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# How is World Sustainability in the Climate Policy Sphere? A scenario assessment of different commitments for curbing CO2 emissions in a Sustainability Framework

*(Draft, please do not cite)*

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**Abstract:** This paper aims at analysing the possible outcomes of the pledges of the Copenhagen Accord, proposed after the United Nations Framework Convention on Climate Change (UNFCCC) 15th Conference of the Parties (COP-15) in December 2009. We consider different levels of cooperation that may arise and analyse them with a dynamic Computable General Equilibrium (CGE) model of the world economy. In addition, we also assess the effect of the different climate targets on sustainability. This is done by using a new sustainability index, the FEEM Sustainability Index (FEEM SI), which - being built within the dynamic CGE - can be projected and compared across different scenarios. We find that whereas environmental sustainability is greatly improved at regional and world level thanks to the reductions achieved with emissions trading, economic and social sustainability can be affected to the point of leading to a decrease in overall sustainability. It is also found, despite the usual debate on the economic costs of climate policies, that economic sustainability is not significantly affected by international emissions trading, while social sustainability is negatively affected. By constructing a scenario in which revenues from the global emissions trading are recycled in sectors expected to increase economic and social sustainability, we show that climate policies that are implemented along with policies aimed at improving other aspects of sustainability are likely to lead to a more sustainable future.

***Keywords**:* Climate policy; Computable General Equilibrium (CGE) Models; Sustainability.

## 1 INTRODUCTION

Dealing with climate change has become a matter of international interest since the adverse effects that come along with it will affect the whole world ecosystem and produce a set of differentiated impacts depending on the characteristics, vulnerability and adaptation capabilities of every country in the world. The difficult task of designing and implementing a feasible climate policy is also controversial due to the economic costs it entails and because it requires efforts that may compromise future growth, in developing countries. In these circumstances there has been a wide set of proposals coming from both developed and developing economies. The long path towards a comprehensive international climate agreement is in a decisive phase after the $15^{th}$ United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP-15) held in Copenhagen on

December 2009. One of the outcomes of the conference has been the Copenhagen Accord signed by several countries and particularly proposing quantified emission targets by a set of leading countries.

The different pledges of countries regarding emission abatement targets inevitably suggest the task of analyzing the possible outcomes of those efforts in environmental, economic and social terms, as addressed by different studies using also different tools or models. A particularly useful method for the assessment of the effects of mitigation efforts proposals is the scenario analysis. Following this framework, Elzen et.al. (2009) propose three scenarios depicting low and high abatement targets as well as a common effort from Annex I and Non-Annex I countries. Mitigation costs expressed as share of GDP are in the range of 0.01-2.24% with the higher cost when all countries in the world engage in abatement efforts related to the more ambitious target of -30% with respect to 1990 for Annex I and -16% with respect to baseline emissions for Non-Annex I countries.

In another study Mattoo et. al. (2009) perform a scenario analysis related to an abatement effort carried out by all countries in the world by means of a Computable General Equilibrium (CGE) model focusing on different manufacturing exports and output. The different scenarios relate to the adoption of emissions trading systems (ETS) or public transfers to developing countries. Their main findings are that manufacturing output and exports would face a decline especially in countries with higher carbon intensity. For low carbon-intensive countries these effects would be lower, and for some countries they could even be beneficial. Moreover, including trading in emission rights and transfers may intensify the production decline in the manufacturing industry.

The European Union proposed an ambitious target for 2020 (Commission of the European Community, 2009) and the implications of that policy are analyzed by Böhringer et. al. (2009), using three different CGE models. That analysis is also performed through scenario comparison based on different implementations of climate policies starting with a uniform carbon price and exploring variants related to ETS and Non-ETS sectors. The study compares welfare losses as a result of different costs determined by considering additional targets such as a lower bound of 20% on renewables penetration.

This paper shares the same focus on scenario analysis combining vows for GHG reduction efforts from a set of countries in the brink of a major commitment to address climate change. Moreover, it introduces a new element in the discussion by considering a sustainability framework which takes into account the effect on economic, social and environmental spheres not only separately but also as a whole by means of a composite index - the FEEM Sustainability Index (FEEM SI) - to summarize current and future performance of countries under the different policy choices they may undertake. In this context, we study the effects of the different cooperation and emissions reduction scenarios that may arise from the implementation of the Copenhagen Accord targets proposed by the signing countries. This is done with the purpose of analyzing the costs and effects of those scenarios, not only in terms of economic costs, but also looking at the impact on overall sustainability.

## 2 The Copenhagen Accord

Climate change represents one of the greatest environmental, social and economic threats that the planet is facing. With the adoption of the Kyoto Protocol[1] under the United Nation Framework Convention on Climate Change (UNFCCC) in 1997, a first step towards a global emission reduction agreement was taken. However, the Kyoto Protocol did not reach enough international consensus to achieve the emissions reductions necessary to mitigate the global effects of climate change. Also recent scientific evidence highlights that the target proposed is not sufficient to reduce the increasing anthropogenic emissions in the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), if

[1] The Kyoto Protocol was adopted in 1997 but entered into force in 2005. It commits most industrialized nations and some economies in transition (Annex I Parties) to reduce their overall emissions of GHGs to 5.2% below 1990 levels, in the period 2008 – 2012 (UNFCCC; 2008).

governments take no action to stabilize the greenhouse gases concentration in the atmosphere, the average temperature by the end of this century would increase from 1.1°C to 6.4°C, with a best estimate at the lower end of 1.8°C and at the upper end of 4°C. It follows that a new international agreement is urgently needed to address climate change. In addition, a recent study (Bosetti et al., 2008) show that delaying climate policies would lead to way higher costs of emissions reductions.

The path towards the future agreement for the post-Kyoto begun in 2007, during the COP-13 that took place in Bali. Focusing on long-term issues, Parties adopted an agreement on a two-year process, the Bali Road Map. This consists of a number of decisions representing the various tracks to reaching a future climate agreement and sets a deadline for concluding the negotiations at COP-15 and COP/MOP-5 in Copenhagen. Since then, conscious that negotiating positions on climate policy are very different, Parties met in numerous sessions of preparatory talks in order to reach a common position by December 2009. At the deadline of January 31st, more than fifty countries submitted their mitigation actions to the UNFCCC secretariat. Most developed countries merely confirmed the emissions reduction targets proposed during the preliminary negotiation talks. Quantitative targets submitted to the UNFCCC Secretariat at the end of January are summarised in Table 1.

*Table 1: Proposed targets with respect to 1990 emission levels*

| Country | Autonomous target | Coordinated Effort Target |
|---|---|---|
| ***Annex I*** | | |
| Australia | 13% | 1% to -11% |
| Canada | 2.52% | 2.52% |
| European Union | -20% | -30% |
| Iceland | -15% | -30% |
| Japan | -25% | -25% |
| New Zealand | -10% | -20% |
| Norway | -30% | -40% |
| Russia | -15% | -25% |
| USA | -3% | -3% |
| ***Non-Annex I*** | | |
| Brazil | 97.4% | 88.8% |
| China[a] | 156.8% | 135.4% |
| India[b] | 157.4% | 157.4% |
| Indonesia | 354.0% | 262.0% |
| Mexico | 21.9% | 21.9% |
| Republic of Korea | 35.7% | 35.7% |
| South Africa | -15.8% | -15.8% |

a) Original target in terms of $CO_2$ emissions per unit of GDP and set accordingly in terms of CO2 emissions from the BAU scenario

b) Original target in terms of $CO_2$ emissions per unit of GDP, already achieved in BAU.

What is important to note is that many developing countries complied with the deadline and submitted to the UNFCCC the mitigation actions that they intend to implement to combat climate change.

## 3 Evaluating sustainability in a general equilibrium framework

Various computer models are commonly being used for the evaluation of sustainability impacts (Klaassen and Miketa, 2003) and, as argued by Böhringer and Löschel (2004), there is no specific model that would be suitable to assess all the impacts of sustainability. However, the authors suggest that CGE models are flexible in a way that they can incorporate several key sustainability indicators in a single micro-consistent framework. CGE models provide an open framework for linkages to sector-specific models and important relationships to other disciplines adopting an integrated assessment approach and, thus, may be used as efficient tools for sustainability impact assessment (Ibid.).

Although it is expected that climate policies should have a beneficial effect on the environment and climate, the actual effect on sustainability is not straightforward. Sustainability is a complex and multi-faceted concept and in order to study the effect of climate policies it is necessary to take into consideration environmental, as well as economic and social variables. This can be done by using selected indicators, and then combining them in a unique measure. In particular, we use the FEEM Sustainability Index (FEEM SI) in order to assess the effect of the different anticipated scenarios.[2] FEEM SI in fact is an index built within the dynamic CGE model ICES SI. Constructing the sustainability index within ICES SI allows projecting it in the future under different policy and growth assumptions and for each country and year during a specific time span.

ICES SI is a recursive dynamic model that generates a sequence of static equilibria under myopic expectations linked by capital and international debt accumulation. The static core of the model is based on different additions to the GTAP-E model designed to assess specific climate change impacts (Bigano et al., 2006; Bosello et. al., 2006a, 2006b, 2007, 2008; Roson, 2003).[3] The current aggregation used in ICES SI is conformed by 40 regions representing major single countries as well as selected macro regions with 17 economic sectors within every region. The exogenous assumptions from selected sources provide the basis for a mid term scenario based on yearly simulations starting from 2002 until 2020.[4]

Thus, ICES SI is an ideal framework for the construction of a policy-oriented sustainability index. Firstly, the large database the model is based on makes it possible to calculate the index for several regions, and to create indicators using data relative to the different sectors. Secondly, the nature of a CGE model, in which all sectors and regions are interconnected, is ideal to capture the tradeoffs between different indicators. Finally, its dynamic framework produces data relative to a growth path which can be used to calculate the index in the future, and under different policy assumptions. This allows analysing how sustainability may change in the different scenarios conceived and to compare them with a baseline scenario in which there is no climate policy.

## 4 Emissions abatement scenarios

According to the proposals made by different countries we prepared a set of three mitigation scenarios with the scope of assessing the possible outcomes of autonomous and coordinated efforts to curb GHG emissions within a sustainability framework. For this purpose we set the ICES SI model to simulate an Emissions Trading System (ETS) in which we imposed the proposed reductions for every region with respect to 1990 $CO_2$ emissions only.[5]

1. ***Minimum Unilateral Targets:*** Resumes the single and autonomous efforts made by a set of leading regions in the climate policy sphere as shown in Table 1. Since these are the minimum efforts proposed without requiring any coordinated action, this represents the least emission reduction scenario that could be expected in 2020 as long as the proposing countries keep their promise.

2. ***Concurred Effort Commitment:*** The previous scenario may be considered as a starting reference since there are some countries who proposed ulterior reductions if a coordinated commitment is reached within a group of regions. The possibility of a coordinated action with higher abatement targets is depicted in this scenario in which most regions from the first scenario formulate more ambitious targets.

3. ***Global Commitment:*** Finally, although it may be very difficult to become true, we think it is worth to imagine a third scenario where all countries in the world reach a commitment to reduce $CO_2$ emissions. All countries in the world sign up for a global ETS and agree to limit growth of global emissions to 19 % with respect to 1990. For the group of leading regions we set the more ambitious targets from the second scenario while for the rest of the countries, including India, we set the target that emissions in 2020 would be reduced by 30% with respect to Business as Usual. This is an hypothesis just to evaluate the outcome on the different pillars of World's sustainability as a whole, along with its cost and benefits in a wide framework.

[2] The full list of indicators used to construct FEEM SI is detailed in Annex 1, Table A1.1, while Figure A1.1 illustrates its aggregation tree.
[3] Detailed information on the model can be found at the ICES web site: http://www.feem-web.it/ices.
[4] The regional and sectoral aggregation is in Annex 2 in Tables A2.1 and A2.2 respectively.
[5] We consider only $CO_2$ because it is the main GHG and produced mainly due to fossil fuel combustion.

These three different scenarios will allow computing the FEEM SI for the single regions and also for the whole world taking into account that all actions by individual countries will have an effect on future sustainability. For the sake of presenting results in a brief and comprehensible way we decided to show more detail in the leading regions proposing a climate policy target and confronting them with the rest of the world.[6]

All climate policies implemented in the three scenarios take effect starting in 2010 and the proposed targets are reached gradually every year until 2020. The ETS module in the ICES SI model comprises efforts from all sectors in the economy to accomplish the selected target. Moreover, since such mechanism requires the exchange of emissions permits and the associated transfer of financial resources, international capital movements reflect a greater flexibility among regions.

### 4.1 *Direct and indirect effects*

The efforts made from leading regions and the rest of the world are summarized in Figure 1, where the profile of emissions is depicted in the area behind the graph showing the strong reduction achieved by leading countries in the first two scenarios proposed and also from the rest of the world in the last scenario. Variations in percentage with respect to 1990 levels are represented in the columns for the Business as Usual and the three additional scenarios showing the sets of leading regions, the rest of the world and the World as an aggregate. Growth of World emissions which in BAU are 93% higher than 1990 levels could be reduced to 40% or 34% in the first two scenarios, and to 19% if all countries commit for a coordinated climate policy in the ***Global Commitment*** scenario.

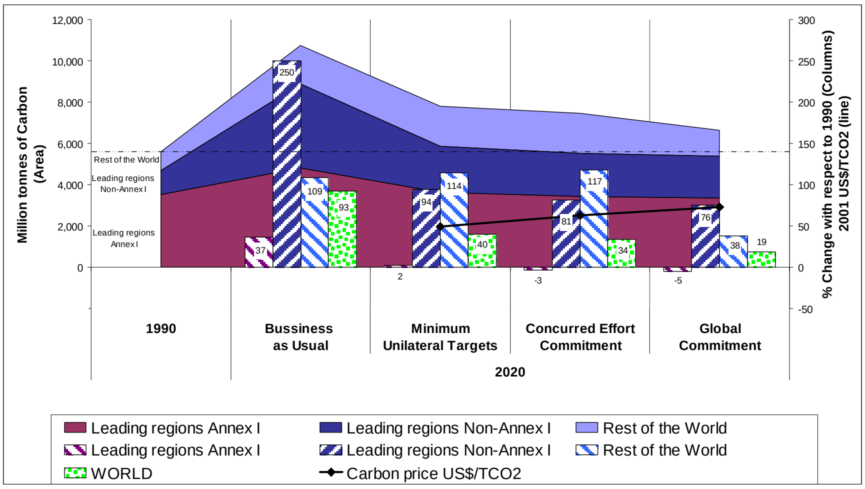


**Figure 1:** $CO_2$ emissions for different abatement scenarios in 2020

Implementing mitigation policies through an ETS system to reduce future emissions produces different effects on Leading regions' economies and also on the rest of the world. Direct effects are the reduction in total emissions from the group of countries participating in the ETS with the corresponding direct cost reflected in the carbon price as mitigation costs. Indirect effects are interpreted trough variations in GDP, summarizing the different interactions in the economic activity; ranging from higher costs due to the carbon price; to the carbon leakage as an increased production of emissions in the rest of the world produced by mitigation efforts enforced by a reduced group of countries. The indirect effect on the leading regions' economies measured as a variation of GDP in 2020 is shown on Figure 2 along with the GDP in USD trillions (expressed in 2001 USD), confirming that the higher the restriction in future emissions the higher will be the cost. An additional outcome of the exchange of permits is the fact that using and ETS offers the optimal allocation of emission at the lower abatement cost. This explains the different indirect cost faced by the majority of participating regions and also the fact that some regions may benefit of that scheme such as

[6] The details for the abatement targets for the 40 regions present in the ICES-SI model is in Annex 3.

USA, China and India in all three scenarios and the Annex I leading regions as a group as shown to the right of Figure 2.

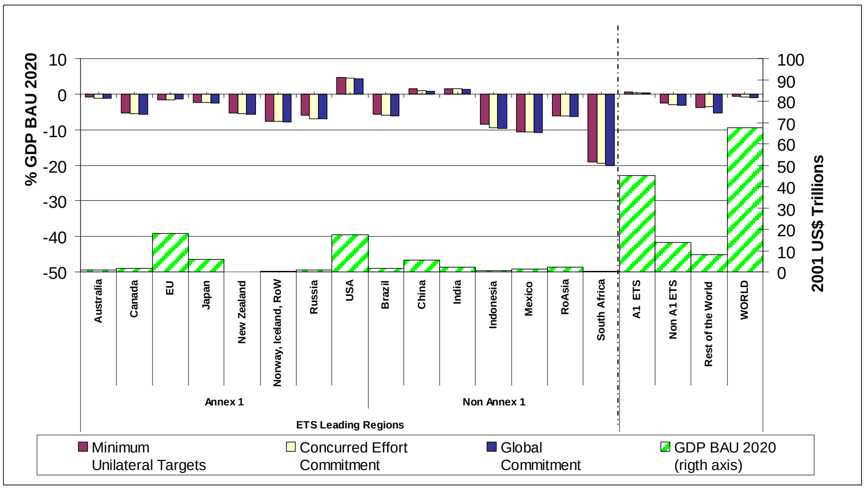


**Figure 2:** GDP in 2020 and the indirect costs of different abatement efforts

Another interesting insight is that when the rest of the world does not participate in the mitigation policies they are also negatively affected by the final outcome of the policy. This constitutes an additional element of support to the claims from developing economies. Implementing climate policies may reduce growth in their economies, and this is a very important aspect in climate policy design at the global level. Moreover, the indirect cost of the climate policies analyzed in this exercise is between 0.6 to 1% of World GDP.

## *4.2 Sustainability effects*

The FEEM SI has been calculated for each region separately and for the world as an aggregate. As climate policy is aimed at diminishing the effect of climate change all over the world, it is interesting to check the overall global effect on sustainability. As FEEM SI is based on three main pillars, namely economic, social and environmental sustainability, it is also relevant to check which parts of sustainability are positively and negatively affected by climate policies. If on the one hand, we would expect environmental sustainability to increase, on the other hand we would also expect economic and social sustainability to decrease due to the policy costs.

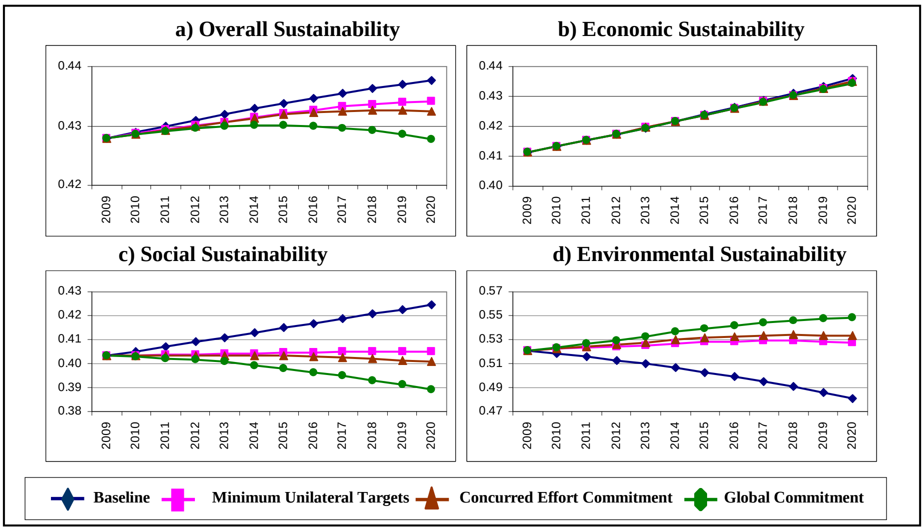


**Figure 3:** Changes in World Sustainability according to the FEEM SI

The overall effect on the world's sustainability is negative for all policies considered. It is found that the stricter the climate policy is, the lower the sustainability. As it is possible to see in panel a) from Figure 3, the effect of the ***Minimum Unilateral Targets*** and of the ***Concurrent Effort Commitment*** are similar and show a small but consistent decrease in sustainability compared to the baseline, especially at the end of the period. In the case of the ***Global Commitment*** scenario sustainability decreases more, due to the strictness of the climate policy considered.

In order to better understand the causes of this decrease in sustainability, it is interesting to see what happens to each pillar of the FEEM SI. Panel b) of Figure 3 shows that economic sustainability decreases slightly compared to the baseline, with not much difference from the initial values. Social and environmental sustainability are instead much more affected, as shown in panels c) and d) respectively. Social sustainability decrease is greater the more stringent the policy. Environmental sustainability increases substantially and the more so the more strict the policy. Note that the improvement in the ***Minimum Unilateral Targets*** scenario and in the ***Concurred Effort*** scenario is much lower than the case in which all countries participate to carbon trading.

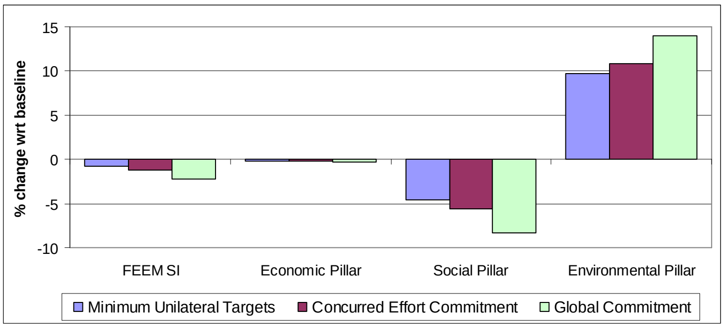


**Figure 4:** Percentage changes in the FEEM SI with respect to the baseline at 2020

Calculating percentage changes with respect to the baseline scenario at year 2020 of the FEEM SI and its three main pillars under the three policy scenarios, allows to better understanding the impact of the policies. From Figure 4 it is possible to see that the consistent increase in the environmental component does not manage to offset the decrease in the social one, thus leading to an overall decrease in sustainability. This is an interesting result. Usually, the main concerns about the costs of environmental policies regard economic costs, not so social costs. In fact, as highlighted in the previous section, the foreseen GDP losses are what could lead some countries to decide to not sign an international agreement on climate change.

### *4.3 Improving social sustainability while reducing GHG emissions*

Because the scenarios considered above are biased towards the improvement of environmental sustainability, we have also considered a fourth policy defined as a ***Global Sustainability*** scenario in which the social component of sustainability is also taken into consideration.[7] In this scenario, the same climate policy as the ***Global Commitment*** scenario is considered, but with the addition of a revenue recycling process. Revenues raised from the auctioning of emission trading quotas are redistributed partly within each country and partly from industrialised countries[8] to the rest of the world. In industrialised countries 20% of the revenue raised from emissions trading is collected and redistributed to developing countries where it is invested to increase research and development, education, and health expenditures. This is like an international Carbon Fund where revenues are used to invest in the improvement of Millennium Development Goals. The rest of the revenues

[7] This additional scenario is proposed in a companion paper with the scope of further analyzing the detailed effects of additional cooperation scenarios at the global level (Lanzi, Parrado, 2010).
[8] The countries which give part of their revenues are EU countries, Australia, Canada, Japan, New Zealand, Russia, Switzerland and the USA.

are invested domestically, always in the same selected sectors, and the resources used up to 2.5% of GWP.

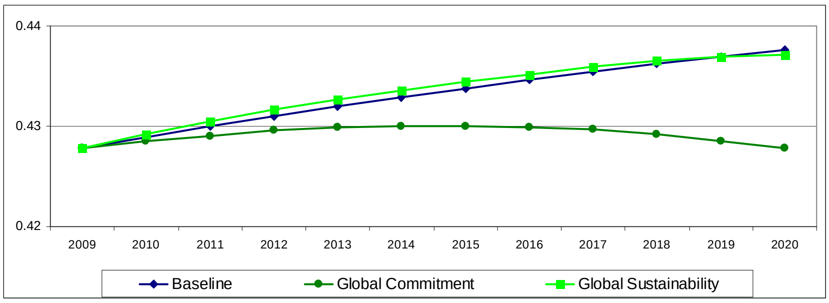


**Figure 5:** Changes in World Sustainability with an additional policy

The FEEM SI shows that taking into consideration other indicators besides GDP, sustainability can be accounted for in a more comprehensive way. In the FEEM SI calculations economic sustainability is only mildly decreasing. However, societal aspects seem to be more affected. In fact, when a policy is undertaken in order to limit the adverse effect on social sustainability, the negative effects are limited and the changes in overall sustainability are very low, as shown with the ***Global Sustainability*** scenario. The additional policy aimed at giving support to selected sectors not only brings the sustainability path closer to the baseline but also accomplishes the intended environmental goals.

## 5 Conclusions

In the current debates and negotiations for the achievement of an international agreement on climate change after the UNFCCC 15th Conference of Parties (COP-15), it is interesting to see how the different cooperation scenarios would affect different world regions in terms of emissions reductions, and economic costs. The present work adds an innovative further analysis which studies the effect that the effective implementation of the Copenhagen Accord may have on sustainability. We aim at answering the question of what would be the consequence in terms of sustainability, if it were to be decided to undertake a strict international climate target agreement. This is done by using the FEEM Sustainability Index (FEEM SI), an index taking a novel approach towards sustainability being built within a dynamic Computable General Equilibrium model that allows for scenario studies.

It is found that whereas environmental sustainability is greatly improved at regional and world level thanks to the reductions achieved with emissions trading, economic and social sustainability can be affected to the point of leading to a decrease in overall sustainability. It is also found, despite the usual debate on the economic costs of climate policies, that economic sustainability is not significantly affected by climate policies based on international emissions trading, while social sustainability is worsened.

We believe that this shows the importance of taking into consideration other policies, particularly those aimed at improving societal wealth, simultaneously to climate change ones. To show this we consider a climate policy in which revenues are recycled partly domestically and partly abroad from industrialised to developing countries. All revenues are invested in sectors aimed at improving economic and social sustainability, namely research and development, education, and health. This leads to improvements in sustainability, as it improves social sustainability thereby achieving a more equal distribution between countries and between the three different components of sustainability. In conclusion, climate policies that are implemented together with policies aimed at improving other aspects of sustainability are likely to lead to a future improvement in sustainability and thus in the general wealth of our society.

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## *Annex 1: FEEM Sustainability Index characteristics*

### *Description of FEEM SI*

The FEEM SI is built on a comprehensive methodology divided in different steps[9]. Indicators are firstly selected from reliable and internationally-recognised literature, such as the EU SDS indicator list and the indicators from the Commission on Sustainable development of the United Nations. Indicators have been carefully evaluated to choose what we believe are the indicators that best fit in the sustainability framework within the potentials of the ICES SI model.

The chosen indicators are divided into three main components, namely Economic, Social, and Environmental. These main pillars are derived from a tree structure whose leaves are the indicators selected.[10] In the economic components Research and Development (R&D) is combined with Economic Structure, which in turn is derived by combining GDP per capita (GDP p.c.) and Consumption as share of GDP (Cons). For what regards the social component, it is derived from three sub levels, Population Growth Rate (Population), Poverty, and Social Wealth. Poverty is composed by two indicators. The first is Food relevance in primary consumption (Food Relevance), which represents the proportion of national expenditure in primary goods spent on food, and it is a proxy for a poverty indicator according to the Engel law. The second is Energy per capita (Energy p.c.), which is the amount of energy consumed per capita, and it is a measure of the degree of connection to energy systems. Finally, the environmental pillar is composed of the Air, Energy, and Natural Endowment Natural Endow) subcomponents. Air is a composite index of carbon intensity of energy (CO2 intensity), and Greenhouse Gases per capita (GHG p.c.). Energy is calculated from three indicators, that is Energy Intensity, Imported Energy – a measure of energy security - and the proportion of Clean energy in overall energy consumption (Clean). Finally, Natural Endowment is calculated from an indicator relative to Water, that is water use over total available renewable water resources, and an indicator of Biodiversity, which combines the relative proportions endangered species in plants and animals.

Indicators are calculated from the output of ICES SI, which has been structured to be able to calculate the desired indicators for each region and year. This allows projecting indicators in the future under different policy and growth assumptions. In order to achieve full comparability between indicators, we apply a normalisation procedure. This is done according to a policy target-based benchmarking methodology, where benchmarks are derived from a wide policy review. Finally, indicators are aggregated onto a single sustainability measure according to a non-linear aggregation function. The aggregation methodology for the FEEM SI introduces a very novel approach in this field. In fact, it enhances the importance to consider the interactions between indicators by attributing weights to the single indicators as well as to all possible combinations of indicators belonging to the same theme or sub-theme. Weights are then combined with a special weighted average based on the Choquet integral, which is a tool particularly well-suited to deal with multi-attribute issues like sustainability.[11]

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[9] Only a brief description of the FEEM SI is given here, as this is enough for the purpose of this paper. However, detailed information is available on the FEEM SI website at www.feemsi.org.

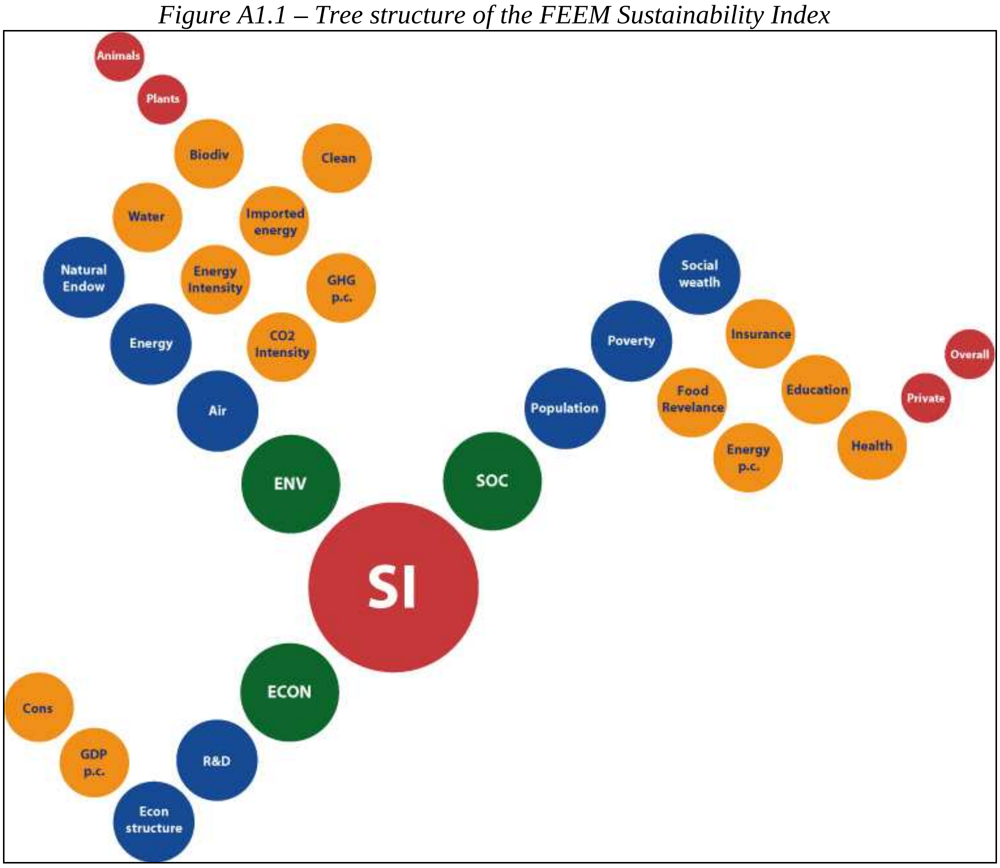
[10] Figure A1.1 illustrates the aggregation tree of the FEEM SI.

[11] A sensitivity analysis can also performed in order to verify the robustness of the aggregation methodology.

*Table A1.1 - List of indicators for the FEEM SI*

| ***Theme*** | ***Sub-theme*** | ***Indicator*** |
|---|---|---|
| **ECONOMIC** | ECONOMIC STRUCTURE | 1. GDP per capita |
| | | 2. Consumption expenditure as GDP |
| | COMPETITIVENESS | 3. Total R&D expenditure as GDP |
| **SOCIAL** | POPULATION | 4. Population growth |
| | POVERTY | 5. Share of food in primary goods consumption |
| | | 6. Energy per capita |
| | PRIVATE EXPENDITURE ON SOCIAL SERVICES | 7. Expenditure in insurance and pensions GDP |
| | EDUCATION | 8. Public expenditure on education as GDP |
| | HEALTH | 9. Health expenditure by privates as overall health expenditure |
| | | 10. Overall health expenditure as GDP |
| **ENVIRONMENTAL** | CLIMATE CHANGE | 11. Carbon intensity of energy |
| | | 12. Growth rate GHG emission per capita |
| | WATER | 13. Water use as total renewable water resources |
| | ENERGY | 14. Energy intensity (energy/GDP) |
| | | 15. Imported energy as overall energy use |
| | | 16. Share of clean energy in primary energy consumption |
| | NATURAL RESOURCES | 17. Biodiversity index-plants |
| | | 18. Biodiversity index-animals |

*Figure A1.1 – Tree structure of the FEEM Sustainability Index*



## *Annex 2:* The ICES SI model

ICES SI is a recursive dynamic model that generates a sequence of static equilibria under myopic expectations linked by capital and international debt accumulation. The static core of the model is based on different additions to the GTAP-E model designed to assess specific climate change impacts (Bigano et al., 2006; Bosello et. al., 2006a, 2006b, 2007, 2008; Roson, 2003).[12]

Industries are modelled through a representative cost-minimizing firm. A representative consumer in each region receives income, defined as the service value of the national primary factors (natural resources, land, labour, capital). Demand for production factors and consumption goods can be satisfied either by domestic or foreign producers which are not perfectly substitutable according to the "Armington" assumption.

The dynamic behaviour of ICES SI has two essential sources. The first is endogenous as it is governed by capital and debt accumulation while the second one is based on exogenous dynamics that allows projecting a baseline in the future using as an input external forecasts of endowments and productivities that are not specifically formulated in the model. Growth is driven by changes in primary resources (capital, labour, land and natural resources) with 2001 as the initial year (GTAP 6 database).[13] Dynamics is endogenous for capital and exogenous for others primary factors. Capital accumulation is the outcome of the interaction of i) investment allocation between regions and ii) debt accumulation.

The general equilibrium structure of the ICES SI - in which all markets are interlinked - is tailored to capture and highlight the production and consumption substitution processes in a social-economic system as a response to external shocks. In doing so, the final economic equilibrium determined takes into account explicitly the “autonomous adaptation” of economic systems.

ICES SI has a wide sectoral and regional disaggregation, which were fundamental for the construction of the sustainability indicators. Compared to ICES, new variables have been included to enrich the model and to calculate the sustainability indicators related to them. In order to do this, changes have been made both to the database and to the model itself. Some specific sectors, namely Research and Development (R&D), Education (Edu) and Health (Hea) were not included in the original GTAP database, though they were part of other more aggregate sectors. Thus, they have been divided with the aid of the SplitCom[14] facility of the GTAP.

Some of the indicators selected for the FEEM SI are related to variables that are not included in the GTAP-6 database, namely use of water, biodiversity and renewable energy. For the construction of these, it has been necessary to include in the model external data relative to these variables.[15] This has been done firstly by adding the variables to the dataset, and then linking them to the model. Linking exogenous variables to variables that are endogenous to the model allows simulating its future behaviour coherently with the endogenous path generated by ICES SI. In doing so it is feasible to obtain level values and percentage changes resulting from projections as well as comparative statics. In the specific case of the FEEM SI, it will be possible to calculate indicators over time.

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[12] Detailed information on the model can be found at the ICES web site: http://www.feem-web.it/ices.

[13] Dimaranan (2006).

[14] SplitCom is a set of programs aimed at facilitating the addition of sectors to a standard GTAP database. With the use of external data, it is possible to split the existing GTAP sectors into a finer aggregation. More information can be found on the SplitCom website: http://www.monash.edu.au/policy/splitcom.htm. The reference manual for SplitCom is Horridge (2005)

[15] The process of extending the database and including additional variables is described in Chapter 2 of the FEEM Sustainability Report (2009).

*Table A2.1: ICES SI Regional aggregation*

| No. | Code | GTAP 6 Countries | No. | Code | GTAP 6 Countries |
|---|---|---|---|---|---|
| **1** | ARG | Argentina | **21** | MEX | Mexico |
| **2** | AUS | Australia | **22** | MEast | Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Palestinian Territory Occupied, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen |
| **3** | AUT | Austria | **23** | NorthAfrica | Algeria, Morocco, Tunisia, Lybia, Egypt |
| **4** | Baltic | Estonia, Latvia, Lithuania | **24** | NZL | New Zealand |
| **5** | BNLX | Belgium, Netherlands, Luxembourg | **25** | POL | Poland |
| **6** | BRA | Brazil | **26** | PRT | Portugal |
| **7** | BUL | Bulgaria | **27** | RUS | Russia |
| **8** | CAN | Canada | **28** | ZAF | South Africa |
| **9** | CHN | China and Hong Kong | **29** | SEA | South-East Asia – Burma, Brunei Darussalam, (East) Timor Leste, Malaysia, Philippines, Singapore, Cambodia, Lao People's Democratic Republic, Vietnam |
| **10** | DNK | Denmark | **30** | ESP | Spain |
| **11** | FIN | Finland | **31** | SWE | Sweden |
| **12** | FRA | France | **32** | CHE | Switzerland |
| **13** | RoFSU | Rest of Former Soviet Union: Armenia, Azerbaijan, Belarus, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Moldova, Republic of Tajikistan, Turkmenistan, Ukraine, Uzbekistan | **33** | TUR | Turkey |
| **14** | GER | Germany | **34** | USA | USA |
| **15** | UKI | UK and Ireland | **35** | AFR | Africa excluding North and South Africa - Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo (Brazzaville), Cote d'Ivoire, Democratic Republic of Congo (Zaire), Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Saint Helena, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe |
| **16** | GCM | Greece, Cyprus, Malta | **36** | RoAsia | Rest of Asia - Afghanistan, Bangladesh, Bhutan, Korea, Korea, Democratic People's Republic of, Macau, Maldives, Mongolia, Nepal, Pakistan, Sri Lanka, Taiwan |
| **17** | IND | India | **37** | RoE | Rest of Europe – Albania, Andorra, Bosnia and Herzegovina, Croatia, Faroe Islands, Gibraltar, Macedonia, Monaco, San Marino, Serbia and Montenegro(Yugoslavia) |
| **18** | IDN | Indonesia | **38** | RoEU | Rest of the European Union – Czech Republic, Hungary, Romania, Slovakia, Slovenia |
| **19** | ITA | Italy | **39** | RoLA | Rest of Latin America - Anguilla, Antigua & Barbuda, Aruba, Bahamas, Barbados, Belize, Bolivia, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador , El Salvador, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos, Uruguay, Venezuela, Virgin Islands, British, Virgin Islands, U.S. |
| **20** | JPN | Japan | **40** | NIR | Noway, Iceland, and Rest of the World – Bermuda, Greenland, Iceland, Liechtenstein, Norway, Saint Pierre and Miquelon, American Samoa, Papua New Guinea, (Western) Samoa, Cook Islands, Fiji, French Polynesia, Guam, KiribatiMarshall Islands, Micronesia, Federated States of, Nauru, New Caledonia, Norfolk Island, Northern Mariana Islands, Niue, Palau, , Solomon Islands, Thailand, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna |

*Table A2.2: ICES-SI sectoral aggregation*

| No. | Code | Sector Description | Comprising GTAP Database V6 Sectors |
|---|---|---|---|
| 1 | Food | Food-related commodities | Paddy Rice, Wheat, Other Grains, Other Crops, Vegetables and Fruits, Plant Fibres, Cattle, Other Animal Products, Raw Milk, Wool, Cattle Meat, Other Meat |
| 2 | Forestry | Forestry | Forestry |
| 3 | Fishing | Fishing | Fishing |
| 4 | Oth_Ind | Other Industries | Beverages and Tobacco, Textiles, Wearing Appeal, Leather, Lumber, Paper and Paper Products, Fabricated Metal Products, Motor Vehicles, Other Transport Equipment |
| 5 | Coal | Coal | Coal |
| 6 | Oil | Oil | Oil |
| 7 | Gas | Gas, gas manufacture and distribution | Gas, Gas Distribution |
| 8 | Oil_Pcts | Petroleum, Coal Products | Water |
| 9 | Electricity | Electricity | Electricity |
| 10 | MServ | Market Services | Construction, Trade, Other Financial Intermediation, Insurance, Other Business Services, Dwellings, Transport |
| 11 | Ins | Insurance Services | Insurance and Pension Funding |
| 12 | En_Int_Ind | Energy Intensive Industries | Chemical Rubber Products, Non-Metallic Minerals, Iron and Steel, Non-Ferrous Metals |
| 13 | Water | Water | Water |
| 14 | RD* | Research & Development | Research & Development |
| 15 | Edu* | Education | Education |
| 16 | Hea* | Health | Health |
| 17 | NMServ | Non- Market Services | Trade, Retail, Financial Intermediation, Renting |

* Additional sectors included to construct the FEEM-SI

### *Annex 3: Abatement by scenario*

*Table A3.1: $CO_2$ Emissions growth in 2020 with respect to 1990 for three abatement scenarios*

| Region | Minimum Unilateral Targets | | Concurred Effort Commitment | | Global Commitment * | |
|---|---|---|---|---|---|---|
| | Target (%) | Effective Growth (%) | Target (%) | Effective Growth (%) | Target (%) | Effective Growth (%) |
| ***ETS - Leading Regions*** | | | | | | |
| Australia | 13 | 29 | 1 | 20 | -11.0 | 17 |
| Austria | -20 | 13 | -30 | 10 | -30.0 | 10 |
| Baltic countries | -20 | -49 | -30 | -52 | -30.0 | -52 |
| BENELUX | -20 | 53 | -30 | 50 | -30.0 | 57 |
| Brazil | 97 | 152 | 89 | 142 | 88.8 | 142 |
| Bulgaria | -20 | -62 | -30 | -65 | -30.0 | -65 |
| Canada | 2.52 | 26 | 2.52 | 20 | 2.5 | 18 |
| China | 157 | 96 | 135 | 79 | 135.4 | 71 |
| Denmark | -20 | -29 | -30 | -31 | -30.0 | -30 |
| Finland | -20 | 15 | -30 | 11 | -30.0 | 9 |
| France | -20 | 27 | -30 | 26 | -30.0 | 30 |
| Germany | -20 | -19 | -30 | -22 | -30.0 | -22 |
| United Kingdom, Ireland | -20 | -11 | -30 | -14 | -30.0 | -15 |
| Greece, Cyprus & Malta | -20 | 41 | -30 | 35 | -30.0 | 34 |
| India | 157 | 92 | 157 | 85 | 80.2 | 82 |
| Indonesia | 354 | 380 | 262 | 354 | 262.0 | 349 |
| Italy | -20 | 29 | -30 | 27 | -30.0 | 26 |
| Japan | -25 | -3 | -25 | -7 | -25.0 | -5 |
| Mexico | 21.9 | 32 | 22 | 26 | 21.9 | 24 |
| New Zealand | 0 | 75 | -20 | 66 | -20.0 | 65 |
| Poland | 0 | -29 | -30 | -35 | -30.0 | -38 |
| Portugal | -10 | 75 | -30 | 71 | -30.0 | 76 |
| Russia | -20 | -14 | -25 | -18 | -25.0 | -20 |
| South Africa | -20 | -12 | -16 | -20 | -15.8 | -22 |
| Spain | -15 | 71 | -30 | 66 | -30.0 | 69 |
| Sweeden | -15.8 | 1 | -30 | 1 | -30.0 | 5 |
| USA | 0 | 8 | -3 | 0 | -3.0 | -4 |
| Rest of Asia | -20 | 78 | 116 | 69 | 72.0 | 67 |
| Rest of EU | -20 | -18 | -30 | -25 | -30.0 | -28 |
| Norway, Iceland, Row | 0 | 62 | 55 | 59 | 26.9 | 58 |
| ***Rest of the World – No ETS**** | | | | | | |
| Argentina | - | 41 | - | 43 | 2.7 | 14 |
| Rest of FSU | - | 15 | - | 14 | -15.6 | -38 |
| Middle East | - | 247 | - | 252 | 127.9 | 123 |
| North Africa | - | 153 | - | 157 | 75.4 | 77 |
| South East Asia | - | 299 | - | 309 | 166.4 | 173 |
| Switzerland | - | 26 | - | 30 | -21.3 | 9 |
| Turkey | - | 253 | - | 264 | 132.0 | 133 |
| Rest of Africa | - | 302 | - | 307 | 182.5 | 189 |
| Rest of Europe | - | -8 | - | -4 | -54.8 | -53 |
| Rest of Latin America | - | 149 | - | 155 | 62.3 | 76 |

* in global commitment all countries participate in the ETS

*Table A3.2: Carbon Price for three abatement scenarios USD/TCO2*

| *Scenario* | *2010* | *2011* | *2012* | *2013* | *2014* | *2015* | *2016* | *2017* | *2018* | *2019* | *2020* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Minimum Unilateral Targets*** | 2.5 | 5.1 | 7.8 | 10.9 | 14.4 | 18.4 | 23.0 | 28.2 | 34.3 | 41.2 | 49.2 |
| ***Concurred Effort Commitment*** | 2.8 | 5.8 | 9.0 | 12.7 | 17.0 | 22.0 | 27.9 | 34.8 | 42.9 | 52.2 | 63.0 |
| ***Global Commitment*** | 3.2 | 6.4 | 10.1 | 14.4 | 19.6 | 25.6 | 32.8 | 41.1 | 50.5 | 61.1 | 73.0 |

## Annex 4: Changes in sustainability by scenario

*Table A4.1: Percentage change in Overall Sustainability and its components with respect to baseline in 2020*

| Region | Minimum Unilateral Targets | | | | Concurred Effort Commitment | | | | Global Commitment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FEEM SI | Eco | Soc | Env | FEEM SI | Eco | Soc | Env | FEEM SI | Eco | Soc | Env |
| Argentina | -0.7 | -3.1 | 2.8 | -0.4 | -0.7 | -3.1 | 3.2 | -0.6 | -0.3 | -3.1 | -2.0 | 4.5 |
| Australia | 8.4 | -0.7 | -5.2 | 17.0 | 10.0 | -0.9 | -6.2 | 20.1 | 10.4 | -1.1 | -6.6 | 21.0 |
| Austria | -1.4 | -3.1 | -2.6 | 3.5 | -1.6 | -3.6 | -3.2 | 4.4 | -1.9 | -4.2 | -3.1 | 4.4 |
| Baltic Countries | 0.5 | -6.4 | -5.6 | 17.8 | 0.5 | -6.6 | -6.1 | 18.9 | 0.1 | -7.2 | -5.9 | 18.2 |
| BENELUX | 1.9 | -0.4 | -2.1 | 3.9 | 2.3 | -0.8 | -2.4 | 4.7 | 1.4 | -0.4 | -1.8 | 3.0 |
| Brazil | 0.4 | -0.9 | -2.8 | 4.8 | 0.4 | -1.2 | -3.5 | 5.7 | 0.3 | -1.5 | -3.6 | 5.8 |
| Bulgary | 8.2 | 1.2 | -0.5 | 22.6 | 8.8 | 1.4 | -0.9 | 24.3 | 8.9 | 1.6 | -0.5 | 24.1 |
| Canada | 2.2 | 0.4 | -2.5 | 9.9 | 2.5 | 0.3 | -3.3 | 12.3 | 2.8 | 0.5 | -3.2 | 13.2 |
| Switzerland | 0.6 | 1.3 | 4.0 | -3.5 | 0.3 | 1.5 | 4.7 | -4.2 | 1.3 | 1.7 | 1.7 | -0.3 |
| China | 17.4 | 2.2 | -11.3 | 64.8 | 17.3 | 2.1 | -12.6 | 69.7 | 17.6 | 2.3 | -12.8 | 71.9 |
| Denmark | 7.4 | 6.8 | -1.0 | 10.3 | 7.8 | 6.9 | -1.3 | 11.0 | 8.0 | 8.0 | -0.7 | 10.8 |
| Spain | 3.2 | -0.4 | -3.2 | 5.9 | 4.3 | -0.7 | -3.5 | 7.7 | 4.5 | -0.9 | -3.4 | 8.0 |
| Finland | 1.7 | -4.0 | 2.7 | 2.9 | 1.8 | -4.2 | 2.5 | 3.5 | 2.2 | -4.0 | 2.9 | 3.9 |
| France | 1.0 | -0.7 | -0.3 | 1.6 | 1.2 | -0.8 | -0.4 | 2.0 | 0.7 | -0.4 | -0.1 | 1.2 |
| Rest of Former Soviet Union | 0.3 | -2.3 | -4.7 | 3.4 | 0.2 | -2.7 | -5.5 | 3.7 | 15.2 | -5.5 | -9.1 | 52.8 |
| United Kingdom & Ireland | 0.0 | -0.8 | -4.7 | 8.0 | -0.5 | -0.9 | -5.6 | 9.3 | -0.6 | -1.0 | -5.9 | 9.6 |
| Greece,Cyprus Malta | -8.7 | -16.3 | -12.3 | 7.3 | -9.6 | -18.0 | -13.1 | 8.7 | -11.2 | -21.4 | -14.0 | 10.3 |
| Germany | 4.0 | -0.4 | -0.7 | 6.9 | 4.4 | -0.4 | -1.1 | 7.7 | 4.2 | -0.1 | -0.9 | 7.1 |
| Indonesia | 2.3 | 1.3 | -4.1 | 9.9 | 2.4 | 0.3 | -5.2 | 12.2 | 2.9 | 0.9 | -5.2 | 13.1 |
| India | 4.7 | 0.5 | 0.9 | 13.7 | 5.7 | 0.7 | 1.4 | 16.0 | 5.6 | 0.2 | 0.3 | 17.7 |
| Italy | 0.4 | -1.6 | -0.7 | 1.2 | 0.4 | -1.8 | -0.9 | 1.4 | 1.7 | -1.9 | -0.9 | 3.4 |
| Japan | 5.4 | 0.9 | -0.7 | 8.2 | 6.3 | 1.0 | -1.2 | 9.6 | 6.1 | 1.4 | -0.8 | 9.2 |
| Middle East | -1.7 | -3.5 | -0.2 | -1.6 | -2.0 | -4.3 | -0.2 | -1.9 | 6.8 | -6.2 | -7.6 | 14.9 |
| Mexico | -0.5 | -1.9 | -5.0 | 6.5 | -0.6 | -1.9 | -6.1 | 7.3 | -0.6 | -1.8 | -6.4 | 7.5 |
| North Africa | -1.5 | -2.6 | -0.1 | -1.7 | -1.8 | -2.9 | 0.0 | -2.3 | -1.5 | -4.7 | -9.0 | 9.2 |
| New Zealand | 1.3 | 1.3 | -2.1 | 3.4 | 1.5 | 1.3 | -2.7 | 4.4 | 1.9 | 1.7 | -2.4 | 4.8 |
| Poland | 6.4 | -3.5 | -8.1 | 21.3 | 6.6 | -3.9 | -9.5 | 24.3 | 6.7 | -4.3 | -10.4 | 26.4 |
| Portugal | -4.0 | -9.7 | -9.0 | 9.0 | -4.0 | -10.1 | -9.5 | 10.8 | -4.2 | -10.7 | -9.9 | 11.9 |
| Rest of Africa | -2.1 | -17.0 | -7.8 | 3.0 | -2.3 | -19.0 | -9.1 | 3.5 | 2.4 | -26.7 | -9.2 | 12.5 |
| Rest of Asia | 3.7 | -1.7 | 0.5 | 13.4 | 4.2 | -1.5 | 0.2 | 15.7 | 4.5 | -1.5 | 1.5 | 14.3 |
| Rest of Europe | -12.8 | -16.4 | -13.0 | -10.5 | -12.7 | -16.5 | -12.2 | -11.5 | -12.6 | -18.3 | -22.0 | 6.0 |
| Rest of EU | 3.7 | -2.3 | -3.2 | 17.2 | 3.8 | -2.8 | -4.1 | 19.1 | 3.8 | -3.3 | -4.7 | 20.8 |
| Rest of LA | -0.4 | -2.3 | 1.7 | -0.1 | -0.3 | -2.5 | 2.5 | -0.5 | 0.4 | -3.3 | -6.9 | 8.3 |
| Norway, Iceland, RoW | 1.1 | 0.3 | 1.1 | 2.3 | 1.0 | 0.1 | 0.9 | 2.6 | 1.1 | 0.1 | 0.9 | 2.9 |
| Russia | 4.6 | 0.9 | 3.6 | 11.7 | 4.9 | 0.0 | 3.1 | 15.0 | 5.2 | 0.0 | 3.2 | 15.9 |
| South East Asia | 4.1 | 0.6 | 8.9 | -2.3 | 4.2 | 0.7 | 10.1 | -2.8 | 6.3 | 0.8 | 3.9 | 13.3 |
| Sweeden | 1.7 | 1.0 | 2.2 | 0.5 | 1.8 | 1.2 | 2.3 | 0.5 | 2.3 | 2.0 | 3.3 | -0.3 |
| Turkey | 0.0 | -1.4 | 3.2 | -0.1 | -0.1 | -1.2 | 4.0 | -1.0 | 1.3 | -1.7 | -3.7 | 17.9 |
| USA | 10.2 | -1.8 | -7.7 | 22.5 | 12.9 | -1.9 | -8.9 | 27.9 | 14.0 | -2.2 | -9.4 | 30.3 |
| South Africa | 8.4 | -2.7 | -6.3 | 31.5 | 9.1 | -2.5 | -7.5 | 34.6 | 9.2 | -2.4 | -7.8 | 34.8 |