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In·Stream

Compounding Sustainability in a Single Measure. The Role of Energy-related Indicators.

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The idea within INSTREAM

(a) suggesting a “new” use of indicators and of existing widely used modelling tools → Building and computing a sustainability index within the framework offered by an economic (CGE) model

Testing with this approach:

- To what extent sustainability could be measured *ex-ante* and not only ex-post.
- the advantages of having all the different dimensions of sustainability (measurable by the model) “connected” and mutually consitent.
- the advantages to work in a controlled environment where it can be easier to perform quantitative assessments and evaluations (sensitivity).

In addition: if and how much the FSI moves beyond GDP (even though GDP is certainly one of its components).

Novelty compared with previous exercise

Following comments from the advisory board during the Bath quantitative workshop:

Enrichment of the socal dimension of the indicator (new “tree”).

Analysis of sustainability performance per country/region in the context of a climate policy.

Inclusion of sensitivity analysis on “experts” opinions.

The model used: ICES

- ✓ It is a dynamic, multi-regional CGE model of the world economy, based on country and region-specific Social Accounting Matrices (SAM). These describe trade, supply and demand flows to and for all the regions and sectors represented.

- ✓ The model is calibrated in 2001, data are provided by GTAP6 database. The present version offers a detail of 40 countries/macro-regions and 17 economic sectors.

- ✓ It replicates a specific “reference scenario” until 2020 (agreed as common benchmark among INSTREAM partners to allow comparability with other modelling exercises).

Sustainability measured by the composite indicator is assessed in the reference and in the policy scenario

Building steps for the index → FSI

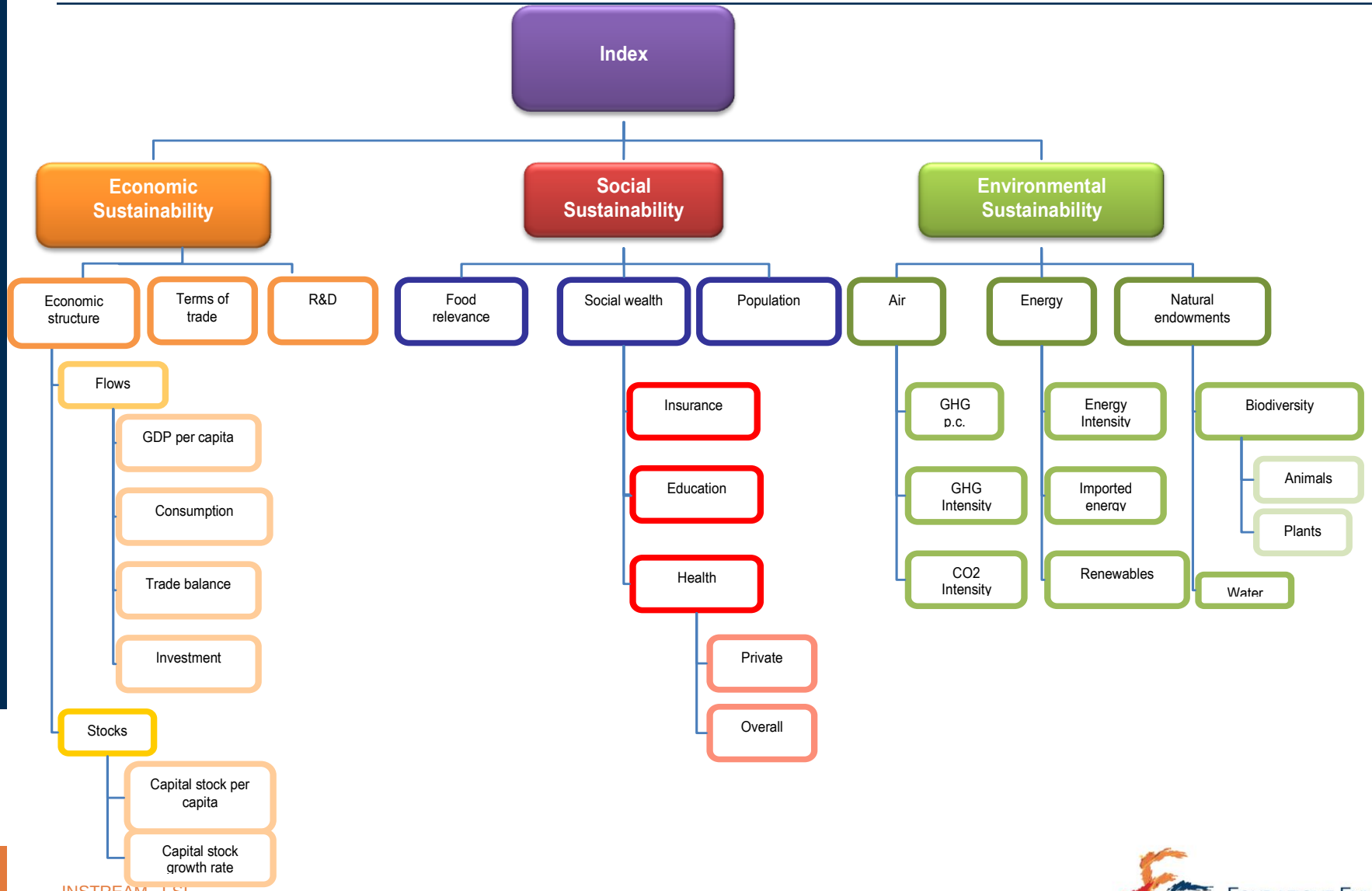
1. **Selection of indicators**
   Based on the list decided within the INSTREAM research team and compatible with model capabilities.

2. **Construction/calculation of indicators**
   Starting from the output of the ICES model (in the baseline and policy case).

3. **Normalization of indicators**
   Following a policy-oriented benchmarking procedure in order to achieve full comparability of across indicators

4. **Aggregation of indicators**
   Condensing information into a single index using a methodology that exploits interactions between indicators.

1. Selection of indicators (23)



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2. Definition/Calculation of indicators from the CGE model

SD Dimension	INDICATORS	DESCRIPTION
Economic	*GDP per capita*	GDP PPP / population
	Consumption per capita	Consumption expenditure PPP / population
	Relative trade Balance	Trade Balance / market openness *100
	Capital stock per capita	Capital stock PPP/ population
	Capital stock growth rate	(Capital stock(t) - Capital stock(t-1))/ Capital stock(t-1) *100
	Investment as %GDP	Investment / GDP*100
	Terms of trade	Value of export / Value of imports
	Total R&D expenditure as %GDP	R&D expenditure / GDP *100
Environmental	*Energy Intensity*	Energy Use / GDP PPP (Toe/ ml$)
	Greenhouse gases emission per capita	$N_2O+CH_4+CO_2$ emissions / Population (Tons CO2 eq. per capita)
	Greenhouse gases Intensity	$N_2O+CH_4+CO_2$ emissions / GDP PPP (Tons CO2 eq/ml $)
	CO_2 intensity	CO_2 emissions / Energy consumption (Tons CO2 eq/ Toe)
	Share of Energy imported	Energy imported/total energy consumption (Toe/Toe)
	Share of Renewable	Renewable energy consumption/ Total energy consumption (Toe/Toe)
	Plant biodiversity	Endangered plants/ total plants*100
	Animal biodiversity	Endangered animals/ total animals*100
	Water	Water use/ water available
Social	*Population growth rate*	Population growth rate
	Food consumption	Food consumption / Private expenditure*100
	Insurance	Insurance expenditure/ GDP *100
	Education	Education expenditure/ GDP *100
	Private health expenditure	Private health expenditure/ Total health expenditure*100
	Total health expenditure	Total health expenditure/GDP*100

3. Normalisation of indicators

- ✓ Use of a benchmarking normalisation technique → Each indicator is rescaled in the interval 0-1

0	extremely unsustainable situation
0.25	indicator is still not sustainable but not as severely as in the previous case
0.50	a discrete level of sustainability, but still far from target
0.75	satisfactory level in the sustainability, yet not on target
1	target level, fully sustainable

- ✓ Benchmarks are policy-oriented when possible. When not, the threshold values characterizing each interval are calibrated on World performances

- ✓ Each step has been “linearised”, taking the mean values of two subsequent intervals and interpolating, thereby creating a continuous function.

4. Aggregation of indicators: weighting

Weights are the result of a “expert’” evaluations (via interviews)

→Expert assigned a weight to all possible combination of indicators in each node satisfing monotonicity

→The Möbius transformation accounts for synergic and redundancy interactions among elements in the coalition. If the Möbius weight is null, no interaction exists among the element of the subset, if it is positive there is a synergy, if negative, a redundancy.

SUSTAINABILITY			Weights	Normalized weights	Möbius transformation
Economic	Social	Environment			
Worst	Worst	Worst	0	0	0
Best	Worst	Worst	20	0.2	0.2
Worst	Best	Worst	50	0.5	0.5
Worst	Worst	Best	30	0.3	0.3
Best	Best	Worst	60	0.6	0.6-(0.2+0.5)=-0.1
Best	Worst	Best	50	0.5	0.5-(0.2+0.3)=0
Worst	Best	Best	90	0.9	0.9-(0.5+0.3)=0.1
Best	Best	Best	100	1	1

→ The Choquet integral, is a generalization of Weighted Average approach, can be directly calculated using the Möbius values as weights.

$$C_m(x_1,\dots,x_n)=\sum_{T\subseteq S} a(T)\cdot \min_{i\in T}(x_i)$$

Contribution of indicators to index

Indicator	Contribution
Food relevance	12.22%
Population	9.72%
R&D	9.21%
Water	8.26%
Terms of trade	5.67%
Energy intensity	4.91%
Renewables	4.26%
Education	4.18%
Imported energy	3.93%
CO2 intensity	3.83%
Plants	3.55%
GHG intensity	3.32%
Capital stock per capita	3.23%
Animals	3.21%
Overall health	3.08%
GHG per capita	3.07%
GDP p.c.	2.69%
Insurance	2.47%
Consumption	2.29%
Capital stock growth rate	2.15%
Investment	1.91%
Private health	1.66%
Relative trade balance	1.18%
Sum	100%

- ✓ The Shapley index describes the relative importance of each indicators or node in the FSI tree
- ✓ It explicits the weights given by the decision makers to each single indicators or node.

Index	Economic Sustainability	28.33%
	Social Sustainability	33.33%
	Environmental Sustainability	38.33%

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Sustainability in the reference scenario

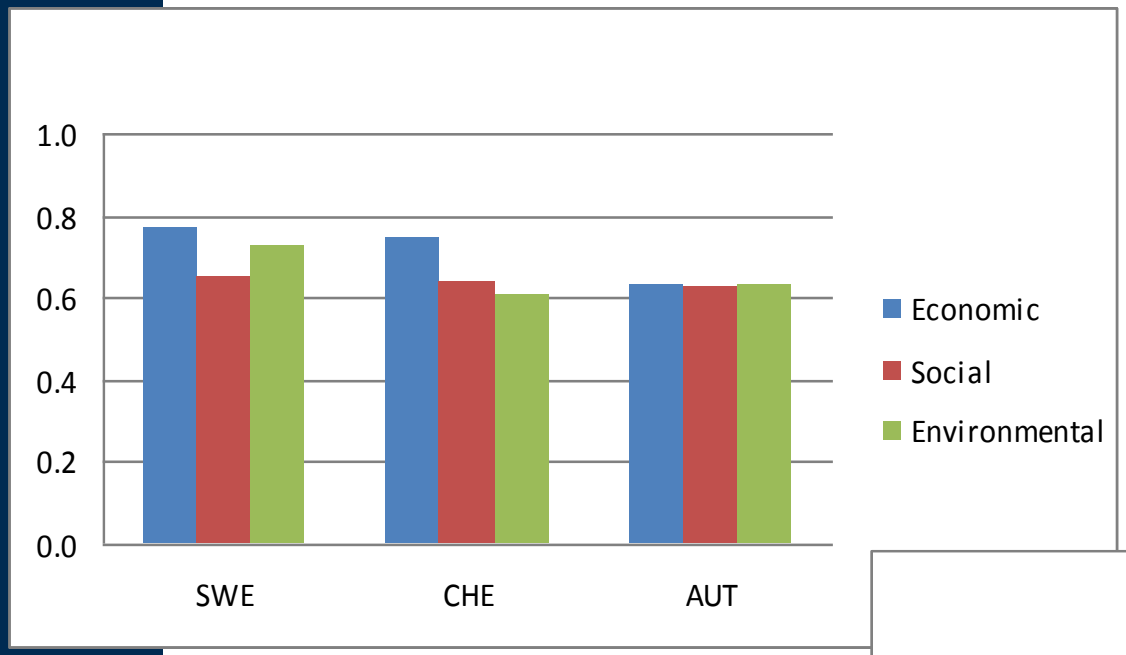
Top ten in 2010

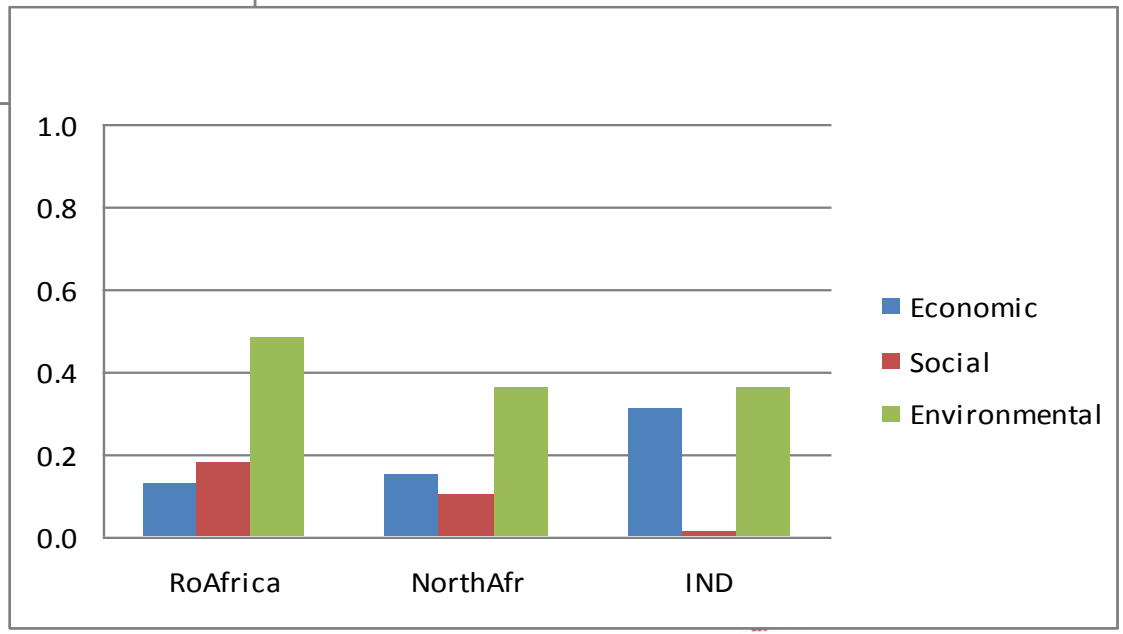
Regions	FSI 2010	Rank	GDP pc 2010	Regions
SWE	0.68	=	1.00	SWE
SWZ	0.63	-2	1.00	DNK
AUT	0.63	-4	1.00	USA
FIN	0.62	-4	0.98	SWZ
GBR	0.58	-1	0.98	BNLX
FRA	0.57	-7	0.96	GBR
DNK	0.56	5	0.91	AUT
CAN	0.56	-1	0.90	FIN
JPN	0.56	-5	0.88	CAN
GER	0.55	-2	0.79	AUS

Bottom ten in 2010

Regions	FSI 2010	Rank	GDP pc 2010	Regions
POL	0.31	9	0.19	RoLA
BUL	0.29	4	0.17	SEA
RoLA	0.28	2	0.17	RoE
FSU	0.27	=	0.16	FSU
TUR	0.27	9	0.14	CHN
CHN	0.26	1	0.14	NorthAfr
MEast	0.23	7	0.12	RoAsia
RoAfrica	0.21	-2	0.09	IDN
NorthAfr	0.16	3	0.08	IND
IND	0.14	1	0.00	RoAfrica

Top three countries (Left) and bottom three (Right) 2010





Comparison among different aggregation methodologies

Comparison between the top ten performers in FSI in 2010 with:

- FSI_23 which equally weights all indicators (1/23).
- FSI_3 which equally weights indicators in each node, which implies a weight of 1/3 for each of the three pillars of sustainability and 1/n (n number of indicators in the node) for each node.

Region	FSI		FSI 23	Region
SWE	0.68	=	0.74	SWE
SWZ	0.63	=	0.70	SWZ
AUT	0.63	-3	0.68	FIN
FIN	0.62	1	0.68	DNK
GBR	0.58	-3	0.66	NOR
FRA	0.57	-4	0.65	AUT
DNK	0.56	3	0.64	CAN
CAN	0.56	1	0.64	GBR
JPN	0.56	=	0.64	JPN
GER	0.55	-1	0.62	FRA

Region	FSI		FSI3	Region
SWE	0.68	=	0.76	SWE
SWZ	0.63	-1	0.72	FIN
AUT	0.63	-4	0.72	SWZ
FIN	0.62	2	0.70	DNK
GBR	0.58	-6	0.68	JPN
FRA	0.57	-3	0.66	NOR
DNK	0.56	3	0.65	AUT
CAN	0.56	=	0.65	CAN
JPN	0.56	4	0.63	FRA
GER	0.55	=	0.63	GER

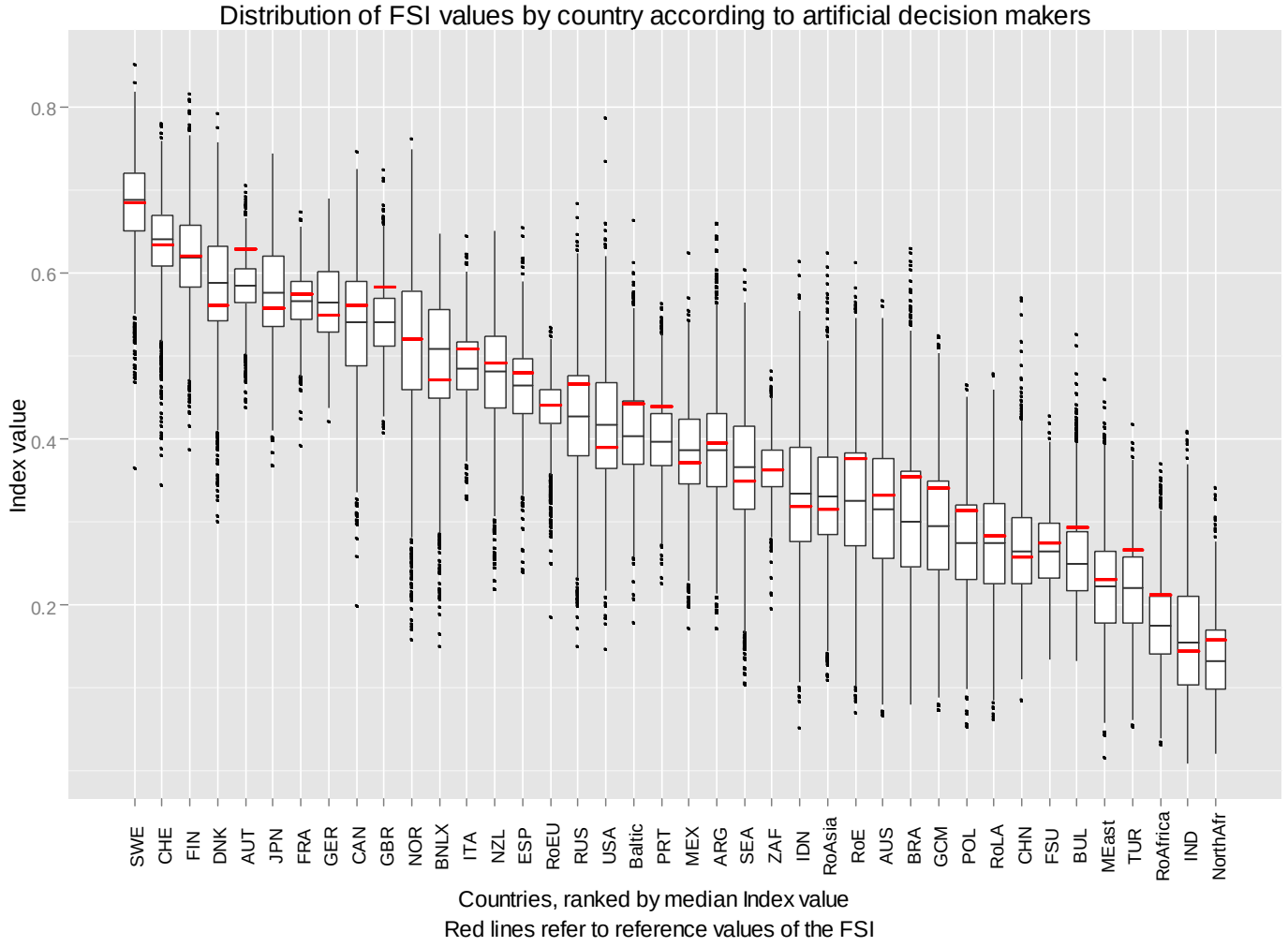
Sensitivity and robusteness

→ To introduce some variability in the determination of subjective weights, a set of 2000 artificial decision makers was generated, in order to simulate the aggregation of the indicators into the FSI using alternative evaluations.

→ Each decision maker provides a set of measures which varies within an interval of +/- 10% with respect to the weights in the original FSI.

→ Variation in the measures set corresponds to a more or less compensative behaviour in terms of willingness to reward lower or higher homogeneous performance of indicators.

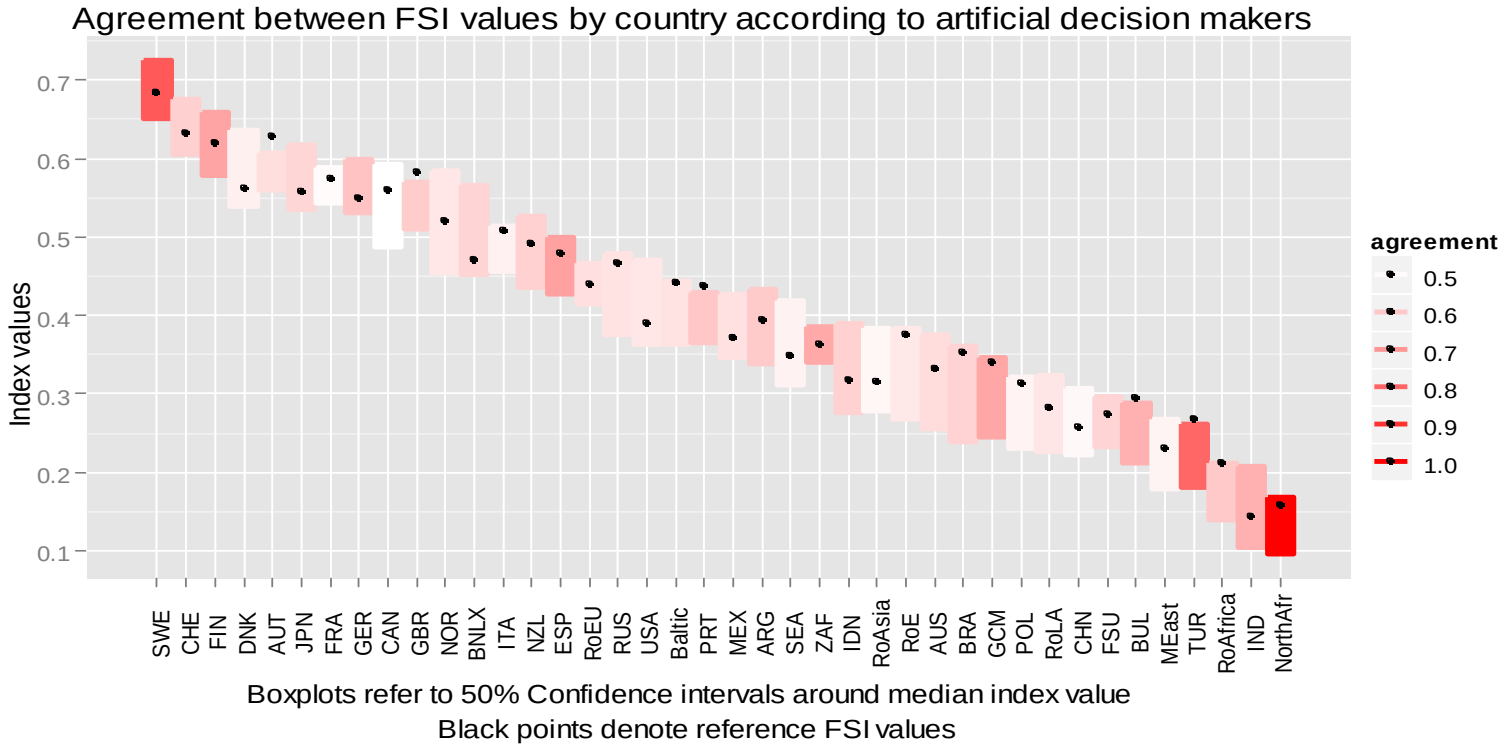
→ Artificial decision makers are given an arbitrarily large freedom in providing unbiased weights of criteria and coalitions of criteria for every node of the FSI tree, while making sure that they supply meaningful and sensible results.


Distribution of FSI values by country according to artificial decision makers
Index value
0.8
0.6
0.4
0.2
SWE
CHE
FIN
DNK
AUT
JPN
FRA
GER
CAN
GBR
NOR
BNLX
ITA
NZL
ESP
RoEU
RUS
USA
Baltic
PRT
MEX
ARG
SEA
ZAF
IDN
RoAsia
RoE
AUS
BRA
GCM
POL
RoLA
CHN
FSU
BUL
MEast
TUR
RoAfrica
IND
NorthAfr
Countries, ranked by median Index value
Red lines refer to reference values of the FSI

Robustness ranking

→ The individual effect tends to be homogeneous across countries, the measure of agreement of decision makers with respect to the median ranking can be determined.

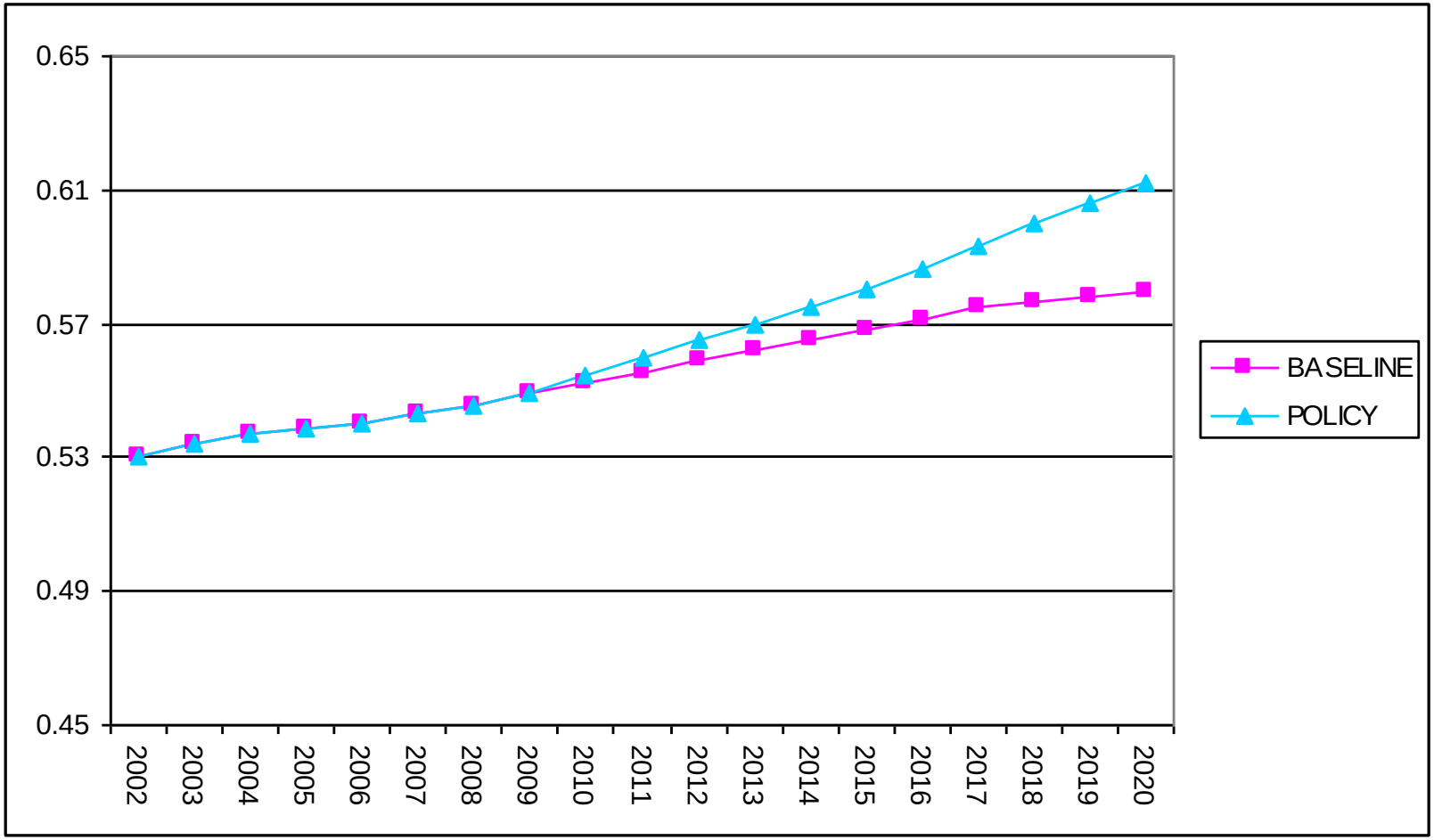
→ This is summarized in a single number for each country represented by the share of "artificial experts" agreeing that a country is more sustainable than the next one in the ranking (This measure would take a value of 1 if there is perfect agreement or 0.5 if only 50% of them agree that a given country is better than the next)



Sustainability in a climate-change mitigation policy

- A climate policy is implemented, which requires a reduction of 20% of greenhouse gas emissions in Europe in 2020 with respect to 1990 levels.
- No reduction in other countries/regions.
- An EU-ETS system works, so that countries with a carbon target can trade with each other within Europe (unique carbon price and max efficiency).
- The cap is imposed starting in 2010 and increases to 2020, when the overall targets are met.
- This allows us to assess how sustainability could change over time if Europe is engaged in this policy, and what tradeoffs would be created between the different sustainability pillars.

FSI performace in the EU



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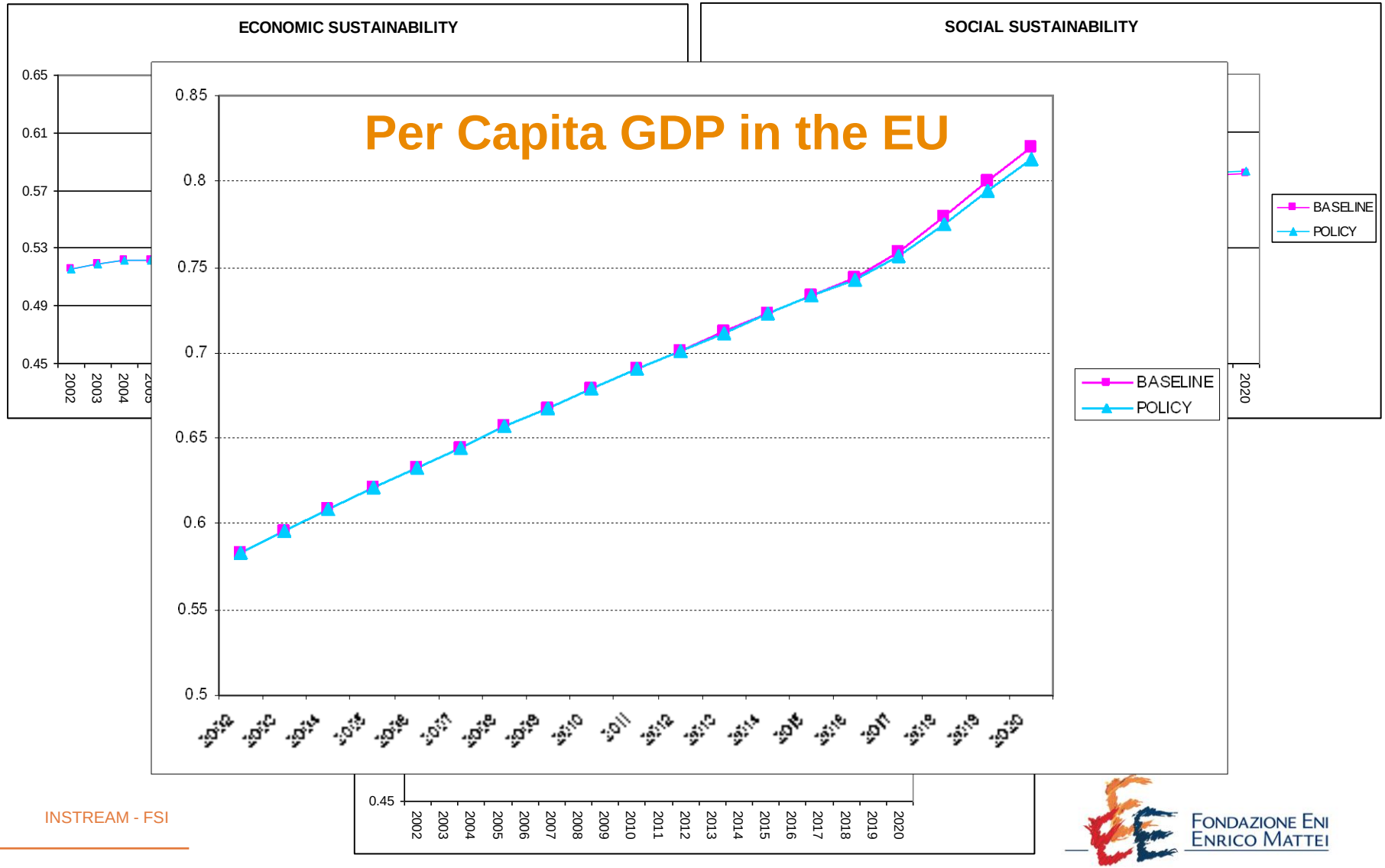
Economic, Social and Environmental pillars in the EU



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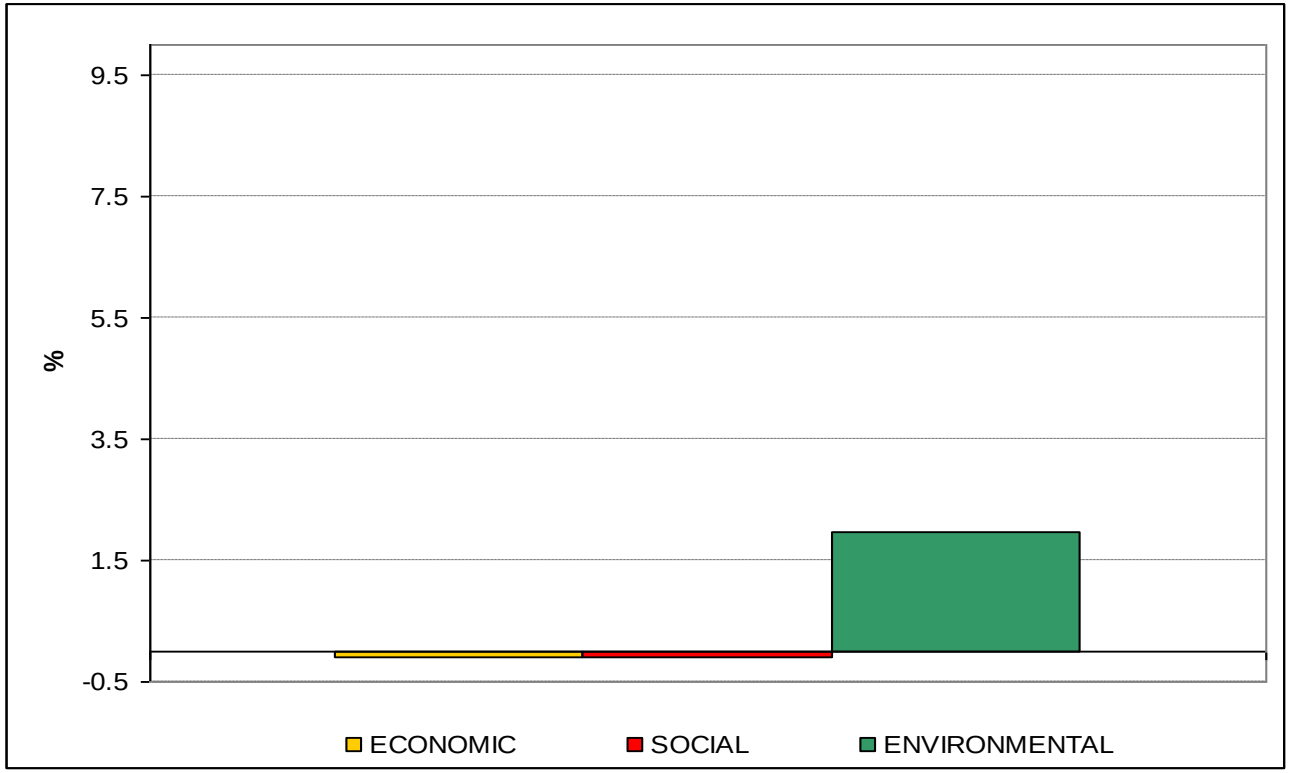
Economic, Social and Environmental pillars globally (2020)



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Conclusions

- The FSI performs differently than GDP and provides additional information => its informative content is different not only in terms of ranking, but also in terms of measuring progresses toward sustainability (“1 vs 0.6”)

- The FSI embeds a quite strong idea of non-substitutability between different components. This can be appropriately captured only with non additive weighting (judgments on combinations of indicators).

- Using CGE (but not necessarily only CGE) models to address the issue of sustainability can offer an important and additional tool to the study of sustainability and to the evaluation of policy effects on it.

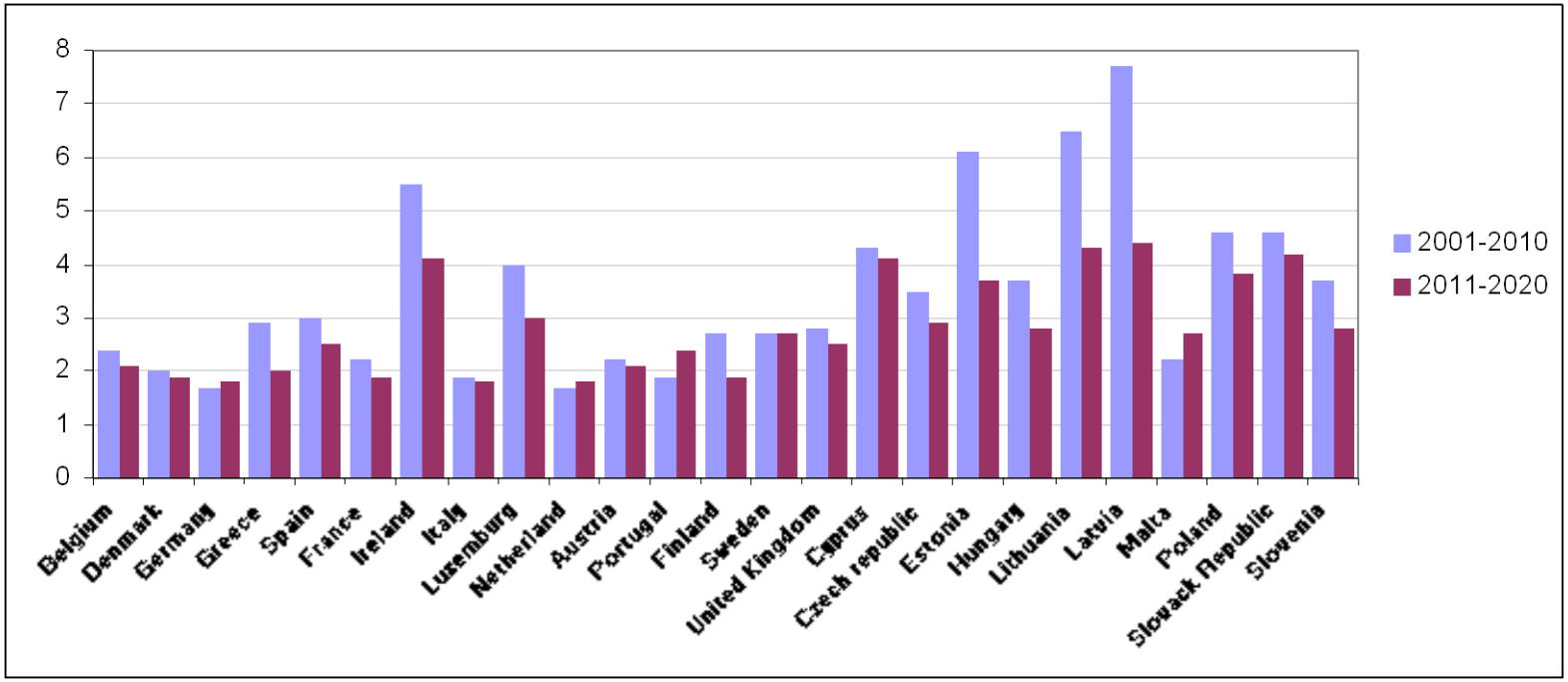
- However the weaknesses of sustainability measures (uncertainty + subjectivity) sum up to those of the modelling tools…

FSI ranking 2020 baseline and policy

Region	2020 base	Rank	2020 policy	Region
SWE	0.69	=	0.69	SWE
AUT	0.65	=	0.67	AUT
SWZ	0.64	-1	0.64	FIN
FIN	0.63	1	0.64	SWZ
GBR	0.62	=	0.63	GBR
FRA	0.60	-1	0.60	GER
CAN	0.58	-2	0.60	FRA
GER	0.58	2	0.60	DNK
DNK	0.57	1	0.58	CAN
JPN	0.57	=	0.56	JPN
NOR	0.54	-1	0.55	ITA
ITA	0.54	1	0.54	NOR
NZL	0.51	-2	0.54	BNLX
BNLX	0.51	1	0.53	ESP
ESP	0.50	1	0.51	NZL
RUS	0.50	-1	0.51	RoEU
PRT	0.47	-1	0.50	RUS
Baltic	0.46	-1	0.49	PRT
RoEU	0.45	3	0.46	Baltic
SEA	0.42	-1	0.42	GCM
RoE	0.41	-1	0.41	SEA
GCM	0.40	2	0.40	RoE
USA	0.40	=	0.39	USA
BRA	0.39	=	0.39	BRA
MEX	0.39	=	0.38	MEX
ZAF	0.38	-2	0.38	POL
AUS	0.38	=	0.38	AUS
ARG	0.37	-1	0.37	ZAF
IDN	0.36	-1	0.36	ARG
TUR	0.35	-1	0.36	IDN
POL	0.35	5	0.35	TUR
BUL	0.33	=	0.34	BUL
RoAsia	0.32	=	0.32	RoAsia
RoLA	0.31	=	0.31	RoLA
CHN	0.28	=	0.28	CHN
FSU	0.24	=	0.25	FSU
MEast	0.24	=	0.24	MEast
RoAfrica	0.22	=	0.22	RoAfrica
NorthAfr	0.18	=	0.17	NorthAfr
IND	0.15	=	0.15	IND

The reference scenario

Imposed GDP growth rates (%) for the EU



Source: EC DG EDFA (2006)

That of non EU aggregates grows ½ of IPCC SRES B2 scenario

Oil Prices %	2010	2020		Gas Prices %	2010	2020		Coal Prices %	2010	2020
ICES-FCI (IEO 2008)	31.60	77.88		ICES-FCI (IEO 2008)	14.25	38.05		ICES-FCI (IEO 2008)	1.44	5.14

Background

- Sustainable development is usually defined by 3 “pillars”: economic, environmental and social. Each of them comprises different indicators related to each specific domain.

- Due to this inctrinsic multidimensionality, a common way to measure or represent sustainability is the use of wide theme-based indicator sets (see e.g. World Bank with its 400 WDIs, WHO with its 600 EHIs etc.)

- An “index” aggregates a set of indicators summarizing a complex phenomenon. Indices have several positive aspects; they allow summarizing the relationship among the variables and facilitate communication to decision makers.
  - ✓ For example: aggregate (e.g. ecological or water footprint) or composite (e.g. HDI from the UNDP) indicators

The ICES model: Spatial detail (this study)

Australia	Canada	Greece	Norway
NewZealand	Mexico	Ireland	RoEurope
Japan	Brazil	Italy	Russia
Korea	RoLA	Poland	RoFSU
China	Austria	Portugal	Turkey
India	Benelux	Spain	MiddleEast
Indonesia	Denmark	Sweden	NorthAfrica
SEastAsia	Finland	UK	RoAfrica
RestofAsia	France	RoEU	SouthAfrica
USA	Germany	Switzerland	RoWorld