

# NOTA DI LAVORO

94.2012

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## **Quantifying Sustainability: A New Approach and World Ranking**

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# Climate Change and Sustainable Development Series

Editor: Carlo Carraro

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### Summary

This paper proposes a new tool to assess sustainability and make the concept of sustainable development operational. It considers its multi-dimensional structure combining the information deriving from a selection of relevant sustainability indicators belonging to economic, social and environmental pillars. It reproduces the dynamics of these indicators over time and countries. Then, it aggregates these indicators using a new approach based on Choquet's integrals. The main novelties of this approach are indeed: (i) the modelling framework, a recursive-dynamic computable general equilibrium used to calculate the evolution of all indicators over time throughout the world, and (ii) the aggregation methodology to reconcile them in one aggregate index to measure overall sustainability. The former allows capturing the sector and regional interactions and higher-order effects driven by background assumptions on relevant variables to depict future scenarios. The latter makes it possible to compare sustainability performances, under alternative scenarios, across countries and over time. Main results show that the current sustainability at world level differs from what the traditional measure of well-being, the GDP, depicts, highlighting the trade-offs among different components of sustainability. Moreover, in the next decade a slight decrease in world sustainability may occur, in spite of an expected increase in world domestic product. Finally, dedicated policies increase overall sustainability, showing that social and environmental benefits may be greater than the correlated economic costs.

**Keywords:** Sustainable Development, Sustainable Indicators, Computable General Equilibrium, Millennium Development Goals, Climate Change

**JEL Classification:** Q54, Q56, C68

*This paper is the outcome of a complex interdisciplinary effort. The authors are grateful to all colleagues at FEEM for many suggestions and remarks. Comments from participants at seminars in Milan, Florence and at the IAEE Conference in Venice are gratefully acknowledged. The usual disclaimer applies.*

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# Quantifying Sustainability: a New Approach and World Ranking

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## Abstract

This paper proposes a new tool to assess sustainability and make the concept of sustainable development operational. It considers its multi-dimensional structure combining the information deriving from a selection of relevant sustainability indicators belonging to economic, social and environmental pillars. It reproduces the dynamics of these indicators over time and countries. Then, it aggregates these indicators using a new approach based on Choquet's integrals. The main novelties of this approach are indeed: (i) the modelling framework, a recursive-dynamic computable general equilibrium used to calculate the evolution of all indicators over time throughout the world, and (ii) the aggregation methodology to reconcile them in one aggregate index to measure overall sustainability. The former allows capturing the sector and regional interactions and higher-order effects driven by background assumptions on relevant variables to depict future scenarios. The latter makes it possible to compare sustainability performances, under alternative scenarios, across countries and over time. Main results show that the current sustainability at world level differs from what the traditional measure of well-being, the GDP, depicts, highlighting the trade-offs among different components of sustainability. Moreover, in the next decade a slight decrease in world sustainability may occur, in spite of an expected increase in world domestic product. Finally, dedicated policies increase overall sustainability, showing that social and environmental benefits may be greater than the correlated economic costs.

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This draft: November, 2012

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## 1. Introduction

Sustainable development is amongst the top priorities within policy agendas worldwide. This concept implies not only increasing and spreading well-being throughout the world, but also avoids compromising the well-being of future generations. This requires substantial changes in production processes, resource use, and life-style as well as the compliance to the idea that global development does not coincide with economic growth.

Despite more than 20 years of research in sustainability assessment and the construction of several different sustainability indices, none of the proposed approaches has convincingly addressed some major shortcomings of sustainability indicators. Indeed, existing sustainability indicators are usually based on past data and therefore do not provide forward-looking information, nor they can be used to test the effectiveness of different future policy measures. In addition, while expanding the sustainability dimensions considered, they are weak in aggregating them (a few satisfactory attempts concern specific areas rather than sustainability as a whole). The utility of summarising a wide range of indicators in a single measure to increase the awareness of policy makers' strategies is undeniable. Therefore, sustainability indicators should address the difficulties of aggregating a large set of indicators in a unique index.

This paper presents an original contribution in this field. It introduces a new measure of sustainability, the FEEM Sustainability Index (FEEM SI), which addresses the necessity of "going beyond GDP" within the assessment of well-being. It summarises and merges the information derived by a selection of relevant sustainability indicators chosen among the most reliable international sets and covers the traditional sustainability dimensions (economic, social and environmental). The evolution of indicators composing the FEEM SI is computed in a recursive-dynamic Computable General Equilibrium (CGE) model (ICES-SI). This allows the assessment of sustainability across different future policy scenarios and the comparison of the sustainability performance across countries and through time in a coherent framework. Furthermore, the FEEM SI methodology introduces a novel aggregation methodology for the construction of the index, particularly suitable to capture trade-offs among all sustainability dimensions. These novel features make the FEEM SI an ideal tool for using the sustainability concept in an operative manner.

Building a sustainability index within a CGE framework is certainly an innovative approach in this field. The sustainable development concept encloses the well-being of future generations, therefore attributing a central role to the temporal dimension. An applied economic model allows projecting future scenarios and making policy simulations. In addition, the multi-dimensionality of sustainability usually makes it difficult to highlight the interactions among indicators of different topics. CGE models are flexible since they can not only incorporate several key sustainability indicators in a single micro-consistent framework, but they can also allow the performance of a trade-off analysis among different components of sustainability, which is especially useful in analysing the effects of a policy implementation (Böhringer and Lösschel, 2006).

Main results using our new methodology show that the current sustainability at world level is quite different from what the GDP depicts as the traditional measure of well-being, highlighting the trade-offs among different components of sustainability. Moreover, in the next decade a slight decrease in world sustainability may occur, in spite of an expected substantial increase in world domestic product. Finally, dedicated policies to some or all sustainability dimensions increase

overall sustainability, showing that social and environmental benefits may be greater than the correlated economic costs.

The structure of the paper is as follows. After a review of the literature on sustainable development measures in Section 2, Section 3 briefly describes our indicators and methodology for the construction of the FEEM SI. Section 4 illustrates the assumptions behind our baseline and policy scenarios and compares the resulting sustainability paths. Section 5 draws our main conclusions.

## 2. Sustainable Development measurements: an overview

Over the last two decades, there has been an ongoing debate on sustainability assessment and the limitations of GDP as a unique measure of well-being and development. Sustainability is a dynamic concept, which brings together aspects intertwined in time and space. There are many alternative ways to describe sustainable development, but even a broadly used definition such as the one initially proposed by the Brundtland Commission<sup>1</sup> is often considered too elusive to provide clear methodological guidelines. Indeed, the multi-faceted nature of sustainability calls for a systemic approach combining economic and environmental aspects (growth and exploitation of resources) with social concerns (division of resources among countries/people) (Saltelli *et al.*, 2007).

Indicators<sup>2</sup> represent the main instrument to put sustainability theory into practice (Parris and Kates, 2003; Singh *et al.*, 2009, UN, 2012, UN CSD, 2012) given their synthetic properties and the increasing use in policymaking and public communication. They are often organised in conceptual bundles, different in core values and sustainable development theories: issue- or theme-based frameworks, causal frameworks, capital and accounting frameworks, headline indicators, goal-oriented indicators and aggregate indices (UN, 2007; Pintér *et al.*, 2005).

Among them, issue- or theme-based indicators have a wide coverage of all sustainability components; they emphasise areas according to policy relevance and are very common since they are well suited to be linked to policy processes and targets. Sustainable development is typically divided into three (economic, environmental and social) or four pillars (economic, environmental, social and institutional); for each of them a set of indicators is defined, following a pyramidal structure from themes to sub-themes (Adelle and Pallemmaerts, 2009).

Several international institutions deal with sustainable development through theme-based indicators. At the intergovernmental level, one of the most important players is the United Nations Commission on Sustainable Development (UN CSD), which has produced and revised a set of theme-based indicators to assess sustainable development. The process started in 1995 and generated a set of indicators first published in 1996. In the revised version of 2001, indicators are grouped into four pillars of sustainability – social, economic, environmental and institutional – each subdivided into themes, sub-themes and indicators. The last revision was published in January 2007 and the 98 indicators were grouped into 15 themes and then divided into sub-themes. UN CSD

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<sup>1</sup> WCED (1987) defines Sustainable Development as a “development that meets the need of the present generation without compromising the ability of future generations to meet their own needs”.

<sup>2</sup> An indicator is a “quantitative or a qualitative measure derived from a series of observed facts that can reveal relative positions (e.g., relative position of a country) in a given area” (OECD, 2008). It should be exhaustive and concise, quantifying and aggregating data regarding to a specific aspect, enabling to assess change in time and giving insight on the reasons for change.

(2012) reports suggestions on themes for Sustainable Development Goals to lead the way towards a worldwide spread “Green Growth”.<sup>3</sup>

In 1989, OECD started a framework to develop environmental indicators (Adelle and Pallemmaerts, 2009). In 2007, the OECD’s second World Forum in Istanbul launched the project on “Measuring the Progress of Societies”. The project aims “to foster the development of sets of key economic, social and environmental indicators and their use to inform and promote evidence-based decision-making, within and across the public and private sector and civil society” (OECD, 2007). Although targeted to a broader scope than sustainability, it is worth noting the important contribution from World Bank through the World Development Indicators (WDI) that account for 420 indicators covering 209 countries, which also capture many dimensions of sustainable development. On the policy side, it is worth noting that European Union is committed to implement the European Union Sustainable Development Strategy (EU SDS).<sup>4</sup>

Sustainability indicators capture the complexity of the phenomenon and convey to policy makers important insights and directions. However, their actual effectiveness has been limited by the lack of a priority system among indicators (UN DESA, 2007). Hence, current trends in sustainable development indicators show an increasing interest for the core sets of goal-oriented indicators and aggregate indices (Pintér *et al.*, 2005). The goal-oriented indicators link the choice of indicators with targets to improve their usefulness in comparing performance among countries, besides providing rankings. The Millennium Development Goals (MDGs) at the international, national and supra national level established policy goals (EU SDS, Lisbon Strategy), which are increasingly used for indicator selection and creation.<sup>5</sup>

Moreover, there are numerous attempts to move beyond the non-integrated indicators and consider different economy-nature-society dimensions in one indicator or index (Ness and Anderberg, 2007). A branch of literature focused on enriching existing indices with the inclusion of new components. For example, the Sustainable National Income attempts to include sustainable resource utilisation in the national accounting system. Adjusted Net Saving corrects gross national savings with the estimate of capital depreciation, human capital investments, natural resources depletion and damages caused by pollution (Ness and Anderberg, 2007; Adelle and Pallemmaerts, 2009).

There is also a flourishing literature focusing not only on improving current indices, but also on answering the policy makers’ need to have a synthetic tool for a wide collection of indicators.<sup>6</sup> The Human Development Index (UNDP, 1990) assesses the ability of a country in attaining a healthy life, education and a decent standard of living. The Wellbeing Index (Prescott-Allen, 2001) is

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<sup>3</sup> For an overview on Green Growth see World Bank (2012), UN DESA (2012) and the GGKP – Green Growth Knowledge Platform website (<http://www.greengrowthknowledge.org/Pages/GGKPHome.aspx>).

<sup>4</sup> The EU SDS is structured as a “hierarchical theme framework” composed by indicators ranging over ten themes. There are eight so-called “key challenges” (Sustainable Consumption and Production, Social Inclusion, Demographic Changes, Public Health, Climate Change and Energy, Sustainable Transport, Natural Resources, Global Partnership); in addition, the key objectives of economic prosperity and the leading principle of good governance are considered. The latest update in 2009 focused on “rapid shift to a low-carbon and low-input economy based on energy and resource-efficient technologies”, “protection of biodiversity, water and other natural resources”, “promoting social inclusion” and “Strengthening the international dimension of sustainable development and intensifying efforts to combat global poverty”.

<sup>5</sup> Even institutions that normally adopt other approaches/models such as the World Bank (WB), the United Nations Development Program (UNDP) and the World Health Organization (WHO) have started to use the MDG indicators as a standard reference.

<sup>6</sup> An index is characterised by a set of indicators chosen to express as many characteristics and aspects as possible of a complex phenomenon (OECD, 2008). UN CSD (2012) defines a composite indicator as “the compilation of individual indicators into a single index, on the basis of an underlying model of the multi-dimensional concept that is being measured”. Aggregate indices have several positive aspects: presenting indicators in an aggregated way allows exploring the relationship among the variables and facilitates presentation of information to decision makers.

generated from two indices: the Human Wellbeing Index, including health, wealth, cultural and educational indicators, and the Environmental Wellbeing Index centred on biodiversity and natural resources. The Environmental Sustainability Index (YCELP *et al.*, 2005) condenses 21 indicators covering six components of environmental sustainability (environmental systems, environmental stresses, human vulnerability to environmental stresses, societal capacity to respond to environmental challenges and global stewardship). The Environmental Performance Index (Yale and Columbia Universities, 2010) includes “25 performance indicators tracked across ten policy categories covering both environmental public health and ecosystem vitality” assessing the closeness of a country to environmental policy goals. A peculiar approach is the Ecological Footprint (Wackernagel and Rees, 1996), which accounts for the quantity of land necessary to sustain the annual individual consumption of goods, services, housing and transport. Another way of measuring sustainability is the use of monetary indexes: some examples are the Index of Sustainable Economic Welfare (Daly and Cobb, 1989); the Weak Sustainability Index (Pearce and Atkinson, 1993); the so-called El Serafy approach (Yusuf *et al.*, 1989).

There are important objections to the aggregation of different indicators in an index, because it implies loss of information and implicit subjectivity. Hence, particular attention to the quality and the transparency of the aggregation methodologies is needed to guarantee consistency of assumptions and interpretability of the obtained ranking (Munda, 2004). On the other hand, the purpose of an aggregate index is undeniable: it attempts to summarise an overly extensive dashboard and to guide policy makers’ assessment and action. In choosing this approach, it is important to follow a simple guideline: “Globally, all these composite indicators should probably be better regarded as invitations to look more closely at the various components that lie behind them” (Stiglitz *et al.*, 2009).

### 3. The FEEM Sustainability Index

The FEEM Sustainability Index<sup>7</sup> (FEEM SI) stems from this wide and heterogeneous literature on sustainable development measures. There are a number of factors making this index innovative within the research field on sustainability assessment.

First, the aggregate index groups all sustainability dimensions simultaneously. Differently from the majority of aggregate indices, the FEEM SI intends to summarise the three main components of sustainability: economic, social and environmental. Figure 1 illustrates the structure of the FEEM SI and presents all indicators considered.<sup>8</sup> The leaves at the bottom of the decision tree are then gradually aggregated (from bottom to the top) in thematic indices. At the top node, the FEEM SI condenses economic, social and environmental dimensions.

Another characteristic of the FEEM SI is the normalisation approach used to express all indicators through a common measurement scale:<sup>9</sup> an indicator-specific stepwise benchmarking function whose intermediate values are either established according to policy targets or observed trends. The upper and lower bounds of this function correspond to fully sustainable and unsustainable

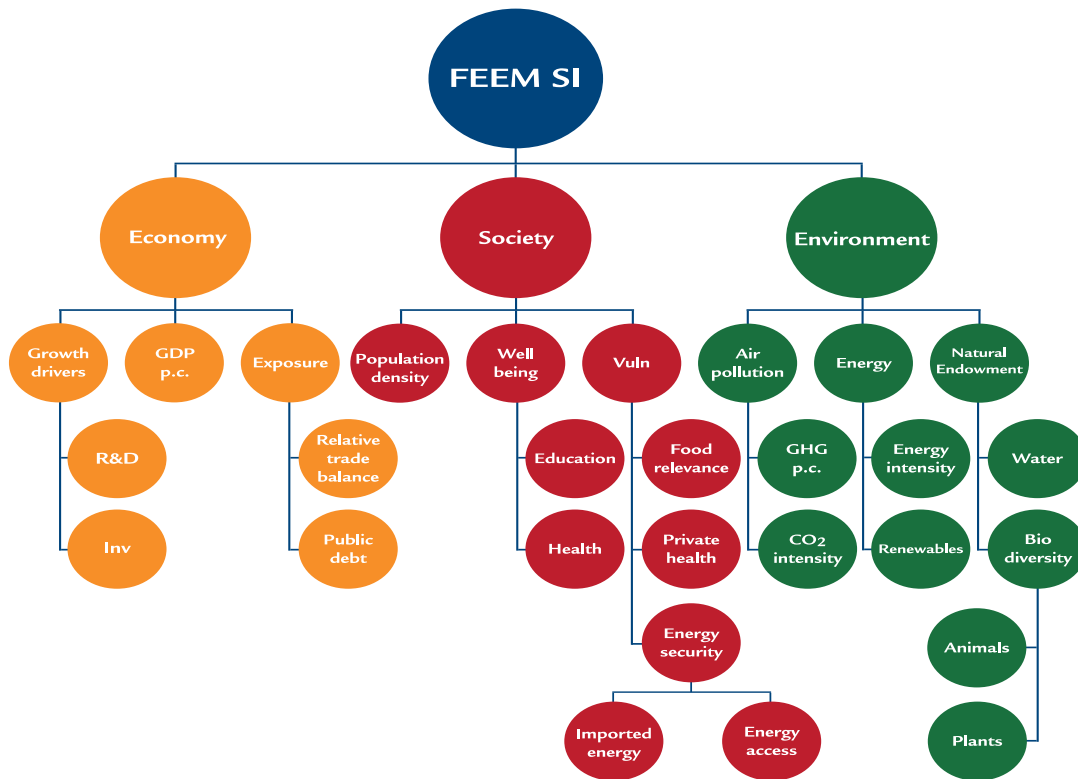
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<sup>7</sup> A further description and extended results of the FEEM SI project can be found in Carraro *et al.* (2011) and at [www.feemsi.org](http://www.feemsi.org).

<sup>8</sup> A detailed description of the indicator construction and sources is available in the Annex I.

<sup>9</sup> The normalisation procedure converts indicator-specific unit measures to a common one in the range [0,1] and then allows full comparability among indicators. This process is performed with respect to a benchmark to enable a uniform interpretation of changes in each indicator.

conditions, respectively. A finer tune on indicators values is guaranteed by the linearization of the benchmarking function.



**Figure 1 - FEEM SI indicators' tree**

As stated above, the indicators' aggregation procedure is a crucial point in determining the reliability and the credibility of an index. The FEEM SI adopts a complex double aggregation process. First, an experts' elicitation process via an *ad hoc* questionnaire produced a set of evaluations for each indicator and their combinations in each node. A non-linear methodology (metric distance) combined diverging responses into a 'representative' set of weights used to compute a consensus measure. The second step was to combine normalised indicators' values and the weights created in the previous step. In this case, a non-linear aggregation methodology, the Choquet integral, is used. Following this approach, the FEEM SI optimises the trade-off between simplicity and effectiveness in representing preferences by focusing specifically on the interrelations across indicators. More details on both normalisation and aggregation methodology are in Carraro *et al.* (2011).

Two factors drove the choice of the above set of indicators. As a first step, a thorough analysis of the most reliable international databases (UN CSD, EU SDS, WDI) was carried out to select the most significant indicators for which quantitative data are available for the whole world at country scale. Then, a further refinement was necessary to make their computation possible in the time-horizon under consideration (2004-2020) within the applied general equilibrium model used for this purpose. The rest of this section will provide an in-depth explanation of the main features of both model and database and their extensions to include as many indicators as possible in the CGE framework.



### 3.1 The ICES-SI model

The FEEM SI builds on the recursive-dynamic general equilibrium model ICES-SI, an extended version of the ICES model (Eboli *et al.*, 2010).<sup>10</sup> The main scope of the ICES model is to assess the final welfare implication of climate change impacts and mitigation policies on world economies, as well as different trade and public-policy reforms in the vein of conventional CGE models. Its general equilibrium structure, in which all markets are interlinked, is capable of capturing and highlighting the production and consumption substitution processes in a socio-economic system as a response to shocks, also considering international trade. In doing so, the final economic equilibrium obtained takes into account explicitly the “autonomous adaptation” of economic systems.

The economy representation is compliant with the usual CGE modelling: industries are cost-minimiser and present a nested production function in which primary factors and intermediates are combined to produce the final output. A representative household in each region receives income, defined as the service value of the national primary factors (natural resources, land, labour and capital). Demand for production factors and consumption goods can be satisfied either by domestic or foreign producers that are not perfectly substitutable according to the "Armington" assumption. The country representative household maximises its own utility coming from the expenditure on aggregate household consumption, public consumption and savings under the budget constraint.

This way, ICES is capable of replicating, on the one hand, past and present patterns and, on the other hand, of projecting possible future development paths. This is the crucial reason for which the present analysis uses such a model. Indeed, time projection is a concept neglected by the usual sustainability analysis either due to the absence of proper instruments or to the lack of faith in the possibility to predict the future behaviour of some indicators. A general equilibrium model offers the possibility to evaluate future trends of the indicators of the FEEM SI within a coherent and theoretically founded framework, which effectively works as a consistency grid for the indicators over time, keeping them meaningful with respect to one another.

The dynamic of the model is driven by two sources: one exogenous and the other endogenous. The first stems from exogenously imposed growth paths for some key variables - population, labour stock, labour productivity, and land productivity. The second concerns the process of capital accumulation, according to which capital stock is updated over time in order to take into account endogenous investment decisions. The model relies on the global trade database GTAP-7 (Narayanan and Walmsley, 2008) describing the world economic flows in the base year (2004).

In order to perform the analysis on sustainability, the ICES model has been extended adding new sectors and new exogenous variables. First, the sectoral detail has been enlarged to include or extrapolate some fundamental sectors for the construction of the sustainability indicators. Secondly, new variables have been included to enrich the model and to calculate the sustainability indicators related to them. For these purposes, changes have been made both to the database and to the model itself, leading to the improved ICES-SI model.

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<sup>10</sup> See also Annex II. For an overall description: <http://www.feem-web.it/ices/>

### 3.2 Additional Sectors

The GTAP-7 (Narayanan and Walmsley, 2008) database collects economic information in Input-Output Matrix format covering the global economic system. The original detail accounts for 57 sectors and 113 country/regions. The database provides details at country level if available; otherwise, more countries are grouped into one single macro-region. We aggregate the original 113 regions to 40, maintaining the world coverage.

Regarding the sector specification, the final commodity aggregation for the ICES-SI includes 20 sectors, with a detailed disaggregation of energy and public services.<sup>11</sup> To perform the sustainability analysis we worked under two different directions. On the one hand, we reduced the number of sectors not relevant for the construction of sustainability indicators in larger sectors. On the other hand, we extracted several sub-sectors (Research and Development, Education, Private and Public Health and Renewable Energy Sources) from the original categorisation using the SplitCom facility (Horridge, 2008) and relying upon external data on trade flows, production and consumption of these sectors/commodities.

The *Research and Development* (R&D) sector is derived from the GTAP “Other Business Services” sector, which includes real estate activities, renting of various types of machineries, computer-related activities, R&D and other business activities. In order to isolate R&D, we used data on R&D expenditure as a percentage of GDP in each country from the WDI database<sup>12</sup>. The share of R&D financed by Government, Firms, Foreign Investment and Other National was obtained from the OECD Main Science and Technology Indicators (OECD, 2010) and was used to attribute R&D to the different economic agents. The original sector residual, after the splitting procedure, was included in the “Market Services” sector. Since no data on international trade flows are available, it has been assumed that there are no direct imports and exports in R&D.<sup>13</sup>

A similar approach has been adopted to split the GTAP sector “Other Services (Government)” that includes services related to: public administration and defence; sewage and refuse disposal; activities of membership organisations and extra-territorial organisation and bodies; education and health. Three new sectors have been extrapolated, namely *Education*, *Private Health and Public Health* using, for the former, data on overall expenditure in health and education from the WDI database and, for the others, the World Health Organization database (WHO, 2010). Regarding imports, exports and agents’ purchase of the commodities, we maintained the same proportions of the initial sector.

The GTAP sector “Electricity” includes electricity produced from every energy sources (both fossil and renewable). The sustainability analysis requires a higher technological detail; for this purpose, we separate from the original sector most of *Renewable Energy Sources* (RES), namely wind, solar and hydro electricity. The residual of this procedure is included in the “Other Electricity” sector. The extrapolation of the RES sectors requires two steps. First, we collected the physical energy production in Mtoe<sup>14</sup> for different energy vectors and each GTAP-7 country/region from the

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<sup>11</sup> Annex III describes the sectoral aggregation of the model in detail.

<sup>12</sup> World Development Indicators, <http://data.worldbank.org/indicator>

<sup>13</sup> This assumption complies with the fact that R&D is usually a domestic activity, as the government and firms would invest in R&D only to benefit their own country’s productivity. In fact, even though firms employ foreign institutes for their research, they generally own the property rights of the inventions.

<sup>14</sup> Million tons of oil equivalent

International Energy Agency - Extended Energy Balances database.<sup>15</sup> Then, we assigned an economic value corresponding to the physical production in each country considering differences in unitary production costs all around the world when available.<sup>16</sup> This information was useful to define the value of production for the new electricity sector (*renewables*) and to split it from the original one. Regarding imports, exports and agents' purchases of the commodity, the same proportions of the initial sector have been maintained for the new one.<sup>17</sup>

### 3.3 Additional variables

Some of the indicators selected for the FEEM SI are related to variables not originally included in the GTAP-7 database, namely: use of water, biodiversity, access to electricity and inhabitable land. In fact, it was necessary to include external data relative to these variables in the model: first adding the variables to the dataset and then linking them to the model. Linking new exogenous variables to pre-existing inter-connected endogenous variables allows simulating their future behaviour coherently with the endogenous path of ICES-SI over time.

The original GTAP-7 database includes a sector/commodity called “*Water*”, but this only refers to water services infrastructures and does not really consider water availability and consumption. Therefore, additional variables have been added to the model in order to obtain a better indicator for water use. The Food and Agriculture Organization (FAO) provides the Aquastat database<sup>18</sup> that contains information on volumes of water consumption, which accounts for the total use of water in agriculture, industry and for private use and the total Renewable Water Resource (WTR). The latter is constantly taken over time,<sup>19</sup> while water use in agriculture, industry and private sectors have been linked respectively with the demand of water services by agriculture, industry and households, this way changing endogenously in the model.

An index that quantifies the number of endangered species for both animals and plants over their total population in each country describes the *Biodiversity* loss. The data to construct these indicators has been obtained from the World Conservation Union (IUCN) Red List of Threatened Species Database. The number of endangered species has been linked to the model so that over time it is possible to detect whether the number of species in danger of extinction is increasing. Biodiversity loss can be related to multiple human activities, such as extension of agricultural fields, forestry abatement, fishing, hunting, industrial activities or pollution. As it was not possible to take into account all those factors, climate change and CO<sub>2</sub> concentration have been thought to be the most significant variables to consider. According to a study by Thomas *et al.* (2004) relative to 1,103 animal and plant species in sample regions covering some 20% of the Earth surface, 15 to 37% of the species are at risk of extinction because of climate change scenarios at 2050. In order to proxy for climate change, the number of endangered species has been inversely linked to emissions

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<sup>15</sup> <http://www.oecd-ilibrary.org/content/datacollection/enestats-data-en>

<sup>16</sup> Annex II reports main data sources.

<sup>17</sup> The ICES-SI model reserves a particular treatment to energy commodities, which are included among value added factors and present a high degree of substitutability with capital. The explicit consideration of the RES sectors implied some modelling changes. Namely, the structure for the production function, consistent with the database structure, incorporates a new nest to allow the inter-electricity substitution between RES and traditional electricity, whereas the electricity was previously considered as undistinguished irrespective of the source (see Annex II for further details).

<sup>18</sup> <http://www.fao.org/nr/water/aquastat/main/index.stm>

<sup>19</sup> In the time-horizon under consideration (2004-2020) this variable is not expected to change substantially.

of CO<sub>2</sub>, so that higher emissions of carbon dioxide lead to an increase in the number of endangered species.

An additional variable, considering the share of population with *access to electricity*, has been added to construct an energy access indicator. The source for the base year is the World Energy Outlook (IEA, 2010). As a Developing Country with unsatisfactory access to electricity reduces over time its GDP per capita gap with the OECD average level, it increases the possibility to afford population for basic needs, such as electricity; this relation determines the endogenous dynamic of this indicator within the ICES-SI model. The initial access to electricity converges slowly across time towards the universal coverage, but this is not even reached in the baseline scenario in some developing countries given the short time span.

Finally, we add the variable *available land* in each country (excluding deserts, ice-cover land and mountains) to define the population density indicator. The data source is the GTAP-7 land use database, relying upon FAO data.<sup>20</sup> There is no dynamic pattern imposed on this dataset: the available land remains constant through the time-horizon under consideration.

#### 4. Quantifying sustainability over time

A sustainability indicator is usually backward-looking. It uses data from past history of countries or regions to compute the values of a set of indicators and aggregates them in a comprehensive index. However, it is unable to provide any information about future sustainability, which is a sort of contradiction. Sustainability is a dynamic, forward-looking concept and it needs to be assessed by taking into account the future dynamics of economic, environmental and societal variables. Hence, two issues become crucial: first, to assess how sustainability will change over time if the current growth and policy trends were to continue; second, to evaluate how sustainability can be enhanced or reduced if a given set of policy measures is put into place.

To address the first issue, we constructed a reference scenario in which main macro-economic variables change according to current trends and without considering any explicit policy intervention to improve sustainability. The present level of sustainability throughout the world is then compared with the expected picture in 2020. These projections also serve as a reference scenario for policy simulations. The second question to address is in fact, how policies could affect sustainability trends.

##### 4.1 Baseline scenario description

The reference scenario reproduces historical data from 2004 to 2009 and then projects data up to 2020. The value added of the present baseline scenario is the replication of the financial crisis and its effect on future projections of economic growth and sustainability. Table 1 reports the main sources for both exogenous and endogenous dynamics.

Along with population and GDP trends, it is worth mentioning that energy sectors play a key role in future sustainability. Apart from the relevance for economic development, energy production, which is still mainly based on fossil fuels, affects the social (energy security) and environmental

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<sup>20</sup> [https://www.gtap.agecon.purdue.edu/resources/res\\_display.asp?RecordID=1900](https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1900)

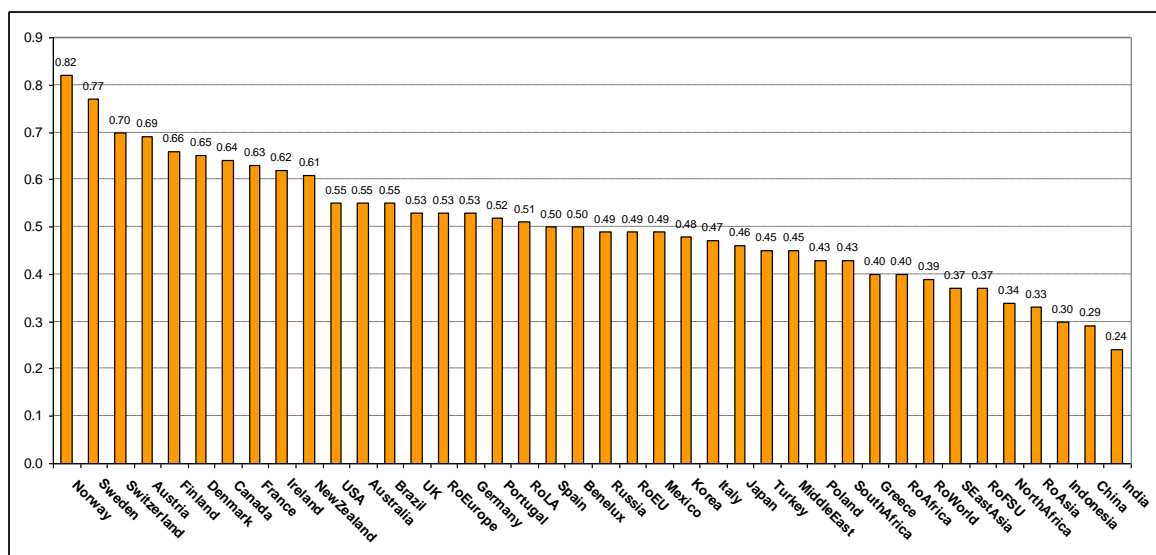
(climate change) dimensions. For this reason, one of the main drivers for future technological advancements in the energy system is the evolution of fossil fuels' prices and energy intensity.

**Table 1 - Main variables and reference sources in the baseline scenario**

Variable	Reference source
Population	UN World Population Prospect (2010 revision) – medium fertility variant
Fossil fuel prices	Eurelectric (2011)
GDP	2005-2009 = WDI (World Bank) 2010-2020 = MMC_G10 scenario Med Pop - Medium Growth - Fast Convergence (Conv) developed within the RoSE project <sup>21</sup> + World Economic Outlook 2010 (IMF, 2010) for downscaling at country level
Energy intensity	2005-2009 = IEA (2010) 2010-2020 = endogenous
CO2 emissions	2005-2009 = IEA (2010) 2010-2020 = endogenous
Public debt	IMF (2010)

#### 4.2 A Sustainability World Ranking

The FEEM Sustainability Index is calculated for each country/macro-region in each year. Figure 2 illustrates the sustainability world ranking for 2011.<sup>22</sup> Not surprisingly, developed countries/regions perform better than developing ones. Scandinavia, Central Europe and Canada show the highest values, since the high level of GDP per capita comes along with excellent performances in social and environmental pillars.



**Figure 2 - World Sustainability Ranking 2011**

<sup>21</sup> “RoSE - Roadmaps towards Sustainable Energy Futures: A Model-Based Assessment of Scenarios for Decarbonising the Energy System in the 21<sup>st</sup> Century”. Project funded by Stiftung Mercator Foundation, Germany. It is worth noting that the above project is an initial attempt to develop new economic scenarios, replacing the SRES (Nakicenovic *et al*, 2000) previously adopted by IPCC – Intergovernmental Panel on Climate Change – for climate change analysis.

<sup>22</sup> Annex IV presents the 2011 ranking for each pillar and Sustainability maps.

Several highly advanced countries (USA, Germany, UK) are less sustainable especially because their energy mix is mainly based on fossil fuels and it implies a higher environmental impact. The central part of the ranking shows quite a heterogeneous composition comprising rich countries affected at a large extent by financial crisis (Italy, Spain) or low social performance (Japan, Korea) and countries with intermediate levels of economic development (Russia, Mexico, Turkey). Finally, the poorest areas in the world are at the bottom of the ranking, while China and India have the lowest scores.

Figure 3 compares the scores of each pillar (economic, social and environmental) and the aggregate index for the best and worst countries. The scores for the top-three countries are similarly high in the three main components of sustainability. Norway is at the top of the ranking, thanks to the high scores in all components. Sweden performs a bit worse than Norway in all dimensions. Even though slightly better in economic terms, Switzerland ranks third place because of the relative lower social sustainability (for instance with reference to population density, that is particularly low in Scandinavia).

Turning to the bottom-three countries,<sup>23</sup> the components are very unequally distributed and this makes the trade-offs at the lower stage of economic development clear. Indonesia leads this special ranking due to the better environmental performance with respect to China, even though the latter has higher scores at the economic and social level. India has a very low economic and social performance, even though on the environmental side it is superior to China.

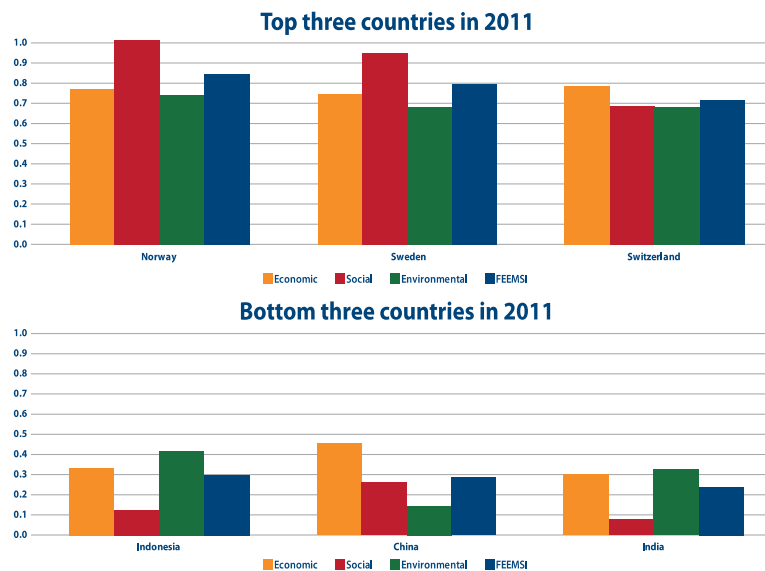


Figure 3 - FEEM SI and sustainability pillars for the Top and Bottom Countries

Cruciani *et al.* (2012) perform an in-depth analysis to check the robustness of the above ranking by building a linear convex combination of the weights assigned by 1000 *artificial experts* ranging

<sup>23</sup> It is worth noting that many poor countries are grouped and appear to be performing better than those bottom-three. If taken separately, other countries may perform worse. Unfortunately, data availability does not allow going into deeper detail.

between the two extreme real experts and then performing a Monte Carlo analysis. The dominance analysis, that is the probability that one country performs better than the follower similarly to the base case illustrated above, shows a robust ranking and marginal variability with respect to the picture presented here.

The main function of an aggregate sustainability index is to provide a more complete picture on well-being with respect to what GDP does. Table 2 compares the FEEM SI ranking with the analogous for GDP p.c. A stronger relation between GDP p.c. and FEEM SI rankings characterises the 10 bottom countries; a low GDP p.c. is normally associated to a low overall sustainability performance. Nevertheless, it is confirmed that the other indicators considered in the FEEM SI may skew the GDP p.c. ranking.

Norway, the richest country in the world in terms of GDP per capita (among those that we consider separately), is also the most sustainable. However, USA, which has the second highest GDP per capita in the world, is only at 11<sup>th</sup> position according to the FEEM SI ranking. This is due to one of the worst results in environmental sustainability not compensated enough by good economic and social performances. Moreover, even though the GDP p.c. is high, public debt strongly penalises the USA performance. Australia is another example of a country that moves down substantially when comparing FEEM SI and GDP p.c., because of the relatively low sustainability of environmental dimension. Conversely, Sweden, Finland and France have the reverse relationship (FEEM SI makes them better off than the GDP ranking). Looking at the very bottom of the ranking, India (38<sup>th</sup> according to GDP p.c.) becomes the worst performer (40<sup>th</sup> according to FEEM SI) because of its poor performance in social and environmental sustainability. Conversely, the poorest RoAfrica region benefits from the relatively good environmental performance.

**Table 2 - GDP per capita and FEEM SI ranking in 2011**

GDP pc ranking	Country	FEEM SI ranking	GDP pc ranking	Country	FEEM SI ranking
1	Norway	1	21	Portugal	17
2	USA	11	22	Poland	29
3	Switzerland	3	23	MiddleEast	28
4	Australia	12	24	RoEU	22
5	Austria	4	25	Russia	21
6	Ireland	9	26	Mexico	23
7	Denmark	6	27	RoEurope	15
8	Benelux	20	28	RoLA	18
9	Sweden	2	29	SouthAfrica	30
10	Canada	7	30	Brazil	13
11	Germany	16	31	Turkey	27
12	Finland	5	32	RoFSU	35
13	UK	14	33	Ro World	33
14	Japan	26	34	SEastAsia	34
15	France	8	35	NorthAfrica	36
16	Spain	19	36	Indonesia	38
17	Italy	25	37	China	39
18	Korea	24	38	India	40
19	NewZealand	10	39	RoAsia	37
20	Greece	31	40	RoAfrica	32

### 4.3 Sustainability over time

We now move forward to consider the expected pattern of sustainability in the next future. Table 3 compares FEEM SI ranking and scores in 2011 and 2020. Most of countries/regions slightly increase their sustainability in the next ten years. Nevertheless, a few but important countries, among which USA, Russia and Brazil, show a decreasing trend in their own sustainability. This is mainly due to increasing public debt and environmental deterioration. Regarding the variations in the sustainability ranking, Benelux (+7 positions), Germany (+5) and Italy (+3) benefit the highest advancements, while United States (-6) and Russia (-5) have the largest decrease.

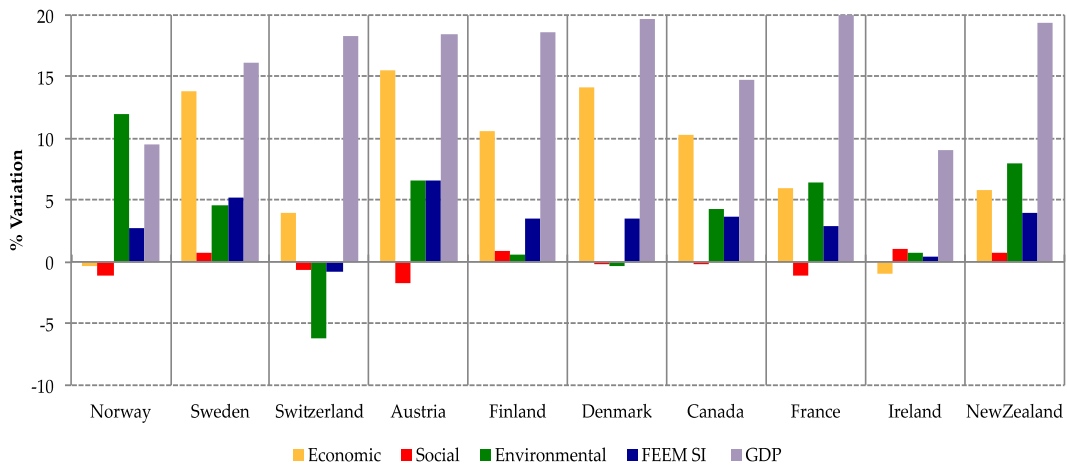
**Table 3 - Sustainability ranking (2011 vs 2020)**

Rank 2011	Country	FEEM SI 2011	Δ Rank	FEEM SI 2020	Country	Rank 2020	Rank 2011	Country	FEEM SI 2011	Δ Rank	FEEM SI 2020	Country	Rank 2020
1	Norway	0.82	=	0.85	Norway	1	21	Russia	0.49	-5	0.50	Spain	21
2	Sweden	0.77	=	0.81	Sweden	2	22	RoEU	0.49	2	0.50	Italy	22
3	Switzerland	0.70	-1	0.74	Austria	3	23	Mexico	0.49	-2	0.49	Korea	23
4	Austria	0.69	1	0.70	Switzerland	4	24	Korea	0.48	1	0.49	Japan	24
5	Finland	0.66	=	0.68	Finland	5	25	Italy	0.47	3	0.48	Mexico	25
6	Denmark	0.65	=	0.68	Denmark	6	26	Japan	0.46	2	0.48	Russia	26
7	Canada	0.64	=	0.67	Canada	7	27	Turkey	0.45	=	0.48	Turkey	27
8	France	0.63	=	0.65	France	8	28	MiddleEast	0.45	=	0.47	MiddleEast	28
9	Ireland	0.62	-1	0.63	NewZealand	9	29	Poland	0.43	=	0.44	Poland	29
10	NewZealand	0.61	1	0.62	Ireland	10	30	SouthAfrica	0.43	=	0.43	SouthAfrica	30
11	USA	0.55	-6	0.58	Germany	11	31	Greece	0.40	=	0.43	Greece	31
12	Australia	0.55	=	0.58	Australia	12	32	RoAfrica	0.40	=	0.40	RoAfrica	32
13	Brazil	0.55	-2	0.56	Benelux	13	33	RoWorld	0.39	=	0.39	RoWorld	33
14	UK	0.53	=	0.55	UK	14	34	SEastAsia	0.37	=	0.36	SEastAsia	34
15	RoEurope	0.53	-1	0.54	Brazil	15	35	RoFSU	0.37	=	0.36	RoFSU	35
16	Germany	0.53	5	0.54	RoEurope	16	36	NorthAfrica	0.34	=	0.34	NorthAfrica	36
17	Portugal	0.52	-2	0.53	USA	17	37	RoAsia	0.33	=	0.34	RoAsia	37
18	RoLA	0.51	=	0.53	RoLA	18	38	Indonesia	0.30	-1	0.32	China	38
19	Spain	0.50	-2	0.53	Portugal	19	39	China	0.29	1	0.32	Indonesia	39
20	Benelux	0.50	7	0.51	RoEU	20	40	India	0.24	=	0.29	India	40

Decomposing the analysis at the level of a single pillar and adding information on GDP evolution helps to understand the results in Table 3. Figure 4 presents the percentage variation in 2020 with respect to 2011 for the best ten performers (listed according to the 2011 ranking). These results illustrate that the sustainability of most countries increases. This increase is mostly driven by a positive change in the economic component, with the exception of Norway, France and New Zealand for which the environmental component has a larger variation. Social sustainability has a slower variation and decreases in a few countries (Norway, Austria and France). The only country whose sustainability is decreasing is Switzerland (-0.8%) due to a decline in the social (-0.6%) and environmental (-6%) dimensions – the latter caused by a marked deterioration in energy intensity – not compensated by the intensification in the economic pillar (4%) and in the GDP per capita

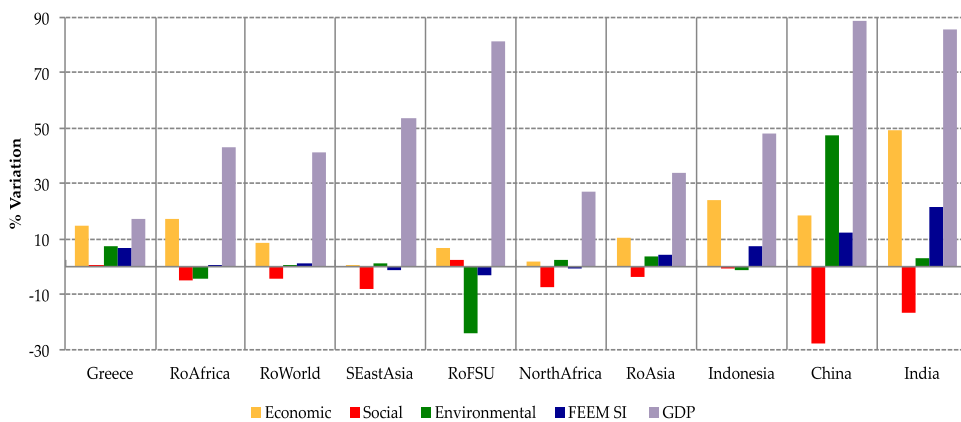


(18.3%).



**Figure 4 - % variation of the best ten performers by dimension (2020 wrt 2011)**

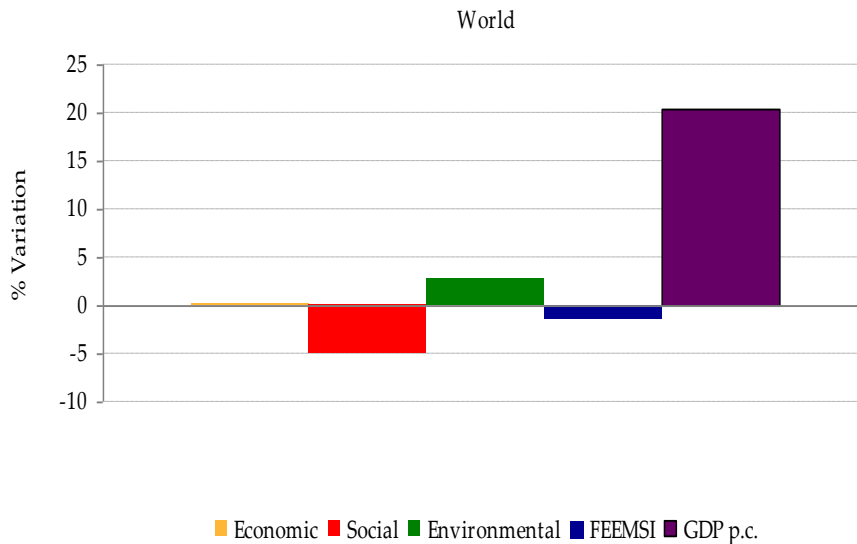
Figure 5 shows the percentage variation for the worst ten performers in 2020 with respect to 2011 for each pillar, FEEM SI and GDP. Results highlight the expected trade-offs, in the initial stage of economic development, between the economic and social (all except Greece and RoFSU) or/and environmental (RoAfrica, RoFSU, Indonesia) pillars. The overall effect on sustainability is relatively small. It is worth noting the RoFSU situation, whose GDP grows by some 80% but strong environmental deterioration produces a negative FEEM SI performance. FEEM SI value expansion is noteworthy for China (12.5%) and it is supported by a substantial change in all dimensions, namely 47% improvement in the environmental, 19% in the economic and a decreasing (-27%) in the social pillar. These variations allow China to raise one position in the ranking at the expense of Indonesia, where the environmental degradation partially counterbalances the greater improvement in the economic component. Finally, India presents a GDP per capita growth of 85.4%, which drives the economic pillar to a 50% increase.



**Figure 5 - % variation of the worst ten performers by dimension (2020 wrt 2011)**

Looking at the world level, the FEEM SI slightly decreases in the 2011-2020 period despite an increase of 20% in GDP p.c. This is strongly driven by the social deterioration that mainly, but not exclusively, affects the least developing countries. This is a clear signal of the wrong message delivered

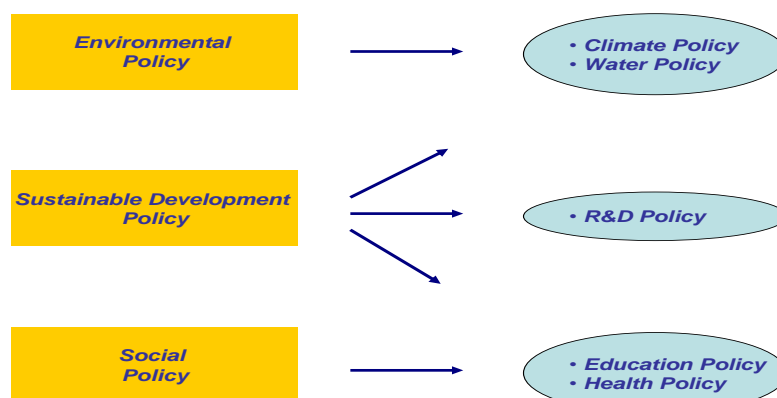
when considering GDP p.c. the only driver of well-being.



**Figure 6 - Percentage variation in aggregated regions by pillar (2020 w.r.t 2011)**

#### **4.4 Enhancing sustainability: policy-relevant scenarios**

One main insight from the previous section is that, despite a significant increase in global GDP per capita in the next decade, global sustainability will slightly decline. It means that there is room for appropriate intervention to increase future sustainability. In order to assess how sustainability may be improved undertaking dedicated strategies, we propose and simulate three policy scenarios. We first performed an Environmental and a Social Policy separately, each considering selective interventions in related spheres. In addition, an all-inclusive scenario (Sustainable Development Policy) considers jointly the previous measures and, further, includes a subsidy on R&D, thus addressing all sustainability dimensions simultaneously.



**Figure 7 – Overall Policy Design**

The general equilibrium framework allows keeping track of variations worldwide even when policies involve directly either a single pillar or a subset of countries/regions. All policies take effect from 2010 to 2020. Each scenario is a combination of policies summarised in Figure 7 and described in Table 4.

**Table 4 – Policy Scenarios Characteristics**

<b>Climate</b>	The climate policy considers the achievement in 2020 of the most ambitious reduction targets voluntarily declared by the most polluting countries in the last international negotiations in Copenhagen and Cancún (UNFCCC Conference of the Parties - COP15 and 16). <sup>24</sup> The Cancún Agreements confirmed the main conclusions already achieved in the Copenhagen Accord, officially recognising the need to limit the increase of global temperature below 2° C. The climate policy fulfilment is put into practice by means of an international carbon emission trading system. China and India do not participate in the international trading scheme, achieving their own target on carbon intensity reduction unilaterally.
<b>Water</b>	This strategy aims at improving worldwide the efficiency of water use in all productive sectors. Water use efficiency throughout the world <sup>25</sup> increases uniformly by 20% from 2010 to 2020 with respect to the baseline scenario in which it is constant, by means of an exogenous shock imposed to the model.
<b>Education</b>	The second of the Millennium Development Goals (MDGs) (UN, 2011) points out the need of achieving universal primary education. The target consists in “ensuring that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling”. While it is not possible to model directly these goals in a general equilibrium approach, we simulate the increase of investments in the education sector consistent with these goals. Glewwe <i>et al.</i> (2006) estimate the costs of meeting the MDG on education for some macro-areas of developing countries. <sup>26</sup> The interested regions are India, Indonesia, Rest of Asia, Brazil, Latin America, North Africa, Sub-Saharan Africa including South Africa and the Rest of the World. The intervention is modelled through a domestic subsidy to the education sector provided by national governments.
<b>Health</b>	The fourth, the fifth and the sixth of the MDGs (UN, 2011) concern human health conditions in developing countries. They state the need of reducing, between 1990 and 2015, by two-thirds the mortality rate of children under five (goal 4) and by three quarters the maternal mortality ratio, achieving universal access to reproductive health (goal 5). Moreover, HIV and malaria are the most dangerous diseases in Developing Countries: goal 6 promotes the reversion of the spread of these diseases by 2015 and the achievement, by 2010, of a universal access to treatment for HIV/AIDS for all

<sup>24</sup> [http://unfccc.int/meetings/cancun\\_nov\\_2010/meeting/6266.php](http://unfccc.int/meetings/cancun_nov_2010/meeting/6266.php). It is worth noting that the most recent COP17 in Durban and Doha in 2011 and 2012 respectively did not produce substantial modifications of those targets.

<sup>25</sup> Indeed, policy targets for water efficiency are not very uniform in the world. The EU has no quantitative policy on water efficiency, and the International Water Management Institute (IWMI) though regarding an ideal 40% reduction in the use of water in agriculture, does not set particular targets. The only country with a water policy setting water efficiency targets is Australia, where the targets are in fact of 10% improvement in water efficiency.

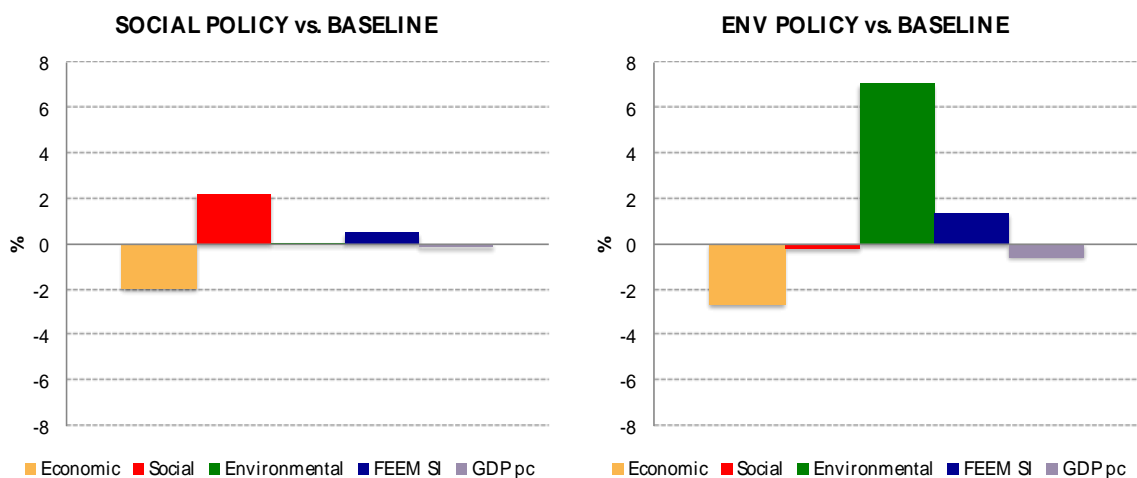
<sup>26</sup> Subsidies are taken from Table 8 (scenario 5), p. 23, in Glewwe *et al.* (2006).

	those who need it. As for education policy, it is not feasible to model directly these goals in a CGE model but it is possible to simulate the increase in the financial resources to be invested in the public health sector to meet these goals. Subsidies have been calibrated according WHO targets. <sup>27</sup>
<b>R&amp;D</b>	In order to increase the technological advancements worldwide, we analyse a two-step policy. First, an increasing subsidy on R&D in developed countries (up to 10% in 2020). Along with the subsidy, there is a technology transfer to developing countries simulated as a gradual 5% increase of industrial sectors' productivity, following Guellec and van Pottelsberghe de la Potteriee (2004). <sup>28</sup> In particular, productivity expands in the following sectors: food, energy intensive industries and (both RES and fossil-based) electricity.

#### 4.5 A policy-driven sustainability ranking

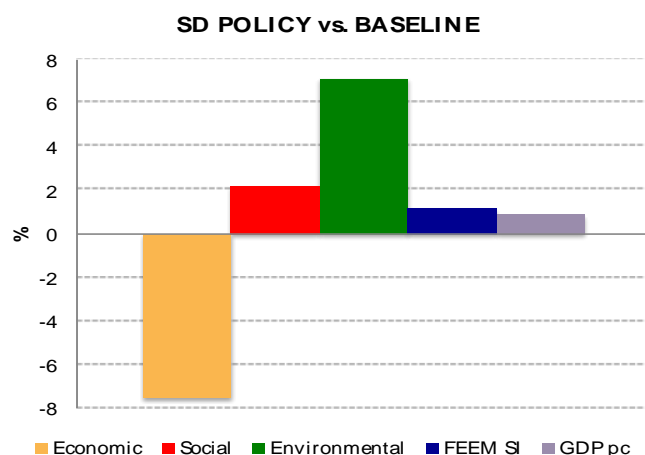
Our modelling framework allows capturing higher-order effects spread throughout the entire world since it brings general re-adjustments in all markets driven by both global and sector- or country-specific policies. This is especially the case of social and environmental policies: the former applies to developing countries and public sectors, the latter mainly to developed countries and energy-intensive sectors (even though water efficiency measures are global).

Figure 8 shows the snapshot of percentage variations for sustainability and GDP per capita in 2020 at the world level in the policy scenario compared to the reference scenario. This emphasises how every sustainability component is affected by the policy action at the world level, revealing potential trade-offs. The inclusion of GDP per capita provides interesting insights as well. The cost of Social and Environmental policies considered separately in terms of a reduction in GDP per capita clearly emerges, while in the case of the SD policy, GDP per capita is higher than in the baseline scenario. The main reason is the enhanced economic growth stimulated by R&D subsidies. In all cases, the economic pillar decreases, especially for the SD policy. This highlights the trade-offs within the economic pillar itself, where an increase in R&D subsidies implies a lower sustainability due to the increase in public debt.



<sup>27</sup> See WHO (2001), page 170, table A2.10: Annual Domestic Resource Mobilization (\$US 2002) by Region.

<sup>28</sup> They estimate that the long-term elasticity of foreign R&D on productivity is in the range of 0.45-0.5.



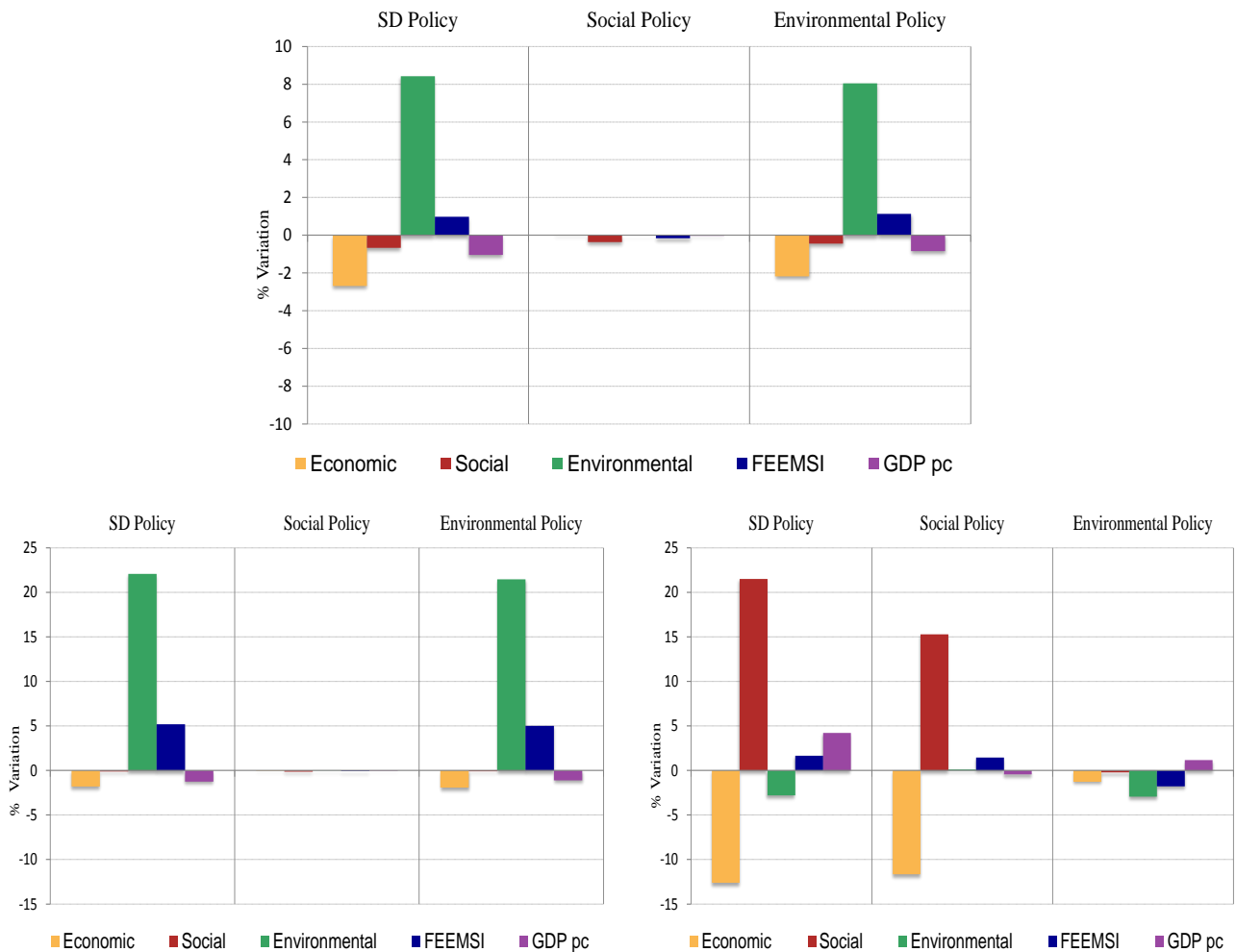
**Figure 8 - Policies' effect in 2020: World**

Even though the SD Policy negatively affects economic sustainability and is slightly lower than the Environmental Policy in terms of increased sustainability, it appears to be the most effective intervention at the global level. The mutual and consistent improvement in the social and environmental pillars boosts overall sustainability without raising the concerns that may occur if only the environmental sphere is considered.

For the sake of brevity, we report the different impacts of policies on sustainability across several regional aggregates to see how the sustainability improvement spreads around the globe.<sup>29</sup> Figure 9 shows the EU27 performance at the top panel and Developed and Least Developed Countries (DCs and LDCs) ones at the bottom panels.

As for the EU27, there is a considerable positive improvement in the environmental pillar in 2020 with both the SD and Environmental Policy, compared to the reference scenario. This improvement in the environmental pillar is due to both the climate policy (-30% of GHG emission reduction in 2020 with respect to 1990) and the improvement of 10% in water efficiency.

<sup>29</sup> Annex V reports the change in FEEM SI value at the highest regional detail.



**Figure 9 - Policies' effect in 2020: EU27 (top), DC (bottom-left), LDC (bottom-right)**

The diverse effects induced by sustainability policies are clear when comparing DCs and LDCs. DCs largely benefit from adopting the Environmental Policy. In particular, there is a large improvement in the environmental dimension, which leads to a marked increase in overall sustainability despite a slight decline in economic performance. The social pillar is unaffected since the Social Policy does not concern DCs.

On the other hand, LDCs improve their sustainability supported by the MDGs stimulus. In the SD Policy, the social pillar improvement (21.5%) determines the overall positive performance of the overall FEEM SI (+1.7%), more than offsetting the reduced economic sustainability (-12.6%) driven by the increase in public debt necessary to subsidise the Education and Health expenditure. The Social Policy alone provides similar results, even though smaller in absolute terms. It is worth noting that in this case the impact on GDP p.c. is negative since there is no positive spill over induced by increased R&D in DC. Lastly, the Environmental Policy has a slightly negative effect on the FEEM SI (-1.8%) explained by a substantial decrease of the environmental (-3%) dimensions, due to the other side of the coin of a higher competitiveness with respect to DC (environmental leakage).

## 5. Conclusions

This paper describes an innovative approach to the measurement of sustainability. Most policy-makers and stakeholders recognise the importance to modify the traditional idea of well-being, adding new attributes beyond the economic dimension. While many agree on the opportunity to change this vision through qualitative approaches, there is increasing attention towards the quantitative measurement of sustainable development. This is challenging since it does not rely upon a single measure, as GDP for economic growth, but it involves a bundle of indicators, raising the issue of comparability among different measurement units and aggregation of different components. In this perspective, the value added of the FEEM SI lies in both the normalisation procedure (all indicators are compared with a benchmark and normalised between zero and one) and the adoption of a novel aggregation methodology of indicators in a composite index based on Choquet's integrals (see Carraro *et al.* 2011 and Cruciani *et al.* 2012 for further details).

At the same time, sustainability is a dynamic concept that needs to be assessed by looking at the future economic, social and environmental performances of different countries and regions. Therefore, it cannot be measured by using past data only. This requires a consistent methodology in which interrelations among countries, sectors and sustainability components are well designed and projected into the future. For this purpose, we used a recursive-dynamic computable general equilibrium framework to design future scenarios and compute the future values of our sustainability indicators, highlighting high-order effects to better understand the main drivers of future sustainability trends.

We presented three sets of results. First, the current level of sustainability across the world shows a quite heterogeneous situation. While advanced economies are characterised by an average satisfactory level of sustainability, developing countries still have a significant gap. After taking a closer look at the determinants of this result, it emerges that a high performance in each sustainability dimension is a necessary condition to reach a high level of overall sustainability. It is therefore not sufficient to move along a high growth economic path.

Second, the baseline analysis from 2004-2020 reveals that even though all countries and macro-regions experiment economic growth in the post-crisis period, the FEEM SI slightly decreases at the world level. In other words, in spite of an increasing GDP per capita worldwide, the level of well-being does not improve at the same pace, highlighting significant trade-offs among sustainability dimensions (mainly due to negative impact of growth on the social component).

Third, the paper illustrates the potential of the FEEM SI in assessing the effects of policies on sustainability. A Social, an Environmental and a Composite Policy for Sustainable Development (SD) have been implemented thanks to the modelling framework through which all indicators can be computed and projected into the future. The Social Policy has a relevant effect on Developing Countries moving closer to the UN Millennium Development Goals. The Environmental Policy allows matching the climate targets defined under the Copenhagen/Cancun framework at relatively low cost for Developed Countries, substantially improving the state of the environment. Finally, the SD Policy ensures a generalised increase in worldwide well-being that relies also upon the potential benefit for the overall society from increasing investment in R&D.

These can be considered just as preliminary experiments, which are however very useful to illustrate the potential of the FEEM SI in both providing a global ranking of sustainability and, above all, in helping to design policies that enhance sustainability worldwide.



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## ANNEX I – THE INDICATORS’ LIST

DIM	NAME	EQUATION	LONG DESCRIPTION	LITERATURE
Economic	<b>R&amp;D</b>	R&D Expenditure / GDP (%)	This indicator assumes a positive relationship between investment in R&D and growth, by maintaining that increased investment in R&D can bring more R&D output that will eventually lead to more innovation and increased productivity	EU SDS – UN CSD - WDI
	<b>Investment</b>	Net Investment / Capital Stock (%)	Investment is one of the main drivers of economic sustainability, allowing for capital accumulation, which boosts economic growth. This indicator is weighted considering the country specific capital stock.	EU SDS - UN CSD
	<b>GDP per capita</b>	GDP PPP / population	It is a measure of the per capita value of all market goods and services produced within a country. GDP p.c. is the typical indicator used to define the average well-being in a country.	EU SDS – UN CSD - WDI
	<b>Relative Trade Balance</b>	Trade Balance / Market Openness	The Relative Trade Balance measures the degree of a country’s exposure in the global commodities markets. It considers the net export value and weights it with the country specific market openness (exports + imports). Relying relatively more upon exports is a signal of strong competitiveness.	-
	<b>Public Debt</b>	Government Debt / GDP (%)	Public Debt has an important role on the future perspective of a country’s economy. It depends on current government choices on expenditure and taxation, and on previously accumulated debt.	WDI – UN CSD - IMF
Social	<b>Population Density</b>	Population / Country Surface	Population Density evaluates the population concentration in a specific country or macro-region (excluding uninhabitable areas). It represents the pressure on the available living space and resources for each individual.	UN CSD - WDI
	<b>Education</b>	Education Exp. / GDP (%)	Expenditure in Education constitutes an investment in human capital. The role of education in improving future economic conditions and enhancing mobility as well as gender equality is supported by several studies.	EU SDS – WDI
	<b>Health</b>	Total Health Exp. / GDP (%)	The generalised access to basic Health services is a major concern throughout the world. Monitoring the growth of expenditures in health by summing public and private expenditures allows to measure the degree of support on this issue.	WDI
	<b>Food Relevance</b>	Food Cons. / Private Exp. (%)	This indicator is used as a proxy for the poverty level. In fact, according to Engel’s law, the higher the proportion of national income spent on food the lower the level of a country’s welfare.	-
	<b>Energy Imported</b>	Energy Imported / Energy Cons. (%)	This is an indicator of energy security. The higher the Energy Dependence from abroad, the higher the risks deriving from changes in energy prices and political instability in energy-rich countries.	WDI
	<b>Energy Access</b>	Population with Access to Electricity / Total Population (%)	Access to Energy is important with reference to living conditions and future perspectives of well-being. This indicator considers the share of population having access to electricity. It allows capturing the intra country aspect of energy security, being more focused on distribution of energy resources than on availability at the country level.	IEO
	<b>Private Health</b>	Private Health Exp. / Total Health Exp. (%)	Monitoring the balance between public and private contribution to the health sector is essential for sustainability because it determines the availability of primary service to the whole society. The higher the share of Private Health expenditure, the lower the ability of poorer people to access to the health care.	WDI
Environmental	<b>GHG per capita</b>	Kyoto GHGs Emissions / Population	The Greenhouse Gases are considered as described in the Annex I of the Kyoto Protocol. Emission per capita is a measure of the burden that the society imposes on climate and environment.	EU SDS – UN CSD - WDI
	<b>CO<sub>2</sub> Intensity</b>	CO <sub>2</sub> Emissions / Total Primary Energy Cons.	This indicator is fundamental to monitor the improvement of the environmental performance of production and consumption activities, the latter playing a major role in the release of Carbon Dioxide into the atmosphere.	EU SDS – UN CSD - WDI
	<b>Energy Intensity</b>	Total Primary Energy Supply / GDP PPP	This indicator aims to assess the evolution of energy use efficiency.	EU SDS – UN CSD - WDI
	<b>Renewables</b>	Renewable Cons. / Total Primary Energy Cons. (%)	The gradual reduction of fossil fuel use is an important step towards security and sustainability of energy systems. The higher the share of green energy, the higher the environmental performance of the energy sectors.	EU SDS – UN CSD - WDI
	<b>Plants</b>	Endangered Species / Total Species (%)	This indicator represents an alarm signal of the general worsening of habitats. It provides a comparable measure of endangered Plant species throughout the world, by considering the number of endangered species over the number of total known species present in that country.	EU SDS – UN CSD - WDI
	<b>Animals</b>	Endangered Species / Total Species (%)	As in the previous indicator, it also represents an alarm signal of the general worsening of habitats. It is calculated in the same way but focusing on animal biodiversity.	EU SDS – UN CSD - WDI
	<b>Water</b>	Water Use / Total Available Water (%)	Human pressure on water is an important indicator of resource pressure. It is estimated as water consumed in a country (for agriculture, industry and private uses) over the total renewable water resources available in that specific country.	UN CSD - WDI

## ANNEX II – THE ICES MODEL

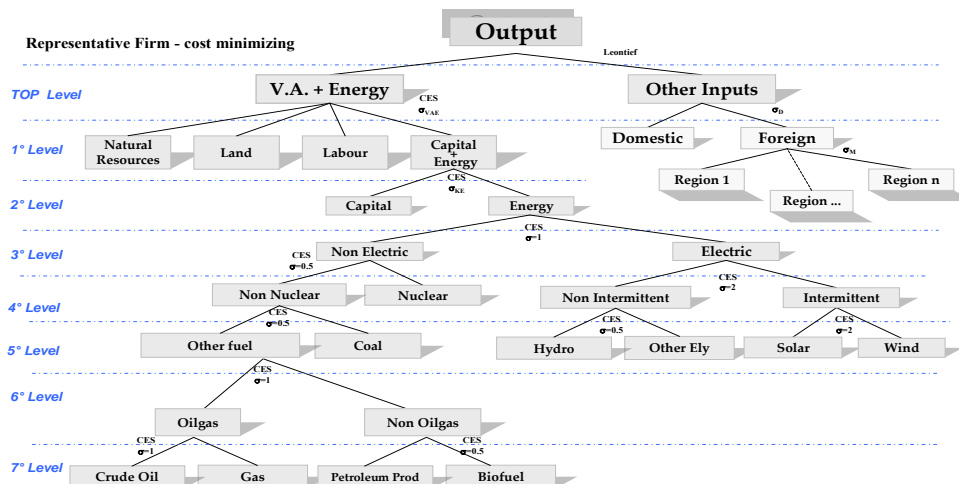
The Inter-temporal Computable Equilibrium System (ICES) model is a multi-regional recursively dynamic general equilibrium model based on the GTAP database, version 7 (Narayanan and Walmsley, 2008) and shares the core structure of the GTAP-E model (Burniaux and Troung, 2002), which in turn is an extension of the basic GTAP model (Hertel, 1997). The calibration year is 2004, which also constitutes the beginning year for simulations. The model is recursively dynamic in that each year of simulation is solved statically, but features of the period  $t-1$  are taken in account in period  $t$ .

The agents considered in each economy are  $n$  industries, a representative household and government. Industries are “typically” modelled through a representative cost-minimising firm, taking input prices as given. In turn, output prices coincide with average production costs. Each firm is characterised by a general production functions, specified via a series of nested CES functions to consider both primary factors (Natural Resources, Land, Labour and the aggregate Capital&Energy) and intermediates.

Similarly to the GTAP-E production tree, the energy inputs are isolated from intermediates and are considered as primary production factors in a nested level of substitution with capital. The purpose of drawing such a complex and nested production function is to have more degree of freedom in specifying elasticities of substitution among productive inputs. As described in Burniaux and Troung (2002), the main innovation of GTAP-E with respect to GTAP is moving away from the assumption of a Leontief relationship between the set of primary factors and the group of intermediates for commodity production. Based on strong empirical evidence, energy sources are no longer considered a perfect complement of primary factors. Rather, they are at some extent substitutes of capital stock, through a Constant of Elasticity of Substitution (CES) function.

Moreover, this version of the ICES model improves the original energy sub-tree according to Bosello *et al.* (2011) through the introduction of several energy sources not originally explicit in both database (nuclear, biofuels, wind, solar, hydro) and model. The database required the collection on physical data (International Energy Agency - Extended Energy Balances) and monetary data (EC, 2008; GTZ, 2009; IEA, 2005; IEA country profiles; Ragwitz *et al.*, 2007; REN21) for each source. The new model specification is as follows. Energy is produced using Electric and Non Electric commodities in the third level of the production function. The Non Electric commodity is produced using Nuclear and Non Nuclear commodities. The latter in turn is a combination of Coal or Other Fuels. Then, it is possible to choose between Oil&Gas and Non Oil&Gas aggregates: Oil&Gas is a composite of Oil and Gas, Non Oil&Gas includes Petroleum Products and Biofuels. The electric branch differentiates between Intermittent and Non Intermittent electricity. The former considers Solar and Wind power, the latter Hydropower and all Other Electricity typologies. Relevant intra-energy substitution elasticities come from previous literature on extended computable general equilibrium and integrated assessment models such as EPPA (Paltsev *et al.*, 2005), GTEM (Pant, 2007) and WITCH (Bosetti *et al.*, 2009).

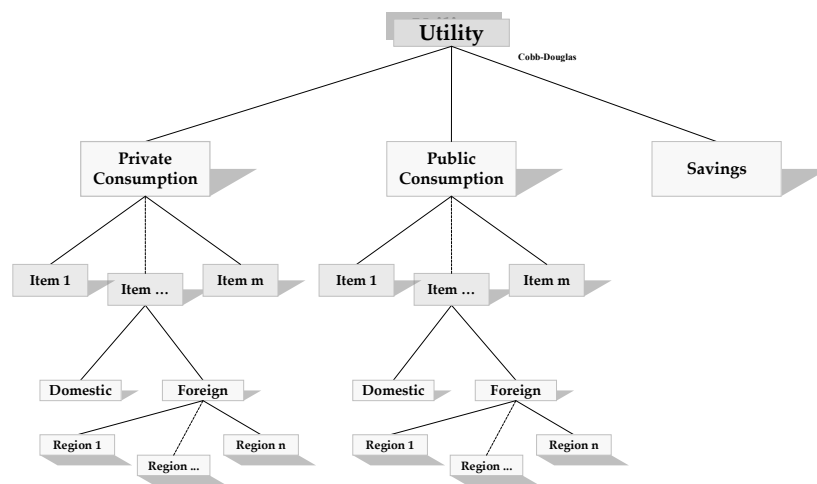
In addition, it is worth noting that domestic and foreign inputs are not perfect substitutes, according to the so-called “Armington assumption”, which accounts for - amongst others - product heterogeneity. In general, inputs grouped together are more easily substitutable among themselves than with other elements outside the nest. For example, imports can more easily be substituted in terms of foreign production source, rather than between domestic production and one specific foreign country of origin. Analogously, composite energy inputs are more substitutable with capital than with other factors.



**Figure II.1 – The ICES nested production function**

Two industries are treated in a special way and are not related to any country, namely international transport and international investment. International transport is a world industry, which produces the transportation services associated with the movement of goods between origin and destination regions, thereby determining the cost margin between f.o.b. and c.i.f. prices. Transport services are produced by means of factors submitted by all countries, in variable proportions. In a similar way, a hypothetical world bank collects savings from all regions and allocates investments in order to equalise the current rates of return.

A representative household in each region receives income, defined as the service value of national primary factors (natural resources, land, labour, capital). Capital and labour are perfectly mobile domestically but immobile internationally. Land and natural resources, on the other hand, are industry-specific. This income is then used to finance three classes of expenditure: aggregate household consumption, public consumption and savings. The expenditure shares are generally fixed, which means that the top-level utility function has a Cobb-Douglas specification.



**Figure II.2 – The ICES consumption decisional tree**

Dynamics inside the ICES model are driven essentially by two different sources: one endogenous and one exogenous to the model. The first involves two components: one, the most important, is the capital and foreign debt evolution process governed by endogenous investment decisions. The other concerns a peculiar treatment of the evolution of natural resources stock. On the other hand, there is a set of assumptions concerning the changes in some key economic - mainly supply-side - parameters and exogenous variables, which are imposed to the model in order to reflect their possible evolution. These assumptions are made consistently with existing statistical sources, other modelling exercises and economic scenarios.

## ANNEX III – REGIONAL AND SECTORAL AGGREGATION

Table III.1 - Sector detail

No.	Sectors
1	Food
2	Forestry
3	Fishing
4	Coal
5	Oil
6	Gas
7	Petroleum Products
8	Other Electricity
9	Renewables
10	Nuclear
11	Biofuels
12	Energy Intensive Industries
13	Other Industries
14	Water
15	Market Services
16	Public Services
17	R&D
18	Education
19	Private Health
20	Public Health

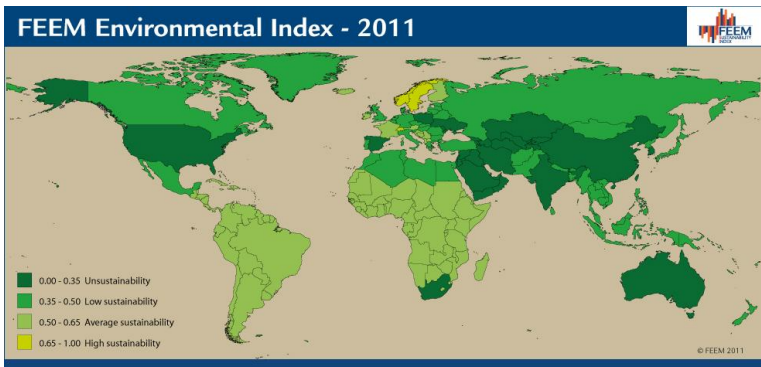
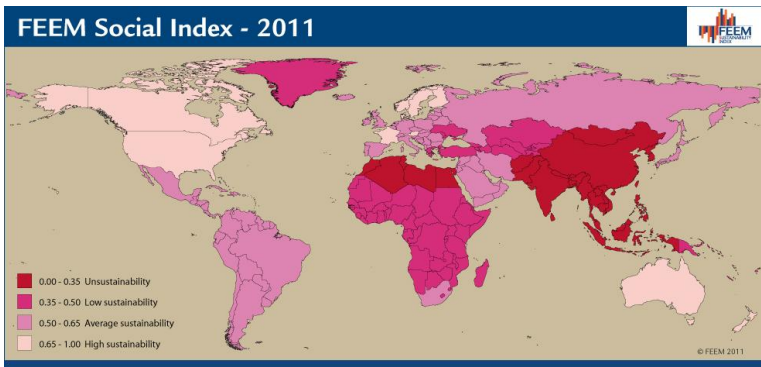
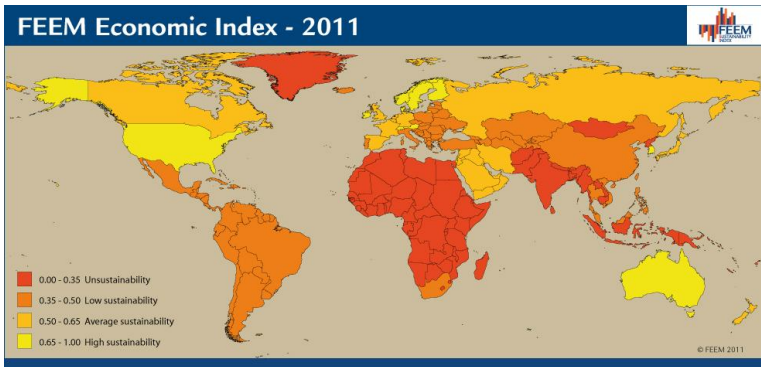
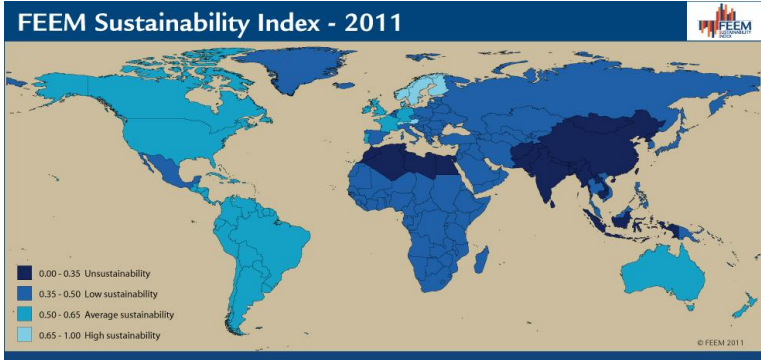


**Table III.2 - Regional aggregation**

No.	Macro-Regions	Countries
1	<b>Australia</b>	Australia
2	<b>NewZealand</b>	New Zealand
3	<b>Japan</b>	Japan
4	<b>Korea</b>	Korea
5	<b>China</b>	China, Hong Kong, Taiwan
6	<b>India</b>	Indonesia
7	<b>Indonesia</b>	India
8	<b>SEastAsia</b>	Malaysia, Philippines, Singapore, Thailand, Vietnam
9	<b>RoAsia</b>	Afghanistan, Bangladesh, Bhutan, Brunei Darassalam, Cambodia, Democratic Republic of Korea, Lao People's Democratic Republic, Macau, Maldives, Mongolia, Myanmar, Nepal, Pakistan, Sri Lanka, Timor Leste
10	<b>USA</b>	USA
11	<b>Canada</b>	Canada
12	<b>Mexico</b>	Mexico
13	<b>Brazil</b>	Brazil
14	<b>RoLA</b>	Argentina, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Falkland Islands (Malvinas), French Guiana, Guyana, Suriname, Costa Rica, Guatemala, Nicaragua, Panama, Belize, El Salvador, Honduras, Saint Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos, Anguilla, Antigua & Barbuda, Aruba, Bahamas, Barbados, Cayman Islands, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Haiti, Jamaica, Martinique, Montserrat, Netherlands Antilles, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Virgin Islands (British), Virgin Islands (U.S.)
15	<b>Austria</b>	Austria
16	<b>Benelux</b>	Belgium, Luxembourg, Netherlands
17	<b>Denmark</b>	Denmark
18	<b>Finland</b>	Finland
19	<b>France</b>	France
20	<b>Germany</b>	Germany
21	<b>Greece</b>	Greece
22	<b>Ireland</b>	Ireland
23	<b>Italy</b>	Italy
24	<b>Poland</b>	Poland
25	<b>Portugal</b>	Portugal
26	<b>Spain</b>	Spain
27	<b>Sweden</b>	Sweden
28	<b>UK</b>	UK
29	<b>RoEU</b>	Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Malta, Slovakia, Slovenia, Bulgaria, Romania
30	<b>Switzerland</b>	Switzerland
31	<b>Norway</b>	Norway
32	<b>RoEurope</b>	Albania, Andorra, Bosnia and Herzegovina, Croatia, Faroe Islands, Gibraltar, Iceland, Liechtenstein, Macedonia, the former Yugoslav Republic of, Monaco, San Marino, Serbia and Montenegro
33	<b>Russia</b>	Russia
34	<b>RoFSU</b>	Belarus, Ukraine, Moldova, Republic of, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Armenia, Azerbaijan, Georgia
35	<b>Turkey</b>	Turkey
36	<b>MiddleEast</b>	Bahrain, Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Occupied Palestinian Territory, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen
37	<b>NorthAfrica</b>	Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Tunisia
38	<b>RoAfrica</b>	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Mozambique, Niger, Nigeria, Reunion, Rwanda, Saint Helena, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe
39	<b>SouthAfrica</b>	SouthAfrica
40	<b>RoWorld</b>	American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, Federated States of, Nauru, New Caledonia, Norfolk Island, Northern Mariana Islands, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Island of Wallis and Futuna, Bermuda, Greenland, Saint Pierre and Miquelon

## ANNEX IV – Rankings and maps by dimension in 2011

Country	Economic	Country	Social	Country	Environmental	Country	FEEMSI
Switzerland	0.766	Norway	0.985	Norway	0.718	Norway	0.823
Korea	0.761	Sweden	0.922	Sweden	0.664	Sweden	0.774
Norway	0.752	Canada	0.845	Switzerland	0.661	Switzerland	0.700
Australia	0.737	Denmark	0.837	RoEurope	0.625	Austria	0.691
Sweden	0.728	NewZealand	0.829	Austria	0.623	Finland	0.661
USA	0.725	Finland	0.799	Brazil	0.597	Denmark	0.653
Austria	0.700	USA	0.790	RoLA	0.585	Canada	0.641
Finland	0.686	France	0.789	Ireland	0.528	France	0.630
Ireland	0.666	Austria	0.755	RoAfrica	0.523	Ireland	0.620
Denmark	0.663	Australia	0.734	Finland	0.512	NewZealand	0.609
Germany	0.617	Ireland	0.683	France	0.509	USA	0.554
Benelux	0.611	Switzerland	0.668	Canada	0.499	Australia	0.553
NewZealand	0.591	Mexico	0.656	RoEU	0.487	Brazil	0.546
Russia	0.586	Portugal	0.646	RoAsia	0.477	UK	0.531
France	0.584	Germany	0.618	Denmark	0.469	RoEurope	0.529
Japan	0.581	SouthAfrica	0.612	UK	0.451	Germany	0.525
UK	0.577	Brazil	0.603	Portugal	0.449	Portugal	0.522
Spain	0.575	Spain	0.597	Turkey	0.448	RoLA	0.512
Canada	0.566	UK	0.582	Italy	0.446	Spain	0.497
MiddleEast	0.558	RoLA	0.570	RoWorld	0.445	Benelux	0.495
RoEU	0.491	Italy	0.559	SEastAsia	0.440	Russia	0.493
Poland	0.463	MiddleEast	0.543	Japan	0.420	RoEU	0.493
Portugal	0.458	Poland	0.538	Indonesia	0.419	Mexico	0.492
China	0.455	RoEurope	0.519	NewZealand	0.411	Korea	0.477
SouthAfrica	0.454	Russia	0.511	Greece	0.402	Italy	0.472
Brazil	0.446	RoEU	0.499	Benelux	0.396	Japan	0.456
Mexico	0.435	Turkey	0.491	Russia	0.393	Turkey	0.453
RoEurope	0.433	RoFSU	0.482	NorthAfrica	0.385	MiddleEast	0.450
Turkey	0.417	Benelux	0.480	Mexico	0.374	Poland	0.430
Italy	0.404	Greece	0.439	Germany	0.372	SouthAfrica	0.426
RoLA	0.392	RoWorld	0.405	Spain	0.347	Greece	0.399
SEastAsia	0.390	RoAfrica	0.378	India	0.328	RoAfrica	0.398
RoFSU	0.386	Japan	0.351	Korea	0.312	RoWorld	0.385
Greece	0.354	Korea	0.330	Poland	0.304	SEastAsia	0.368
NorthAfrica	0.350	NorthAfrica	0.285	MiddleEast	0.283	RoFSU	0.367
Indonesia	0.331	SEastAsia	0.261	Australia	0.251	NorthAfrica	0.342
RoWorld	0.306	China	0.260	RoFSU	0.244	RoAsia	0.325
India	0.301	RoAsia	0.185	SouthAfrica	0.230	Indonesia	0.299
RoAsia	0.285	Indonesia	0.127	USA	0.210	China	0.287
RoAfrica	0.279	India	0.077	China	0.147	India	0.240



### ANNEX V - Sustainability ranking (2020: SD policy vs baseline)

Rank Baseline	Country	FEEM SI Baseline	Δ Rank	FEEM SI SD	Country	Rank SD policy
1	Norway	0.846	=	0.857	Norway	1
2	Sweden	0.814	=	0.827	Sweden	2
3	Austria	0.736	=	0.746	Austria	3
4	Switzerland	0.695	-2	0.700	Canada	4
5	Finland	0.684	=	0.695	Finland	5
6	Denmark	0.676	-1	0.690	Switzerland	6
7	Canada	0.665	3	0.688	Denmark	7
8	France	0.648	-1	0.660	NewZealand	8
9	NewZealand	0.633	1	0.650	France	9
10	Ireland	0.622	=	0.628	Ireland	10
11	Germany	0.581	-1	0.602	Australia	11
12	Australia	0.576	1	0.597	Germany	12
13	Benelux	0.558	-2	0.581	Brazil	13
14	UK	0.547	-2	0.577	USA	14
15	Brazil	0.544	2	0.558	Benelux	15
16	RoEurope	0.537	-5	0.551	UK	16
17	USA	0.534	3	0.536	RoEU	17
18	RoLA	0.526	-1	0.534	Portugal	18
19	Portugal	0.526	1	0.530	RoLA	19
20	RoEU	0.514	3	0.517	Russia	20

Rank Baseline	Country	FEEM SI Baseline	Δ Rank	FEEM SI SD	Country	Rank SD policy
21	Spain	0.500	-3	0.516	RoEurope	21
22	Italy	0.499	-1	0.510	Mexico	22
23	Korea	0.493	-2	0.509	Italy	23
24	Japan	0.493	-2	0.509	Spain	24
25	Mexico	0.483	3	0.507	Korea	25
26	Russia	0.481	6	0.506	Japan	26
27	Turkey	0.476	-3	0.489	SouthAfrica	27
28	MiddleEast	0.465	-1	0.474	Poland	28
29	Poland	0.437	1	0.464	MiddleEast	29
30	SouthAfrica	0.429	3	0.455	Turkey	30
31	Greece	0.426	=	0.437	Greece	31
32	RoAfrica	0.401	=	0.416	RoAfrica	32
33	RoWorld	0.390	=	0.375	RoWorld	33
34	SEastAsia	0.364	=	0.371	SEastAsia	34
35	RoFSU	0.356	-3	0.354	RoAsia	35
36	NorthAfrica	0.342	-1	0.354	Indonesia	36
37	RoAsia	0.339	2	0.345	NorthAfrica	37
38	China	0.323	-1	0.323	RoFSU	38
39	Indonesia	0.321	3	0.318	China	39
40	India	0.291	=	0.304	India	40

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