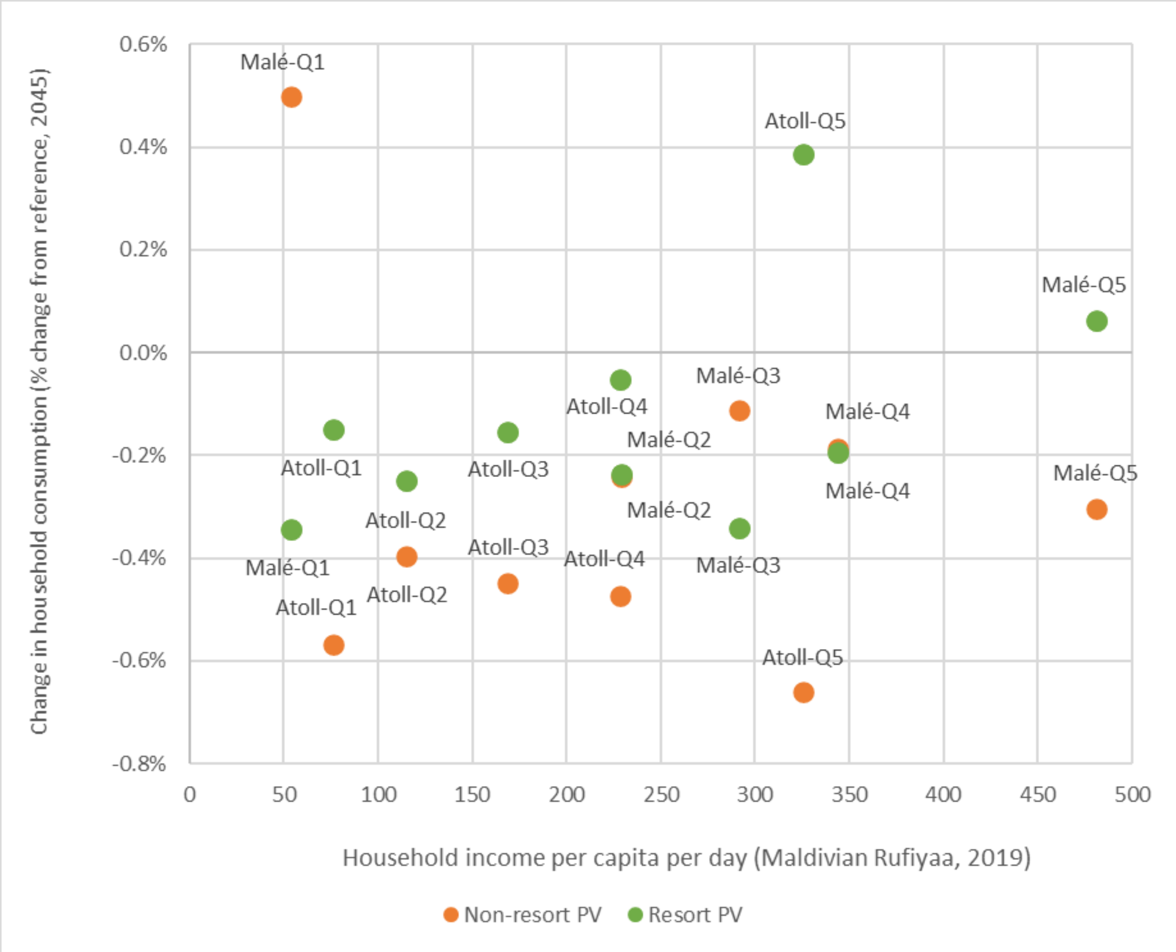


Figure 15 Impacts of domestic response measures on households in 2045



High emission reductions are achieved at the cost of household's welfare as a significant reduction in household welfare is observed in the non-resort scenario. This reduction is driven by higher product costs, broadly lower wages and capital returns, and the increase in the general goods and services tax rate aimed at funding investment in PV. However, when these results are compared with global response measure scenarios, the magnitude of the impact on welfare is less pronounced. Only three types of household experience an increase in welfare: the poorest Malé household, which is shielded from the impact on factor incomes by government transfers, and the two richest households, which benefit from higher capital returns in the resort scenario (see figure 15).

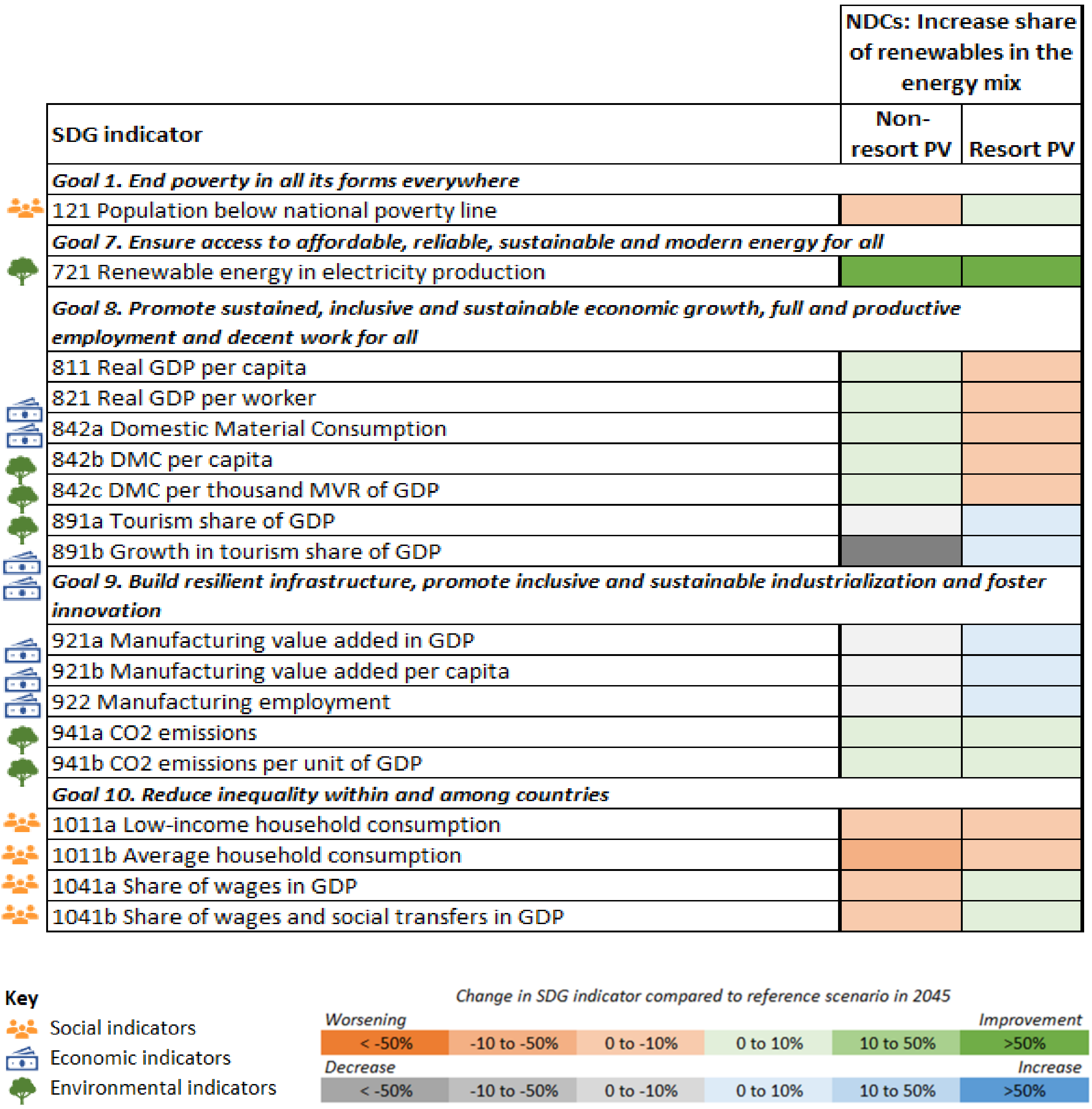
5. Navigating the interplay between domestic response measures and the Sustainable Development Goals

The impact of the NDC scenarios on progress towards the SDGs shows that the transition in the energy mix leads to a decrease in household welfare, while environmental indicators generally show improvement, as shown in figure 16. Although the poverty rate remains stable under the resort PV scenario, it slightly deteriorates under the non-resort PV scenario. The impact on economic and environmental indicators, other than emissions, is mixed. In contrast to in the global temperature goal and maritime and air transport scenarios, these impacts arise from direct domestic consequences, rather than cross-border effects.

The results underscore the critical strategic imperative for Maldives to transition towards renewable energy sources. Given the current land availability (including roofs) and economic conditions in Maldives, achieving an energy mix comprising 15% renewables appears not only feasible but also essential for the country's sustainable development. However, sustaining this transition and overcoming potential challenges, such as land area loss due to climate change, will require significant investment in innovative technologies. In this regard, embracing solutions like floating PV and ocean energy holds promise for further expanding the renewable energy portfolio, thereby enhancing Maldives' energy resilience and reducing its vulnerability to external shocks such as fluctuating oil prices.

Moreover, strategic policy interventions aimed at reducing the country's reliance on fuel imports are paramount, not only for enhancing energy security but also for bolstering economic stability and environmental sustainability. Nonetheless, it is crucial to approach this transition with caution, considering the susceptibility of renewable infrastructure to extreme weather events. Thus, adopting a diversified portfolio approach to renewables, inclusive of other technologies like tidal energy where feasible, is deemed necessary to mitigate risks and ensure long-term energy sustainability. Furthermore, there is an intricate interplay between Maldives' energy trajectory and global fossil fuel markets, emphasizing the need for comprehensive analyses to anticipate and respond effectively to various market scenarios. Ultimately, the overarching goal is to navigate the transition towards renewable energy while simultaneously addressing climate vulnerabilities and promoting sustainable development in Maldives.

Figure 16 Impacts of domestic response measures on progress towards the Sustainable Development Goals in 2045



III. Informing policy decisions with study findings

The aim of this chapter is to illustrate how the findings of this study can serve as a valuable tool for informing stakeholders' climate policy decision-making.

1. Can Maldives achieve its nationally determined contribution without extra climate policies?

The results suggest that market forces alone will not facilitate the transition towards the share of renewable energy in the energy mix required for Maldives to fulfil its NDC commitment. Projections from the reference scenario indicate that the existing market incentives are insufficient to bring the necessary shift in the energy mix for emission reductions, thus necessitating additional policy interventions. The need to fund changes in the energy sector will make substantial demands on investible funds. The Government will need to play a role in incentivizing and possibly financing investment in renewables. Moreover, if economic growth, and consequently electricity demand, surpasses projections, there will be a heightened need for stronger expansion of renewables.

2. Will all parts of Maldives' economy be affected by climate policies?

Climate policy impacts will induce changes across all sectors of the economy, each adjusting at varying rates. Structural shifts in production will evolve gradually, primarily driven by incentives aimed at restructuring the energy sector, particularly electricity production. Employment patterns will undergo transformation, while changes in consumption patterns typically manifest swiftly. Trade patterns will change partly due to changes in relative import and export prices and partly due to changes in exchange rates. Changes in relative exchange rates will have a significant impact on the economy in terms of trade and other international transactions.

Additional interventions may be necessary to address the implications of climate policies. The Government needs to proactively manage fiscal policies to ensure the stability of its budget and to mitigate income distribution effects to some extent. The implications of changes in different tax instruments will be important. Where the relative incomes of poor households and the wage rates of lower-skilled workers are adversely affected by the costs of mitigation policies, domestic policy interventions to address these implications may be important to avoid social discord.

3. Can cross-border impacts lead to improvements in all aspects of sustainable development (economic, social and environmental)?

There are strong trade-offs between environmental and social and economic goals. The 'externality effect' of global response measures with less than global participation brings about a conflict of goals. Non-participation in global response measures gives countries an opportunity to capitalize on lower oil prices to make progress towards social and economic goals. This comes at a cost to environmental goals and makes achieving a country's NDC more difficult as a result of increased emissions and reduced incentive to invest in renewables, although this may be partly offset by transfers targeted at green investments. These effects are clear for Maldives as an oil-importing, import-dependent country. Maldives has the policy option to introduce a carbon tax or other duty to 'choke off' some of the cheaper oil imports, thereby reducing the increase in emissions.

4. What is likely to happen if oil producers respond to falling prices by restricting supply?

The cross-border impacts of global response measures in Maldives are driven by changes in oil prices. The responses of fossil fuel exporters will be critical for both net importers and net exporters. These responses are unknown, and therefore analyses of the consequences of a range of responses by fossil fuel exporters are crucial. If oil producers respond to falling prices by restricting supply, oil prices are likely to be higher (although they may still be lower than in the reference scenario). The economic and social benefits of lower oil prices will be reduced and the increase in emissions will be lower, meaning the trade-off between social and economic benefits and environmental costs will be smaller.

Speeding up the energy transition insulates Maldives from changes in world oil markets. A strategic policy intervention to change the energy mix towards renewables lessens Maldives' dependence on fuel imports, which would insulate the country from oil price rises should oil exporters respond to falling global prices by restricting supply. The increase in energy security resulting from the decoupling from global oil markets should be weighed together with the possibility of extreme weather events damaging PV infrastructure, which may be more vulnerable to damage than diesel generators. A portfolio approach to renewables that includes other technologies such as tidal, where possible, is therefore desirable.

5. Can a reform of the fossil fuel subsidy help Maldives to achieve its nationally determined contribution?

Reforming the fossil fuel subsidy on electricity production offers scope for greater emission reductions. Removing the fossil fuel subsidy from diesel-based electricity production reduces emissions and increases the incentive to invest in renewables. The impact on household welfare should be considered and policy interventions put in place to support vulnerable households.

6. Are there any concerns about the transition towards renewables for Maldives?

A shift in the energy mix towards renewables is feasible with currently available land area but alternative technologies may be needed to expand PV further when land area is threatened by rising sea levels. The expansion in PV to achieve 15% renewables in the energy mix is likely to be achievable given current land area (including roofs). However, concerns about land area loss due to climate change and the increasing availability of new technologies suggest that floating PV could allow for further expansion in PV, assuming that its shading effect on marine life is benign, alongside ocean energy technologies.

7. Would Maldives benefit from participating in global maritime and air transport climate policies?

The main impact of global maritime and air transport climate policies in Maldives comes from the participation of other countries outside Maldives in the policies. Maldives uses international maritime transport to import goods and international air carriers to bring tourists to the islands, both of which are subject to transport climate policies. If Maldives remains outside CORSIA, Maldivian, the national airline, would not see a climate-policy-driven increase in airfares. However, despite Maldivian covering some markets, including China and India, it is unlikely to be scalable enough to offer a carbon-tax exempt option for most inbound tourists. Another option would be for Maldives to participate in CORSIA to reinforce its commitment to tackling climate change and to consider a revision of the goods and services tax rate on tourism to reduce the non-flight component of the holiday cost. An exploration of this option, including its implications for government revenue, should be analysed in depth ahead of any policy change.

8. What role can Maldives' tourism sector play in the transition?

A clear tourism and diversification strategy is key. It has been recommended that SIDS strengthen the link between their agricultural and hospitality sectors (Pratt, 2015); however, increasing this interdependency further increases the reliance on tourism such that threats to tourism ripple through the rest of the economy. In Maldives, resorts provide 16% of total demand for fish and 34% of total demand for passenger transport services; thus the contraction of the tourism sector under CORSIA will have effects beyond the tourist industry. The potential for negative impacts on a key sector within the narrow economic base of Maldives requires action to protect the sector and explore opportunities for economic diversification. Options for the tourism sector include a focus on more price-insensitive high-value tourism, and an expansion of the digital economy offers options for diversification (World Bank, 2022).

The tourism sector is directly affected by global response measures. Efforts to limit emissions from the hard-to-abate aviation sector directly affect tourism demand via higher airfares. This in turn affects the number of tourists travelling to SIDS, many of which rely on income from tourism. This mechanism is also relevant to oil-producing countries considering diversifying their economies via investment in tourism.

9. What factors should countries consider in planning their transition strategies?

The following seven factors influence the extent to which climate policies are likely to affect an economy:

1. The extent to which a country is tied into international oil markets, as either an importer or exporter;
2. The extent to which a country is reliant on shipping for imports and exports;
3. The extent to which a country is reliant on income from tourism;
4. Whether a country is participating or not in a global response measure;
5. Whether current policies are sufficient to bring about the energy transition or further policies are needed to support the transition;
6. Whether there is scope to reform domestic energy subsidies;
7. Whether it is feasible for renewables to meet expected future energy demand.

IV. Lessons learned on use of economic models for policymaking

This chapter examines the challenges faced and insights gained while working towards the objectives of customizing and implementing two CGE models, designing a user-friendly modelling interface, creating a SAM and conducting staff training; and offers recommendations based on the lessons learned.

A. Stakeholder engagement

The benefits of impact analysis using modelling tools must be demonstrated prior to engaging with stakeholders. A key challenge is to demonstrate the return on investment in modelling tools. Country partners are asked to invest their time, resources, data and personnel in developing the tool. It is important to explain the strengths and weaknesses of the CGE approach and what they can expect to gain from their investment. Additionally, explaining how these tools complement other quantitative and qualitative methodologies is important. A high-level presentation at the start of a project illustrates the insights that can be gained, using examples from previous studies, and the benefits of close collaboration with country partners.

The use of a user-friendly interface for the modelling tool enhances stakeholder engagement and collaboration. Firstly, the UNFCCC-MIRO interface enabled stakeholders to interact with more complex models with less training. This increased accessibility fosters transparency and trust by demystifying the modelling 'black box'. Secondly, the process of setting up, running and interpreting scenarios takes users through the process of considering potential impacts and promotes consideration of unintended consequences of both domestic and international policies. Thirdly, users can explore a wider range of scenarios, enriching the research output beyond those that can be included in a written impact assessment report. Fourthly, the interface provides an accessible entry point to CGE simulations for stakeholders that are interested in investing in models for their own economies. Finally, the use of common models through the interface encourages discussion and collaboration among stakeholders, facilitating a shared approach to impact assessment.

Engaging experts as consultants is necessary to effectively use advanced toolkits in the short term for building national capacity for the long term. While low-income countries or SIDS may face challenges in independently using advanced toolkits, such as the one discussed, in the short term, engaging consultants can provide essential support. However, it is imperative for these countries to simultaneously prioritize building the capacity of national policy analysts to ensure sustainable use and ownership of the toolkit in the long term.

Close collaboration between consultants and the country partner is essential to ensure representative results. The accuracy of CGE model findings depends on the quality of data and the degree to which the model, assumptions and scenarios reflect the situation in the country. Close collaboration between local policy advisors and analysts is important for obtaining accurate data, framing appropriate policy responses and effectively communicating insights to policymakers.

Involving a country team of domestic climate change specialists during the project fosters ownership of results and skills development, which are important elements for using results in policymaking. The collaborative work of a country team of domestic climate change specialists with consultants during the project builds trust. Long-term ownership of the results and insights from the toolkit requires the allocation of domestic resources to national statistical agencies and capacity-building for national policy analysts.

The provision of a clear statement of international and domestic policy objectives with respect to climate change improves the toolkit. Clear guidance on policy goals helps to shape policy scenarios and encourage active engagement in the analysis. Having a well-defined set of objectives facilitates more targeted and meaningful analysis within the toolkit, ultimately contributing to better-informed decision-making on climate change policies.

B. Data

The process of modelling starts with the data. The key challenge is to ensure that the data are available and of good quality. Parties interested in undertaking similar analyses are encouraged to make an inventory of the currently available data and compare it with the requirements below. A programme of data collection can be developed to fill any gaps:

- The database for the global model is likely, for the foreseeable future, to be the GTAP database. The data for the country model will be case specific;
- The database for the country model is a SAM, which is a record of income and expenditure transactions in a country in a given year. Ideally the year should be representative of a stable time in the country, meaning not during a pandemic, conflict, famine, etc.;
- If a SAM is not available, the minimum data should be consolidated national accounts and domestic supply and use tables from the national statistical agency supplemented by household incomes and expenditure and labour force surveys, environmental accounts and detailed tax data;
- Data quality is important as it determines the quality of the results from the toolkit. The production of national accounts by the national statistical agency is central to the quality of the economic analysis and ownership of the results and insights. Ideally the core economic data are provided in a detailed SAM produced by the national statistical agency.

C. Capacity-building

Domestic capacity is needed if domestic policy analysts are to provide in-house analysis to domestic policy advisors. The key challenge is to identify and develop domestic capacity, where needed. Without substantial domestic capacity countries will experience difficulties owning the results and insights.

Knowledge about the strengths and weaknesses of models is central to ensuring the results, and insights can inform policy decisions.

Basic training in modelling techniques should be undertaken at the beginning of the project cycle to provide domestic analysts with information to enhance their engagement in the project.

Funding for capacity-building should be provided by the domestic agency or agencies employing the policy analysts. This increases the probability of managers providing time and resources for participants in the capacity-building programme.

D. Use of modelling tools for policymaking

Models are useful tools as they can eliminate logical inconsistencies. They help to extract information from data, which can then be transformed into knowledge. Models are a framework that helps to recognize and structure complex problems and think through the consequences. They are used to quantify effects and help to choose between decision options.

Economy-wide models like CGE models are strong in showing interlinkages between markets where one might not necessarily make connections. Modelling results highlight areas of concern, prompting further investigation into why certain regions, households or markets are more affected than others. By illuminating dominant relationships, model results assist in directing policy focus towards critical areas. For instance, the Maldives case study reveals that the impacts of the carbon tax and global maritime transport scenario are primarily influenced by changes in world oil prices. Similarly, the reduction in tourism demand under the global air transport scenario redirects employment opportunities to fishing and fish processing, sectors that benefit from lower oil prices.

Assumptions employed in modelling are often criticized, but they help in thinking about how the world develops. A CGE model is based on assumptions that are founded in economic theory. When a scenario outcome seems unreasonable, it highlights areas where current behaviour and economic structure result in an unlikely outcome in the future, and thus identifies inconsistencies in current structures and behaviours, where changes in behaviour or markets should most likely be expected. Questioning the assumptions is an important process in opening discussion about transformation. For example, the Maldives case study simulations clearly show the limits of market-based policies (carbon tax) in achieving the emission reductions necessary to stay on the 1.5 °C pathway (with or without overshoot). The model reports very high costs, which may be labelled unreasonably high for a number of regions. This does not mean the model is wrong; it means that more changes than currently assumed in the scenarios are needed to make the transition, and highlights regions and sectors where transition is most needed. Model results thus highlight the need for governments to actively support diversification of the economy, highlight the relevance and value of research and development, and raise awareness of the need to support technological change.

The simulations could include additional technological change to support economies in adjusting to the economic impact of reducing emissions. But the architecture of future structural change is highly uncertain and introducing unknown technologies to the system risks assuming 'manna from heaven' unless the technological change is based on research and development and additional investment. The model accounts for responses to changing prices inside the borders of the current production and demand system. However, a full transformation of the economic system is not simulated in the global model. As it is not the focus of the Maldives study, the global modelling exercise did not include possible response policies such as supply responses and other policies aimed at transferring the economy to another production system and inducing structural change. The study highlights that the level of technological change brought about by market forces alone will not bring about the shift to new production systems, and additional policies are needed to drive the large-scale shifts needed.

The model analysis discloses policy inconsistencies and trade-offs. The global scenario, for example, investigates different possibilities for how to limit the burden of global response measures on developing countries. Results clearly show the trade-off related to exempting regions from the uniform carbon tax. While exempted regions are better off, the subsequent leakage effect (a policy-induced relocation of carbon emissions to non-participating countries) increases the burden on participating regions. Results show that it is less costly for participating regions to transfer a part of the tax income to support transition in developing countries. The analysis for Maldives highlights trade-offs between environmental and social goals, as well as potential policy mismatches such as levying import duty on oil and subsidizing the use of oil in electricity production.

Investigating the model database helps to understand the economic structure of economies. The national and global database is a matrix representation of national account statistics. The database is crucial as a basis for modelling and also provides useful insights into the economic structure of a country and relationships between countries. It can identify relevant areas for strategic development or government activity. For example, Maldives is highly import dependent, being wholly reliant on imports for diesel fuel, minerals (a key input into the construction industry) and machinery. Aside from fish, Maldives is highly dependent on imports for food including dairy products (import dependency ratio 100%) and grain mill products (93%). There are linkages between domestically produced goods and the large tourism sector, with resorts providing 16% of total demand for fish and 34% of total demand for passenger transport services. The import dependence and strong link between food and tourism increases the vulnerability of the economy to tourism-based shocks such as in the global air transport scenario.

The use of a model structures thinking about complex problems. Participating in the process of setting up a scenario and model for an analysis in a general equilibrium framework is valuable to structure discussions and start thinking about impacts. When translating a policy into a policy scenario, decisions about a number of design details are required that the modeller requires to run a scenario. Design details can include, for example, the type of the policy and the size of change; which parts of the economy, and subsets thereof, are targeted (households, commodities, sectors); whether the scenario simulates an increase or decrease, and if a counterfactual should be simulated; and the time-horizon under review. The scenario design typically involves thorough background research, including the collection of expected outcomes. This requires reasoning through the economic intuition underlying the model and develops the understanding of the relevant aspects of the formulation and representation of policies. This leads to an improved understanding about the problem under review and the identification of possible knowledge gaps or inconsistencies even before the model is run.

Thinking through the scenario reveals expected costs and benefits of a policy. It helps in interpreting results and drawing policy recommendations. For example, lack of adequate information about the foreign labour force was identified during the SAM construction, despite being more than a third of the total workforce of Maldives. Identifying gaps brings awareness of the limitations of the model and indicates where future gains can be made to improve it. In addition, in CGE models, the imposition of response measures imposes additional constraints on the economic systems. In the scenario set-up of the case study the model results report only economic effects related to the implementation of specific response measures; the costs of climate change or benefits of mitigation are not included. These costs of taking action need to be weighed against costs of climate change – the cost of not taking action or delaying action. Less ambitious pathways will also result in higher adaptation costs from global warming. These higher adaptation costs can be simplified under two categories: environmental impacts that are hard to reverse, such as projected sea level rise and human health impacts; and higher temperatures that require more and earlier action for mitigation, and are related to economic costs, such as accelerated scrappage of electricity generation plants, reductions in living standards needed to fund accelerated investment programmes, etc.

Economy-wide models such as CGE models can help in understanding impacts of policies that are planned and comparing impacts of alternative policies. The model is designed and well suited to answer 'what if' questions. The tool can for example be used to investigate a variety of scenarios and assumptions to understand which element of the policy design is important for the outcome. For example, the role of oil prices as the main driver of changes in the terms of trade for Maldives is shown by comparing the oil price only effect with the overall effect (see figure 7). The model can also be used as a tool for sensitivity analysis to evaluate performance in a variety of futures, such as the global generic carbon tax associated with a variety of pathways (1.5 °C, 1.5 °C with overshoot, 2 °C and 2.5 °C).

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