Are hybrid models well equipped to assess resilience to external shocks?
The case of energy and climate

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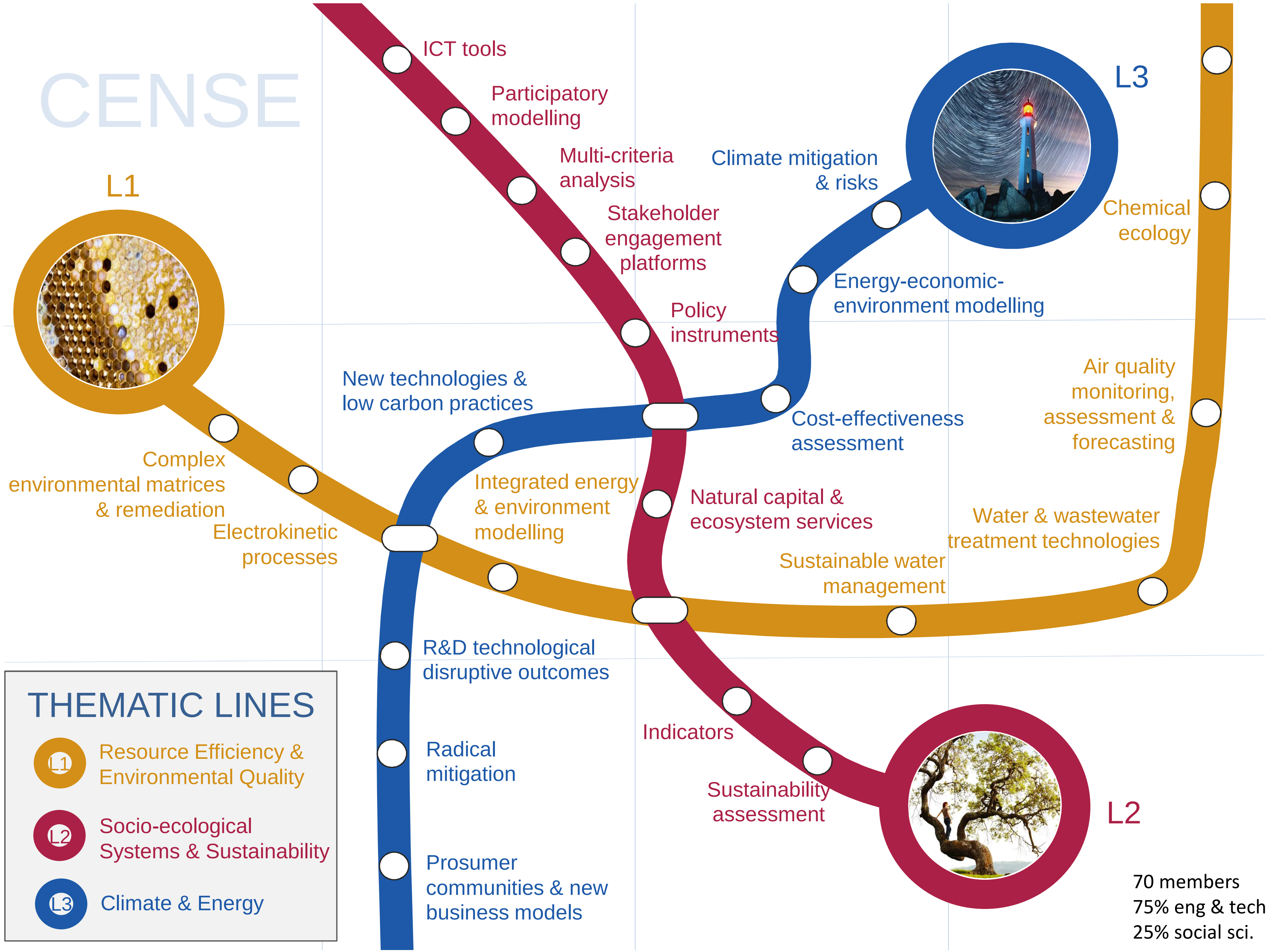

CENSE
L1
L2
L3
ICT tools
Participatory modelling
Multi-criteria analysis
Stakeholder engagement platforms
Policy instruments
Natural capital & ecosystem services
Indicators
Sustainability assessment
Climate mitigation & risks
Energy-economic-environment modelling
Cost-effectiveness assessment
New technologies & low carbon practices
Integrated energy & environment modelling
R&D technological disruptive outcomes
Radical mitigation
Prosumer communities & new business models
Complex environmental matrices & remediation
Electrokinetic processes
Sustainable water management
Water & wastewater treatment technologies
Air quality monitoring, assessment & forecasting
Chemical ecology
THEMATIC LINES
L1 Resource Efficiency & Environmental Quality
L2 Socio-ecological Systems & Sustainability
L3 Climate & Energy
70 members
75% eng & tech
25% social sci.

AGENDA

I. Low Carbon Energy and Climate are shocks for the economies?

II. Modeling energy and climate: bottom-up TIMES_PT models and top-down GEM-E3_PT

III. Hybrid modeling tool for the Portuguese case

IV. Final remarks

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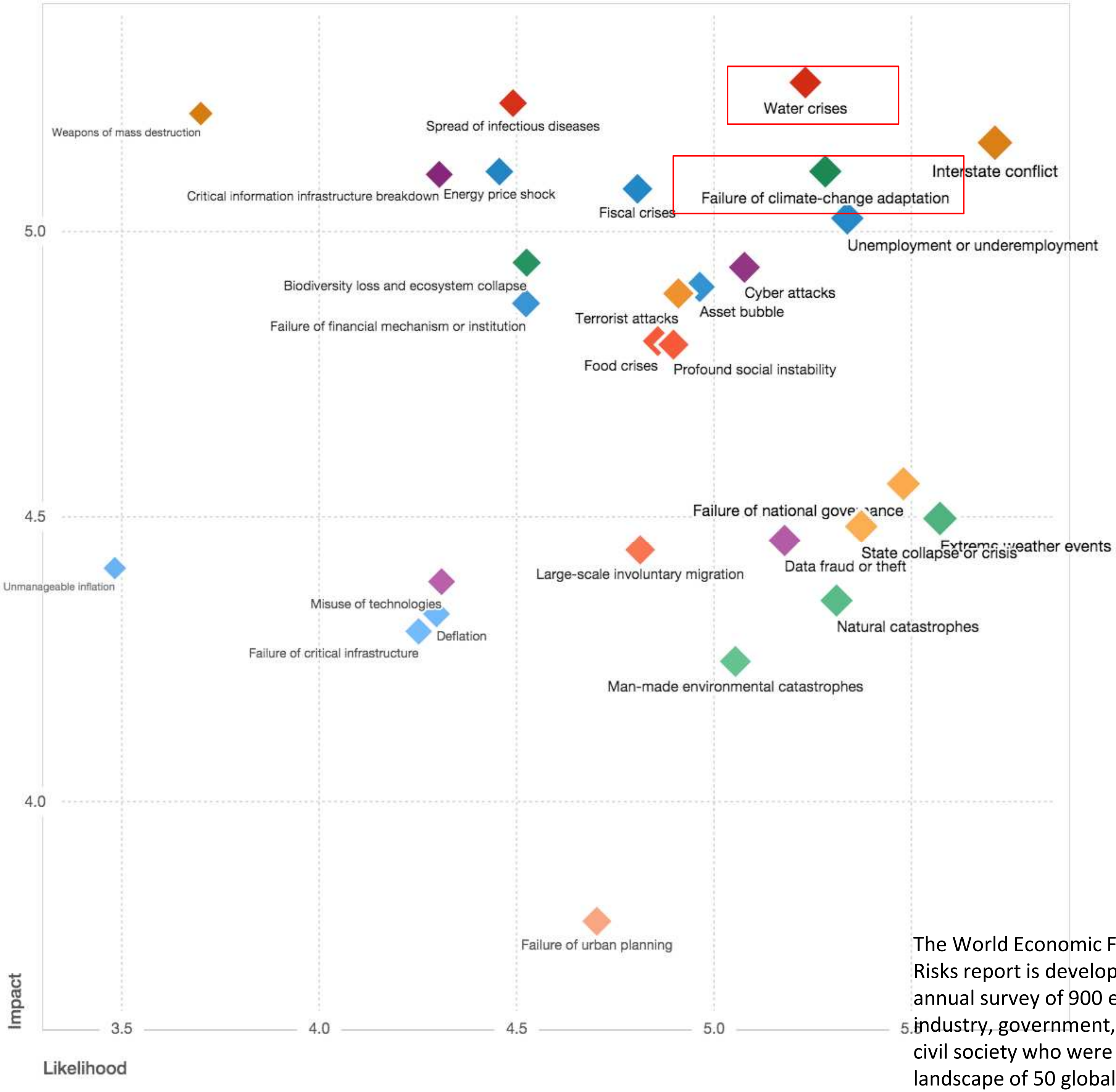
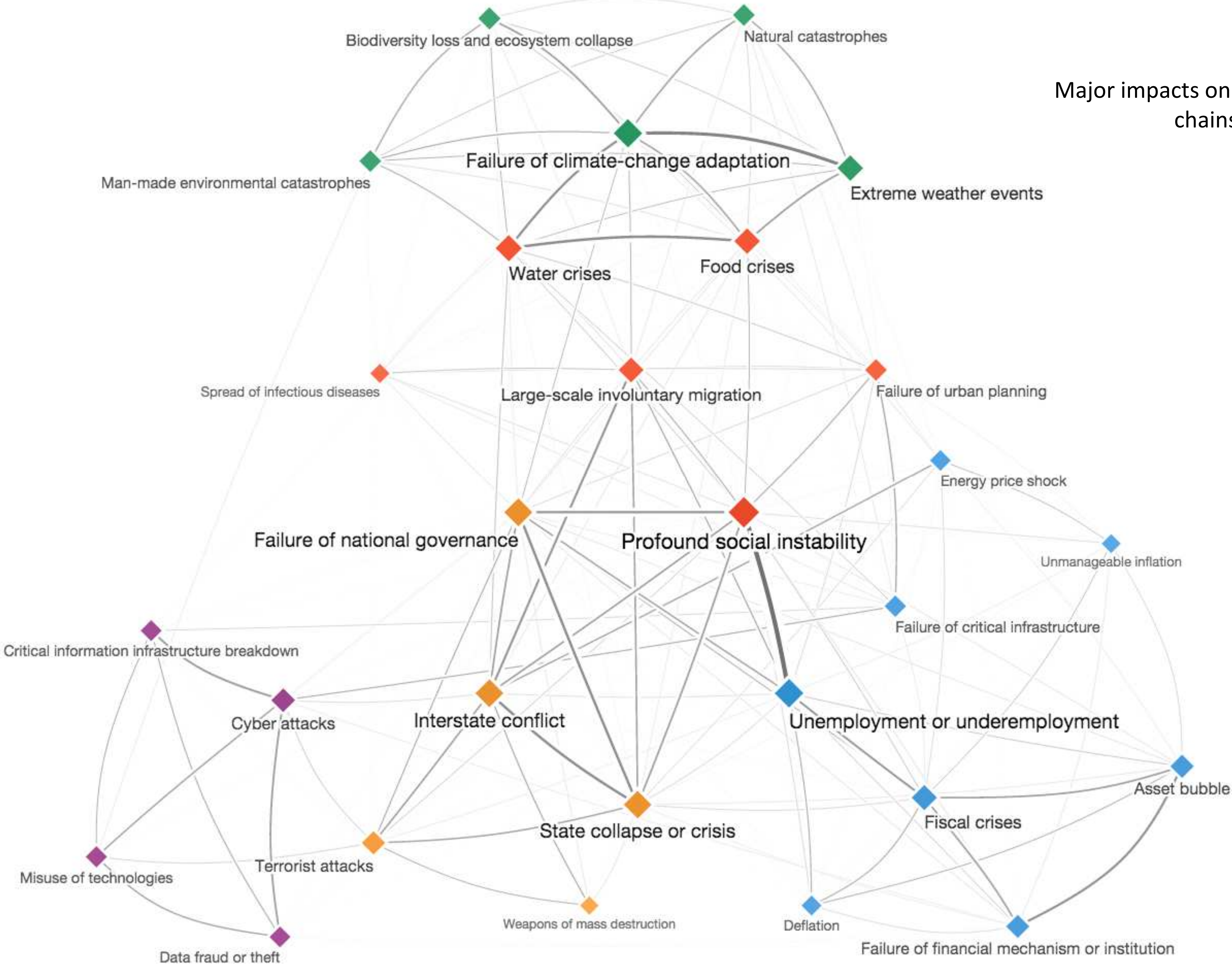


Global Risks Landscape 2015, © 2015 World Economic Forum

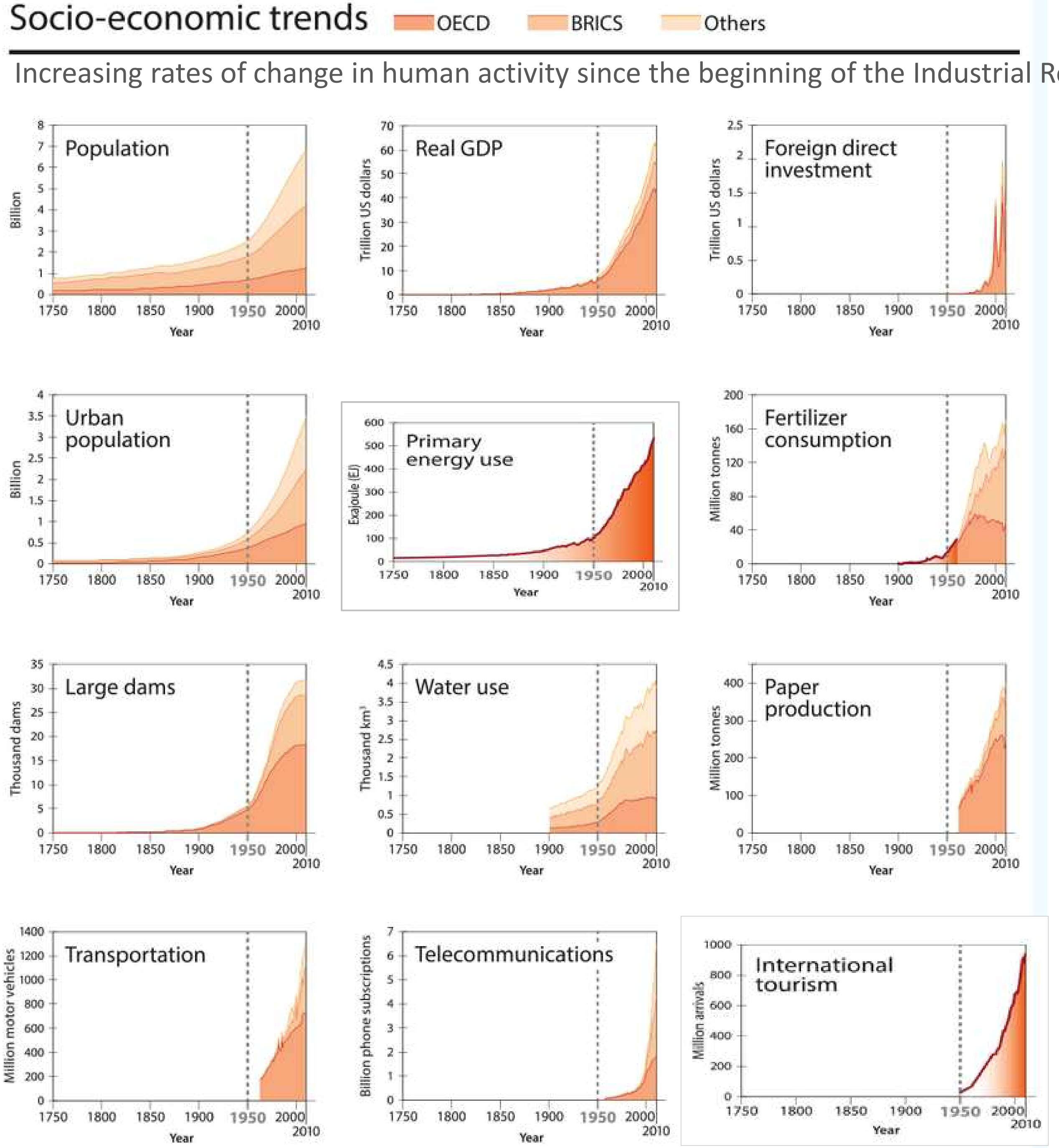
The World Economic Forum's Global Risks report is developed from an annual survey of 900 experts from industry, government, academia and civil society who were asked to review a landscape of 50 global risks.

Major impacts on global supply chains of industries



Socio-economic trends

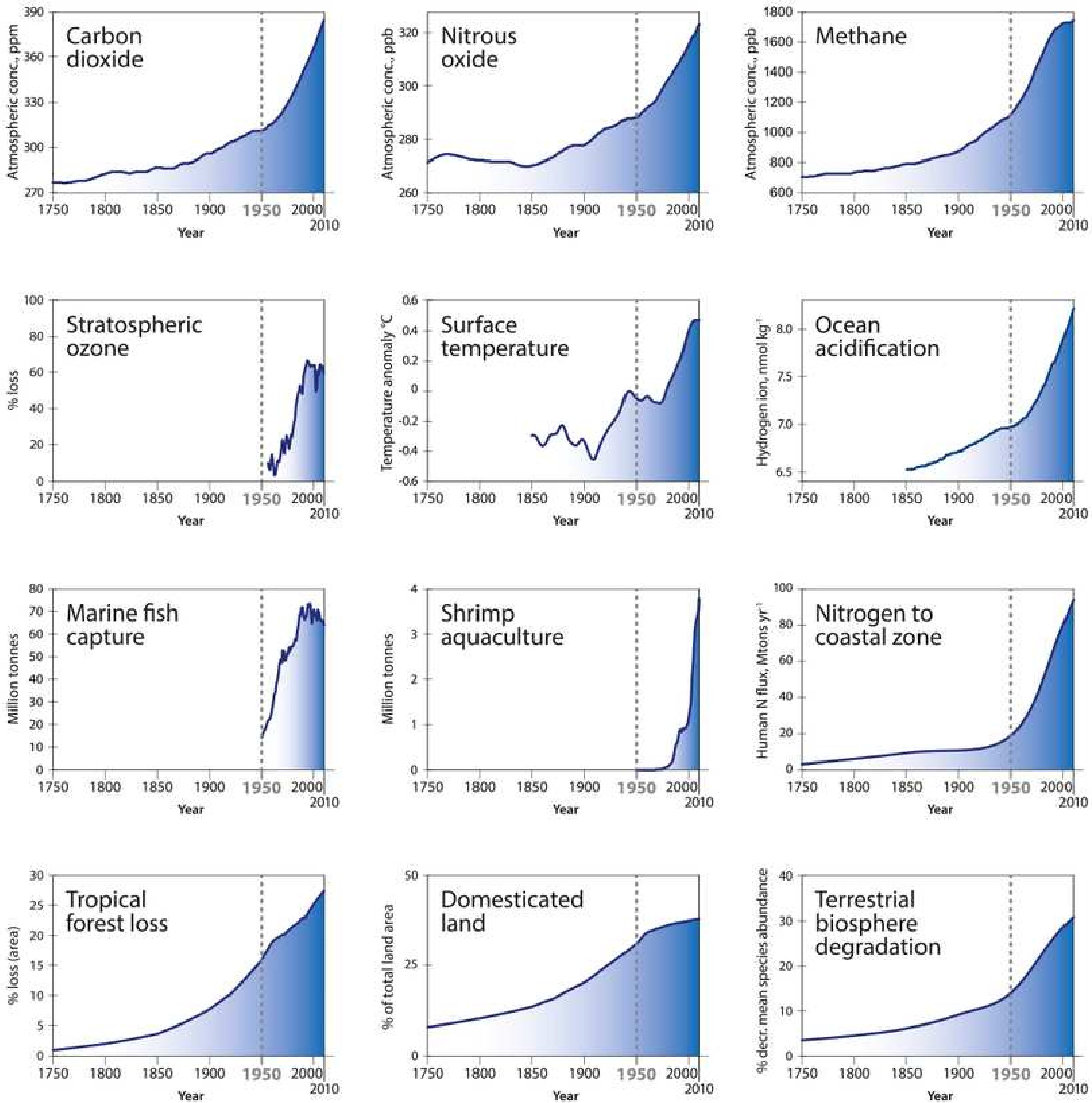
Increasing rates of change in human activity since the beginning of the Industrial Revolution.



Steffen *et al.* The trajectory of the Anthropocene: The Great Acceleration (*Anthropocene Review)* 16 January 2015. Design: Globaia

Earth system trends

Global-scale changes in the Earth System as a result of the dramatic increase in human activity



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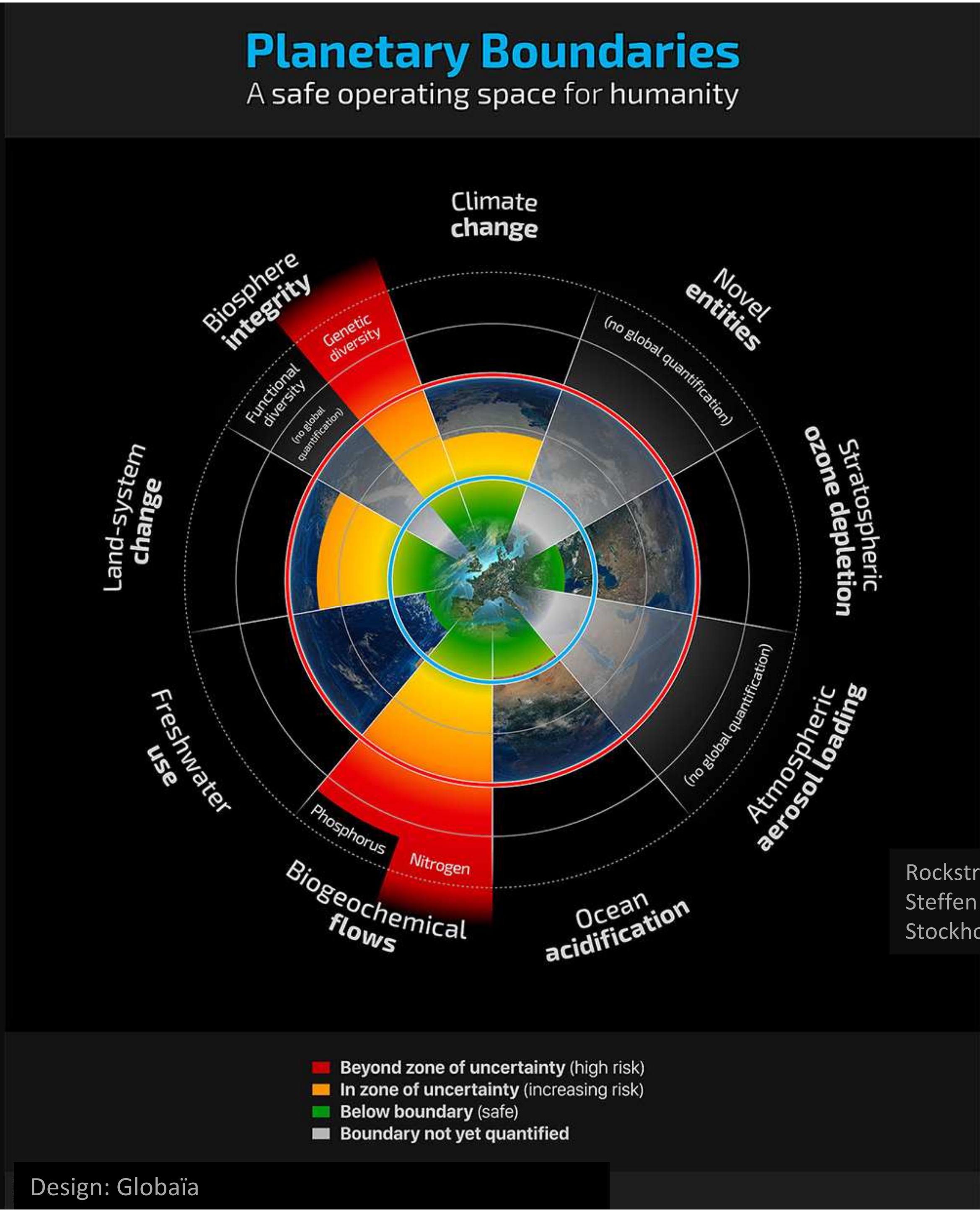


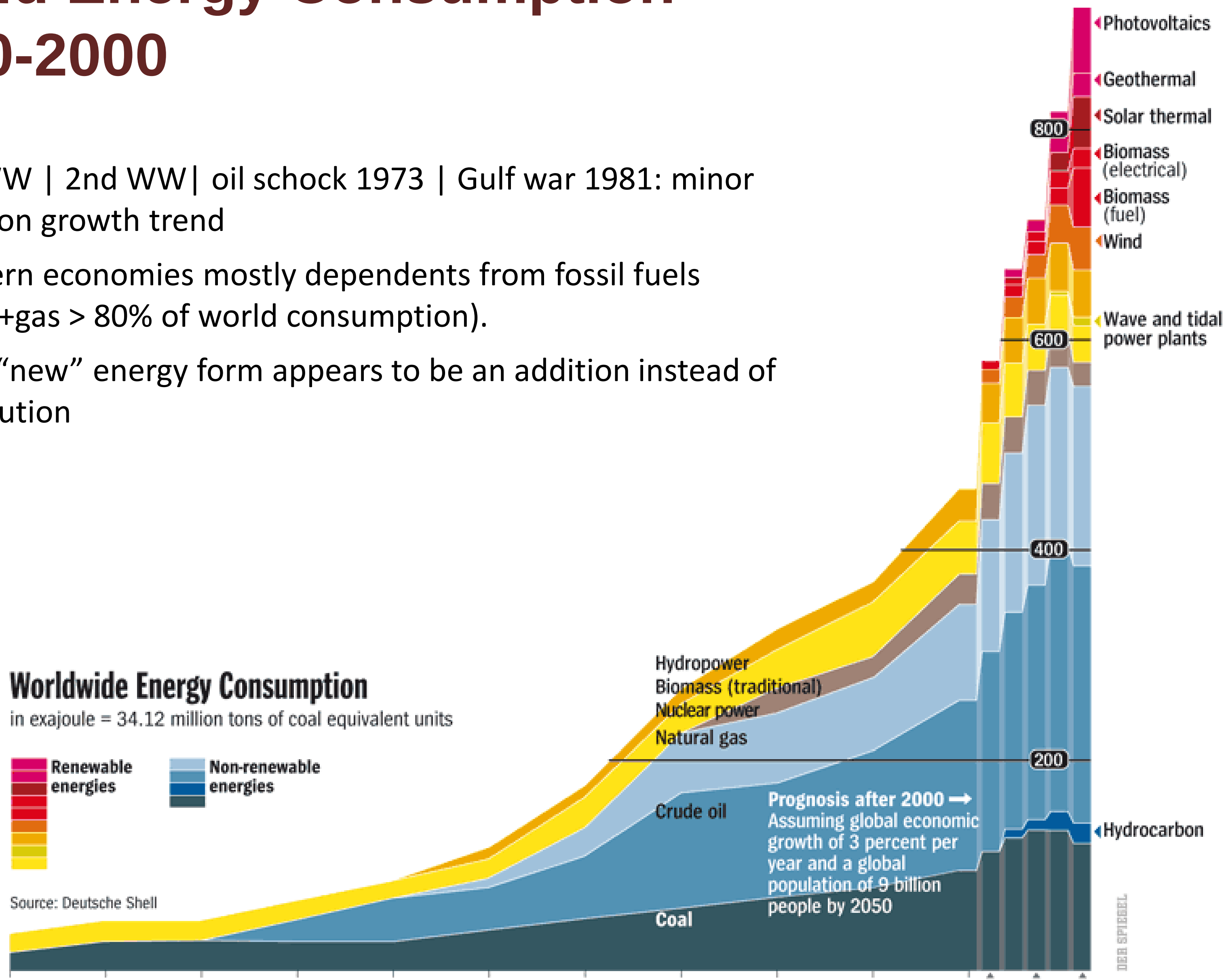
Rockstrom et al, 2009, Nature
Steffen et. al. 2015. Science
Stockholm Resilience Centre, Sweden

World Energy Consumption 1900-2000

→ 1st WW | 2nd WW| oil schock 1973 | Gulf war 1981: minor impacts on growth trend

→ Modern economies mostly dependents from fossil fuels (oil+coal+gas > 80% of world consumption).

→ Each “new” energy form appears to be an addition instead of a substitution

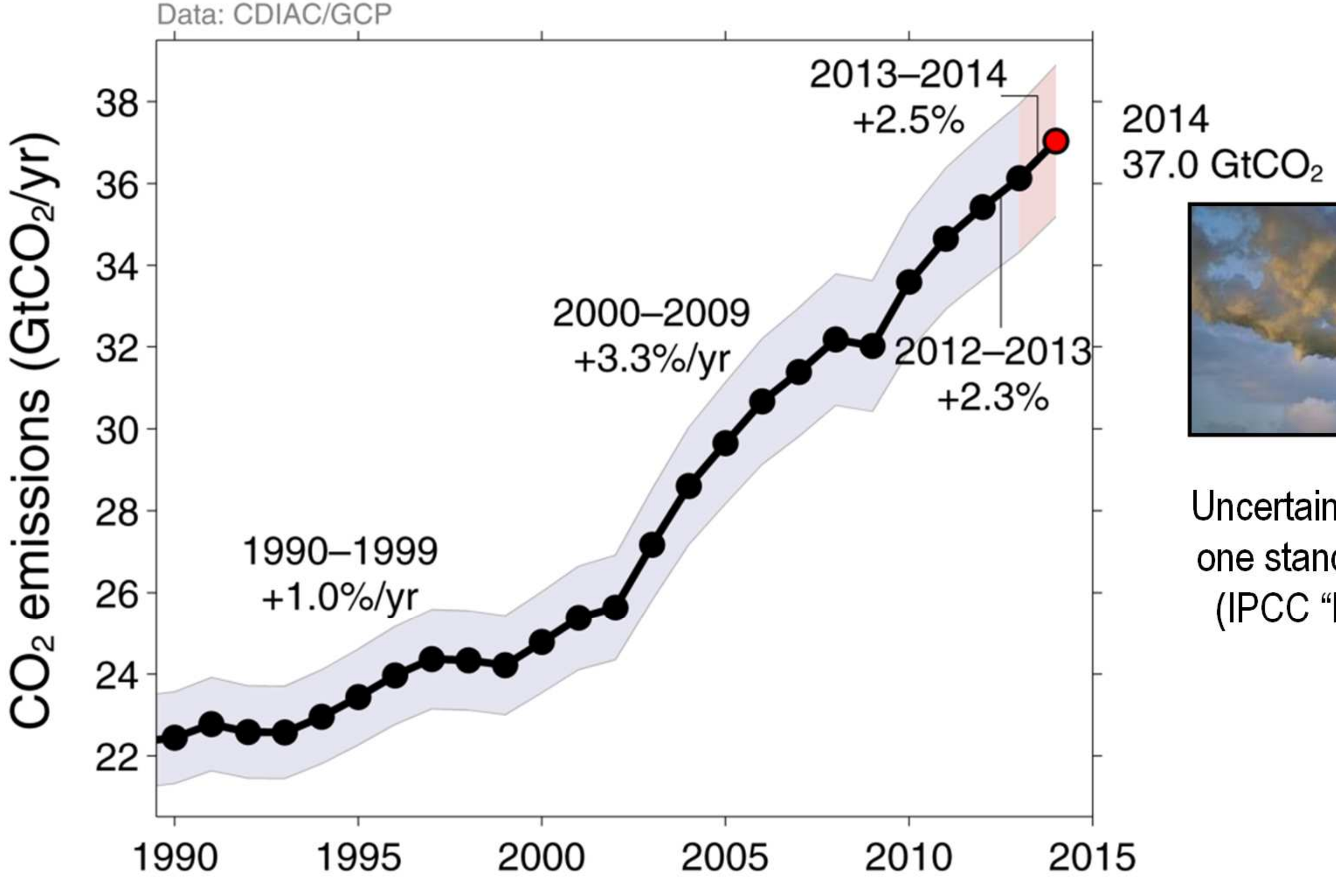


Fonte: Deutsche Shell

Fossil Fuel and Cement Emissions

Global fossil fuel and cement emissions: 36.1 ± 1.8 $GtCO_2$ in 2013, 61% over 1990

● Projection for 2014 : 37.0 ± 1.9 $GtCO_2$, 65% over 1990



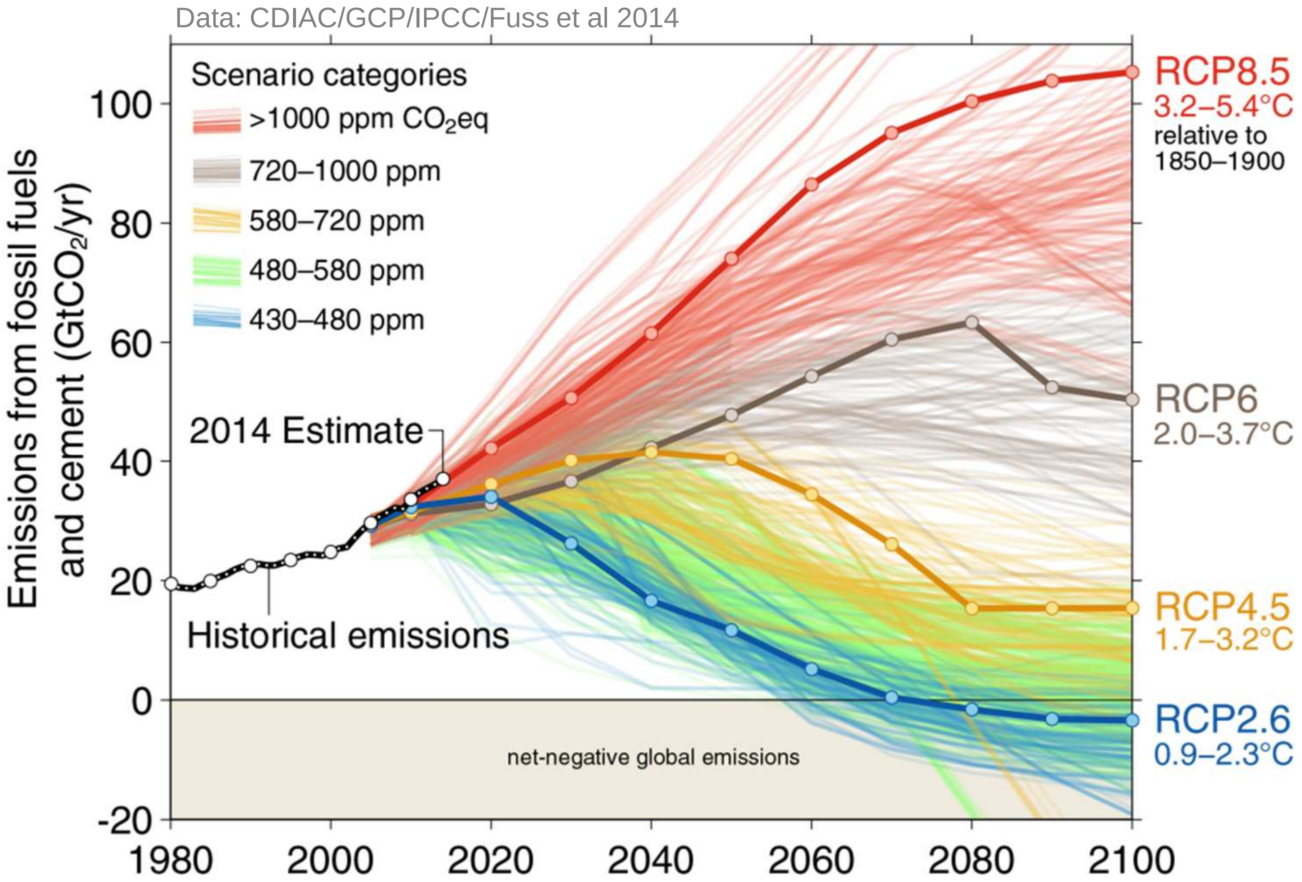
Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

Source: CDIAC; Le Quéré et al 2014; Global Carbon Budget 2014

Observed Emissions and Emissions Scenarios

Emissions are on track for 3.2–5.4ºC “likely” increase in temperature above pre-industrial

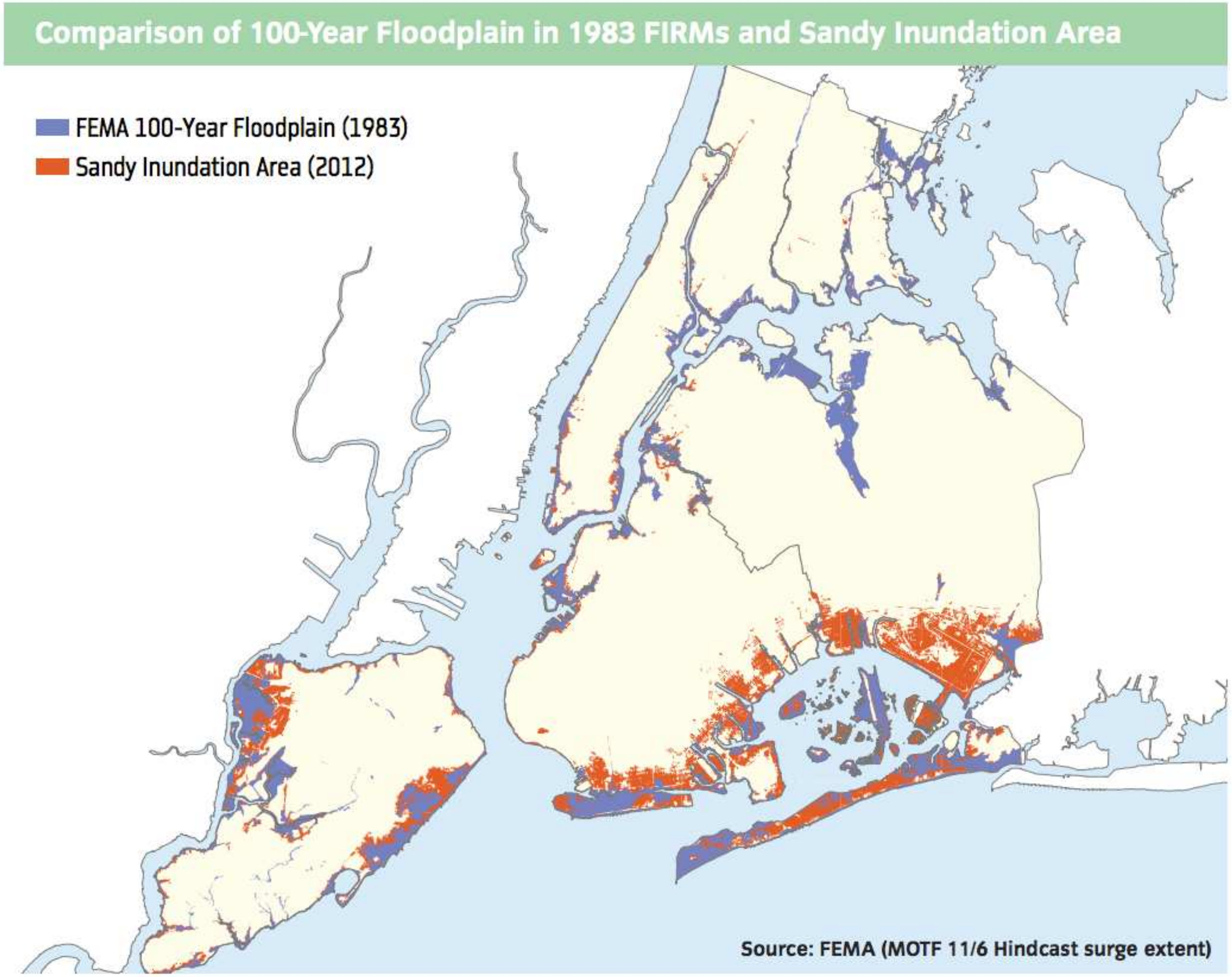
Large and sustained mitigation is required to keep below 2ºC



Over 1000 scenarios from the IPCC Fifth Assessment Report are shown

Source: Fuss et al 2014; CDIAC; Global Carbon Budget 2014

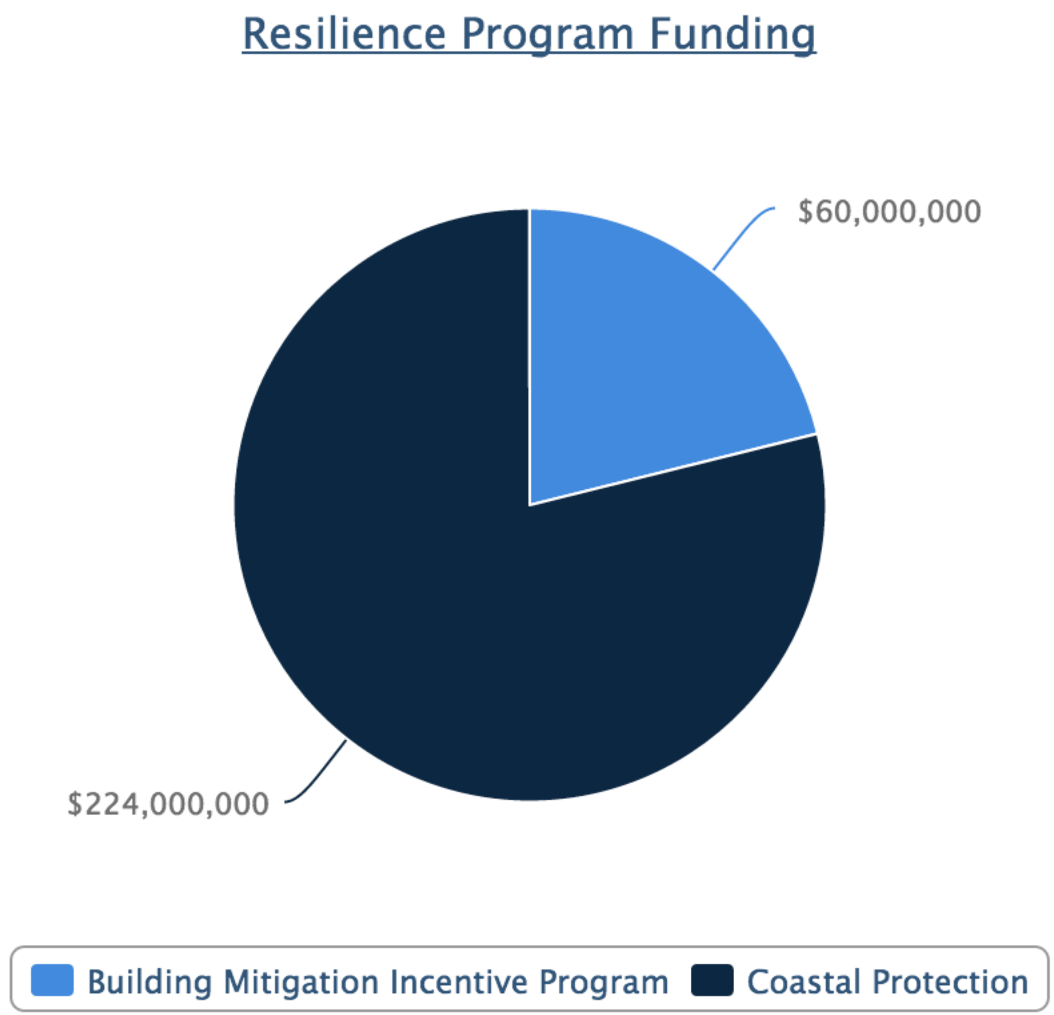
Impacts of climate change: the case of Sandy storm in New York City



Total losses caused by Sandy, an estimated $19 billion (according to the City's analysis provided to the Federal government), could be broken down into over $13 billion of physical damage and almost $6 billion of lost economic activity

http://s-media.nyc.gov/agencies/sirr/SIRR_singles_Lo_res.pdf

Impacts of climate change: the case of Sandy storm in New York City



http://www1.nyc.gov/sandytracker/#4030186099

Figure 3
Insured catastrophe losses, 1970–2014, in USD billion at 2014 prices

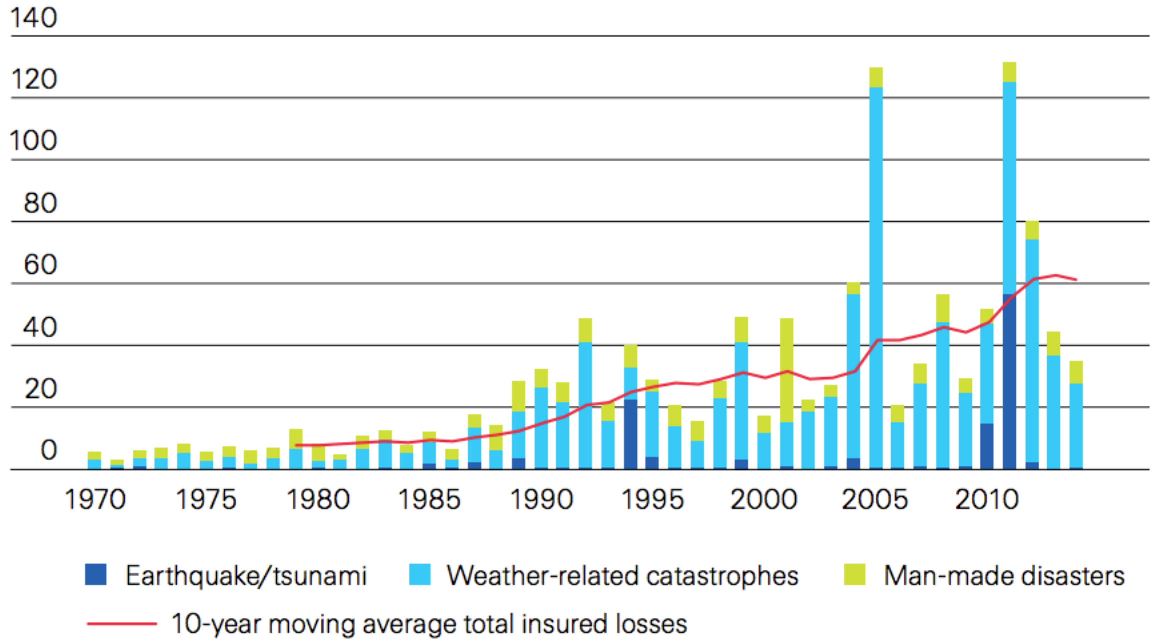
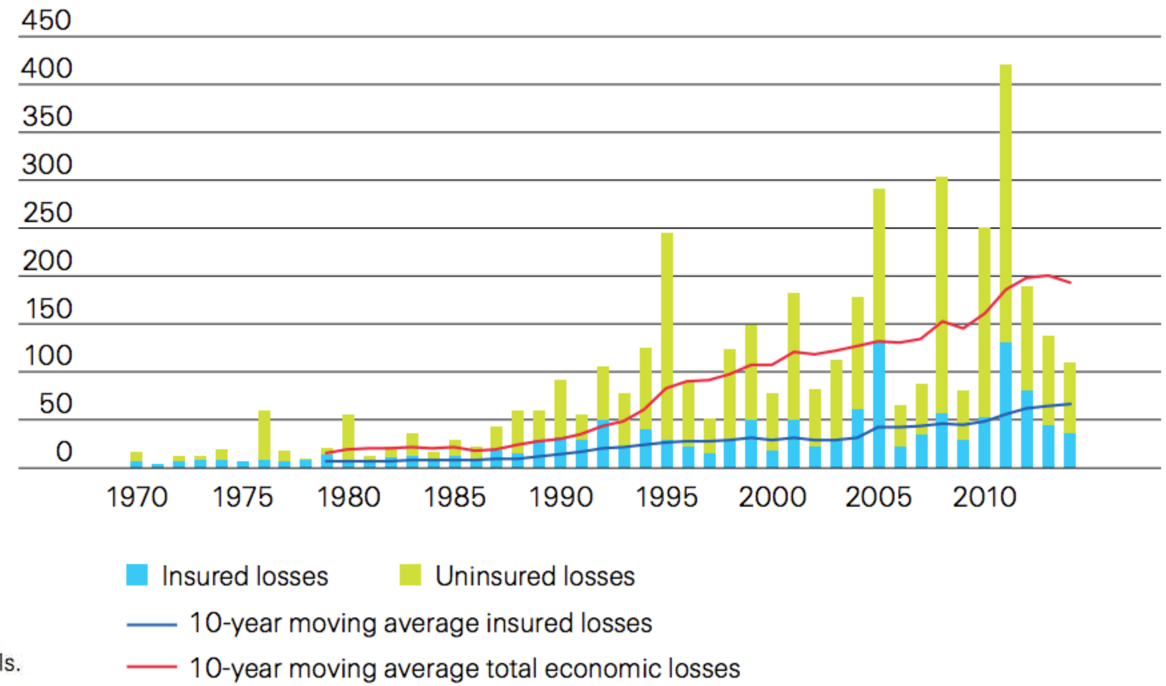


Figure 4
Insured vs uninsured losses, 1970–2014, in USD billion in 2014 prices

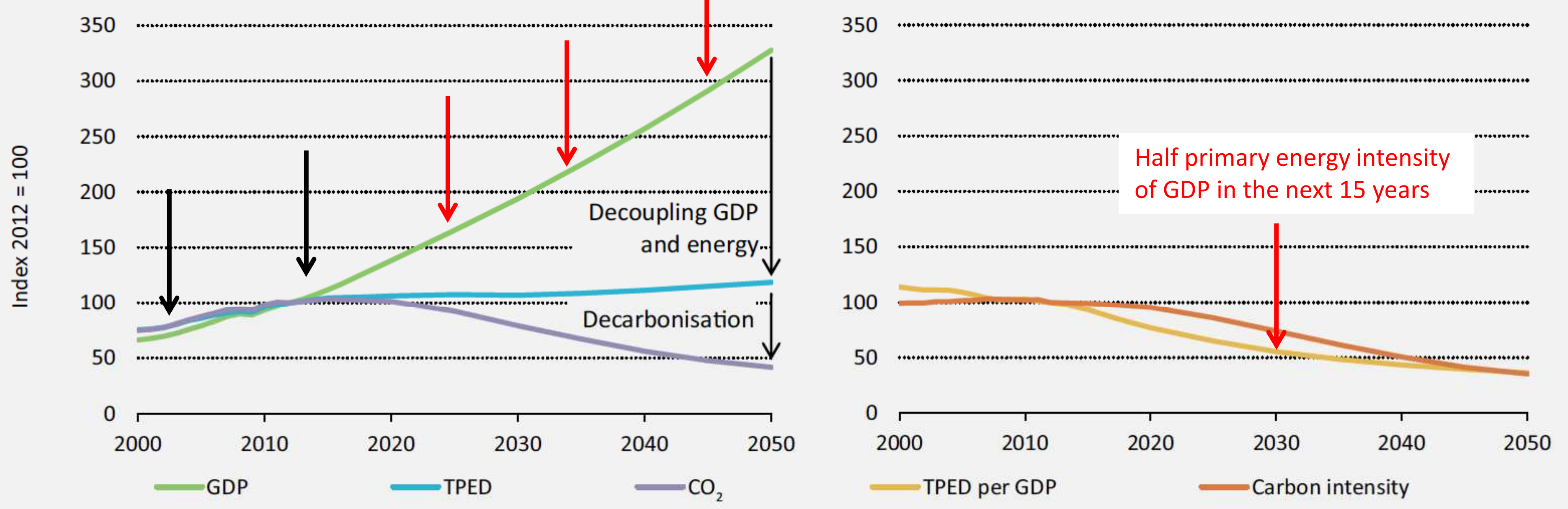


Total losses = insured + uninsured losses

Source: Swiss Re Economic Research & Consulting and Cat Perils.

BAU How to accommodate this shift/shock? **2ºC**

Figure 1.2 Development of global GDP, primary energy and CO_2 emissions in the 2DS



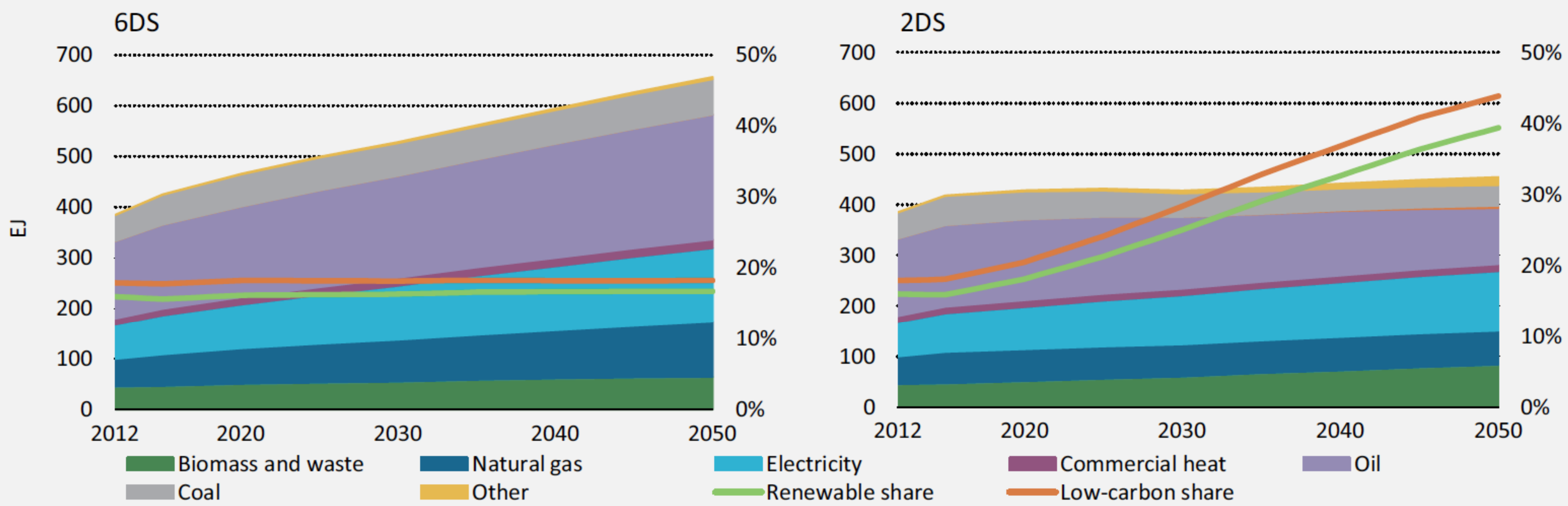
Note: TPED = total primary energy demand.

Key point *While efforts to decouple economic growth and primary energy use need to be accelerated, the larger challenge is to sufficiently reduce the CO_2 intensity of primary energy in the 2DS.*

IEA, 2015

BAU How to accommodate this shift/shock? **2ºC**

Figure 1.5 Low-carbon and renewable shares in the global final energy demand in the 6DS and 2DS



Notes: The low-carbon share includes the direct use of final renewable energy sources (biomass, solar, geothermal), and also takes into account the share of low-carbon technologies (renewables, nuclear, CCS) in providing final electricity and commercial heat demands.

Key point *Renewables provide 40% of the 2DS global final energy demand in 2050; taking into account also electricity, heat and hydrogen generated from nuclear and CCS, 44% of final energy is based on low-carbon energy sources.*

- Double the share of renewables
- Decrease 1/3 of final energy

IEA, 2015

European Commission

ec.europa.eu/clima/

Reducing greenhouse gas emissions by 40%
below the 1990 level by 2030.

This target will ensure that the EU is on the cost-effective track towards meeting its objective of cutting emissions by at least 80% by 2050.

Increasing the share of renewable energy to at least 27%
of the EU's energy consumption by 2030.

Renewable energy will play a key role in the transition towards a competitive, secure and sustainable energy system.

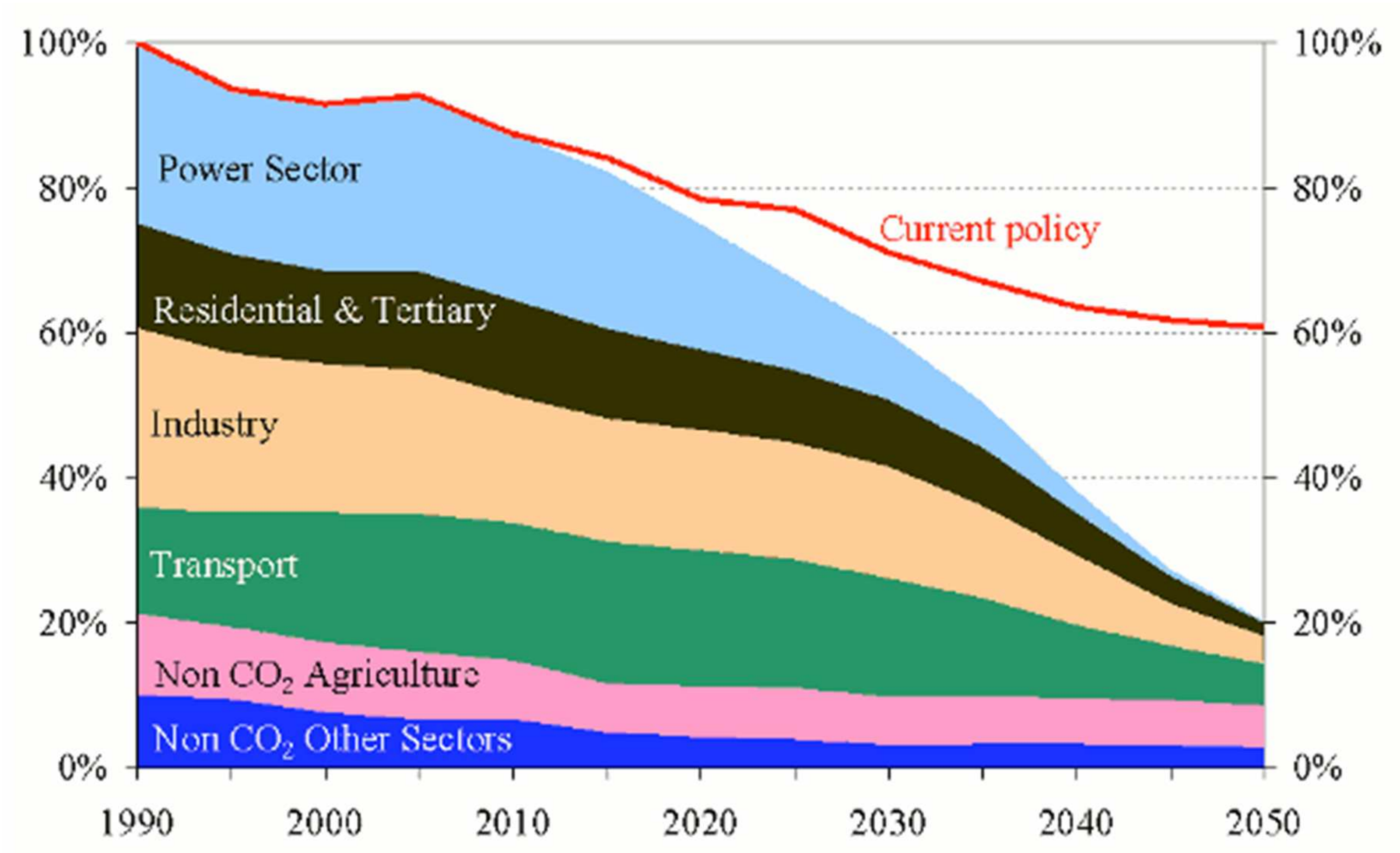
Continued improvements in energy efficiency

The role of energy efficiency in the 2030 framework will be further considered in a review of the Energy Efficiency Directive due to be concluded later in 2014.

Roadmap for moving to a low-carbon economy in 2050

European Commission

ec.europa.eu/clima/



Greenhouse gas emissions reduction by 80%

Questions:

1 – The shift of the energy systems of such magnitude (aggressive GHG emissions reductions: 85-90% by 2050/1990) has been / should be approached as a shock for economies?

2 – How can a shift to a low carbon economy be planned and what will be the economic impacts of such transition?

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Energy – Climate Mitigation Modelling

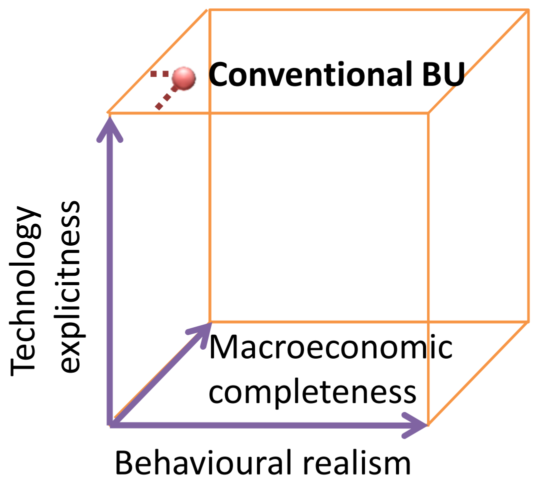
- Since the '70s energy modeling has been a powerful tool to analyse energy systems;
- Back than energy models were used to analyse the consequences and alternatives associated with oil embargo;
- Currently, **Energy-economic-environmental** models are widely used to outline how the transition to a low carbon economy and a sustainable energy system can be achieved;
- Two main approaches:
  - **Technological**, Bottom-up models, e.g. TIMES;
  - **Economic**, Top-down models, e.g. computable general equilibrium model GEM-E3

Top-down versus Bottom-up models

Bottom-up models

\+ Represent the energy system with great detail

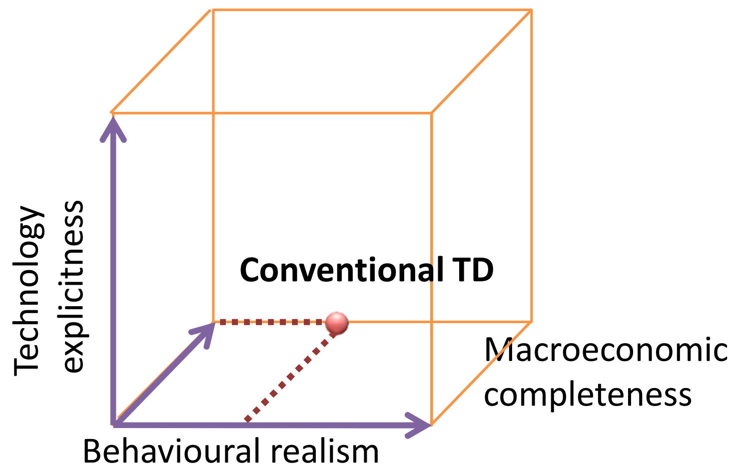
– Ignore the full macroeconomic feedbacks of different energy system pathways



Top-down models

\+ Describe the interaction between the energy system and the economy as a whole

– Do not contain technological detail, representing the energy sector in aggregate form

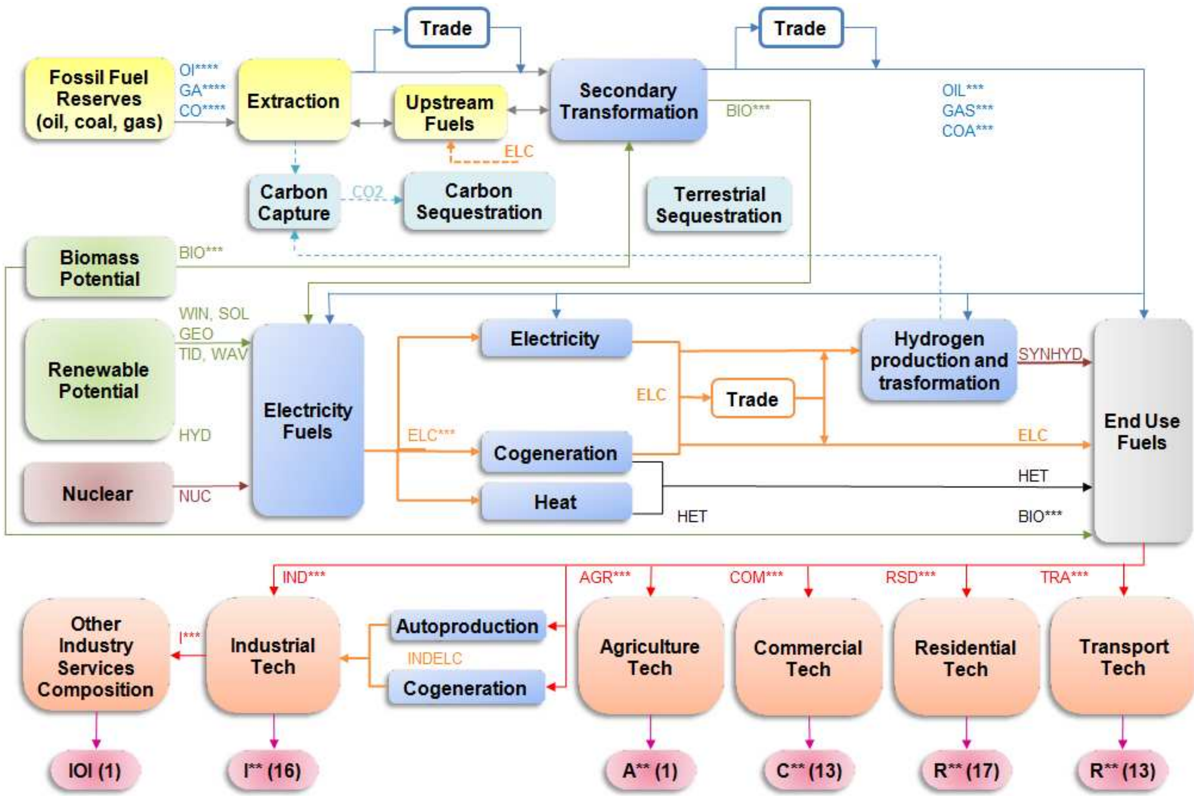


Source: Rivers and Jaccard, 2006

Technological TIMES_PT model

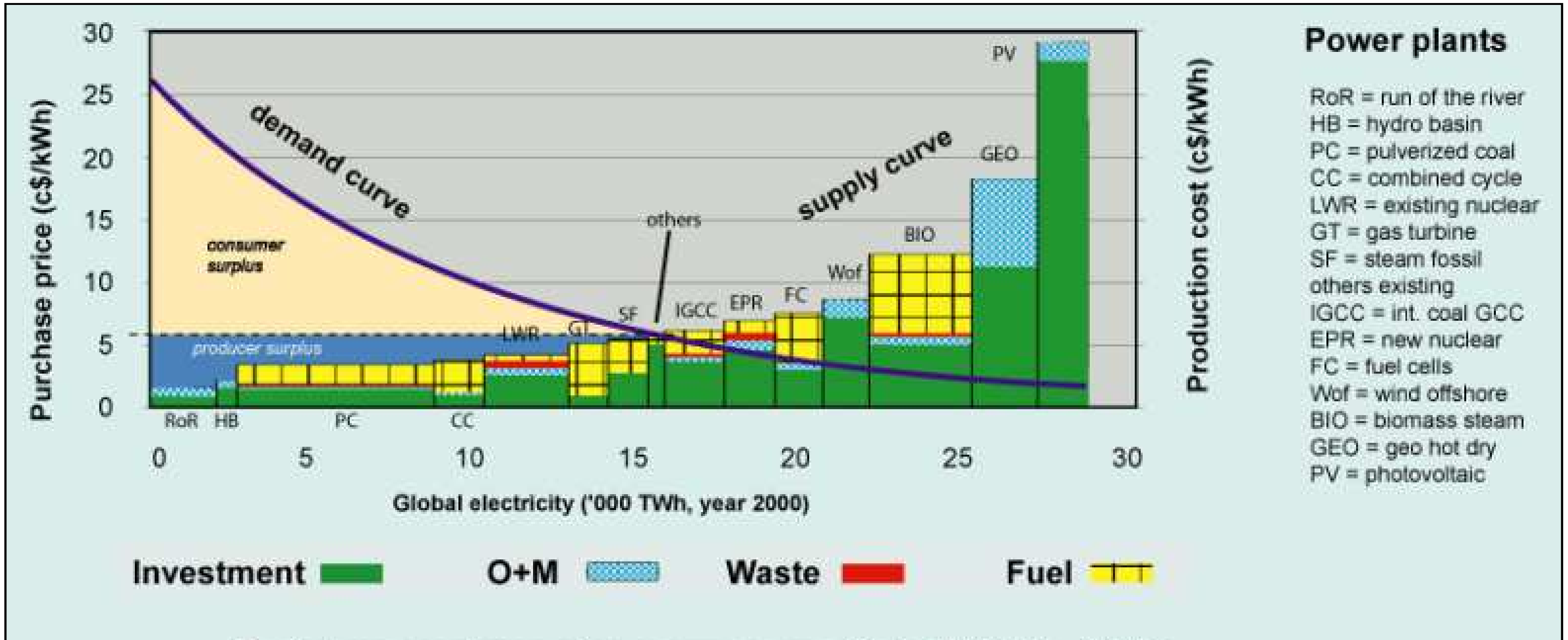
- Represents the Portuguese energy system with a very detailed technology description (2000's technologies and energy sources) with information such as:
  - Investment, operation & maintenance costs;
  - Life time, starting year, efficiency, availability;
  - Emission factors.

Reference Energy System (RES)



TIMES_PT

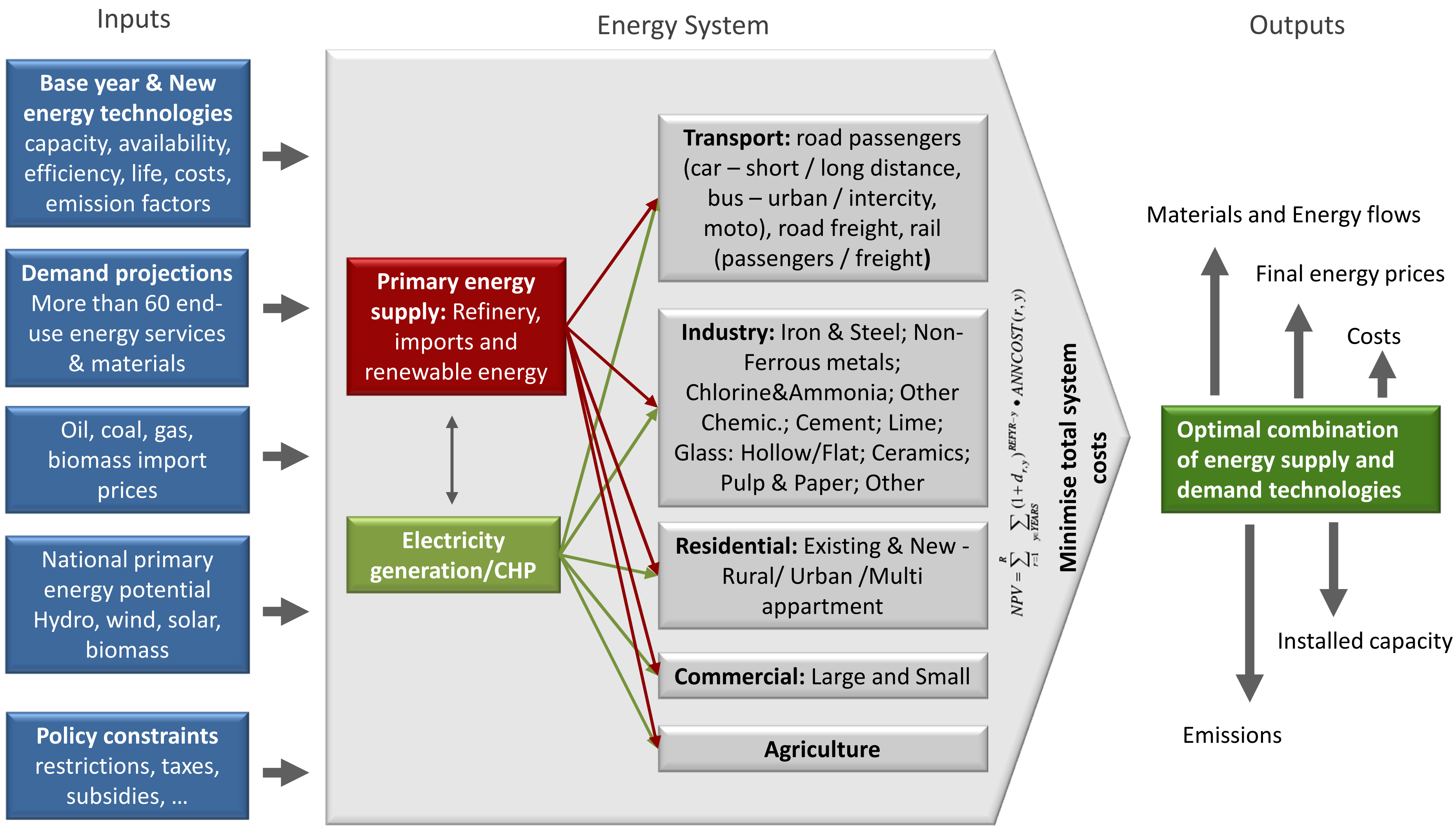
- **Objective:** Surplus maximization (i.e. least-cost combination of energy system technologies) to meet a given energy services demand subject to several restrictions (e.g. emissions, technologies availability, energy resources potential) through linear programming.



Typical representation of an energy commodity in MARKAL - TIMES.
The algorithm maximises the global surplus over thousands such markets.

Source: ETSAP, 2012

TIMES_PT


Inputs
Energy System
Outputs
Base year & New energy technologies capacity, availability, efficiency, life, costs, emission factors
Demand projections More than 60 end-use energy services & materials
Oil, coal, gas, biomass import prices
National primary energy potential Hydro, wind, solar, biomass
Policy constraints restrictions, taxes, subsidies, ...
Primary energy supply: Refinery, imports and renewable energy
Electricity generation/CHP
Transport: road passengers (car – short / long distance, bus – urban / intercity, moto), road freight, rail (passengers / freight**)**
Industry: Iron & Steel; Non-Ferrous metals; Chlorine&Ammonia; Other Chemic.; Cement; Lime; Glass: Hollow/Flat; Ceramics; Pulp & Paper; Other
Residential: Existing & New - Rural/ Urban /Multi appartment
Commercial: Large and Small
Agriculture
$NPV = \sum_{r=1}^{R} \sum_{y \in YEARS} (1+d_{r,y})^{REFYR-y} \bullet ANNCOST(r,y)$
Minimise total system costs
Optimal combination of energy supply and demand technologies
Materials and Energy flows
Final energy prices
Costs
Installed capacity
Emissions

TIMES_PT in the support of climate/energy policy

PortugalClima2020
Impact Assessment of 20-20-20 policy package

novastecnologiasenergéticas
RoadmapPortugal2050
New Energy Technologies Road Map till 2050

RNBC
Low Carbon Road Map till 2050

Green Tax Reform till 2030

TIMES_PT

1982 1984 1995 1999 2000 2008 2011 2012 2013 2014

PEN 82 2010

PEN 84 2010

CCE 1995-2015

Energy Demand 2000-2020

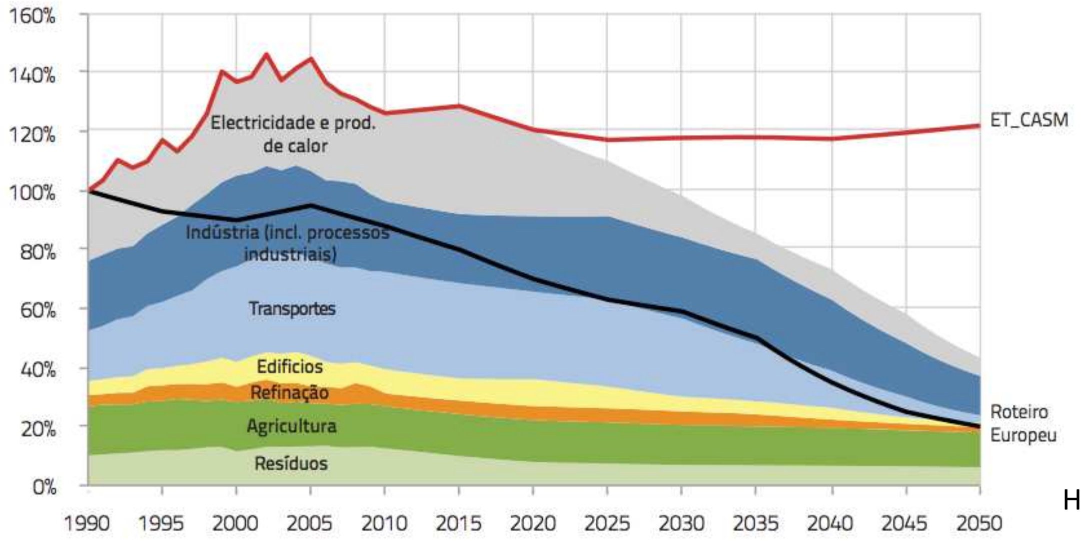
GHG Emissions 2020

PNAC
Climate Mitigation Program till 2030

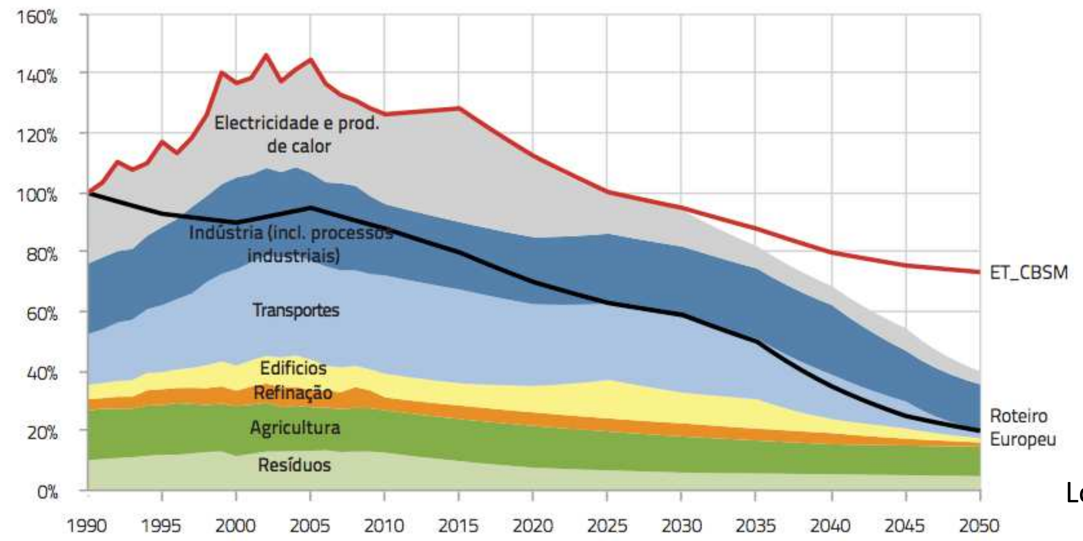
Low Carbon Roadmap:

-70% GHG emissions 2050 over 1990

TIMES_PT outcomes



High GDP growth (3% pa)



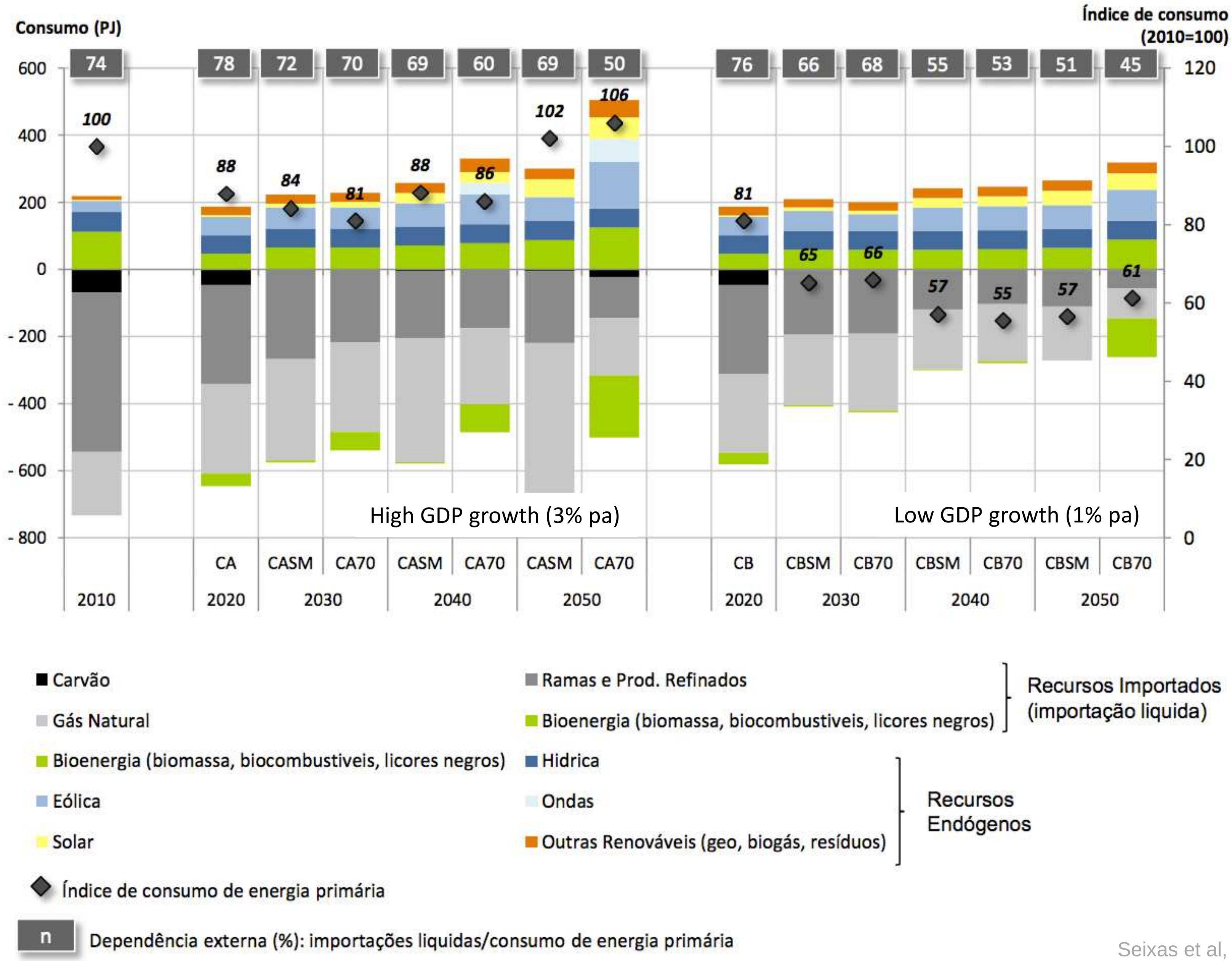
Low GDP growth (1% pa)

:A 3 - Trajetórias sectoriais de baixo carbono com restrição de emissões de 70% no sistema energético; cenário Alto (em cima) e Baixo (em baixo) (1990=100%). Valores históricos de 1990 a 2010 (APA, 2012)

Seixas et al, 2013, RNBC

AGGREGATED RESULTS FOR THE PORTUGUESE ENERGY SYSTEM: -70% GHG 2050/1990

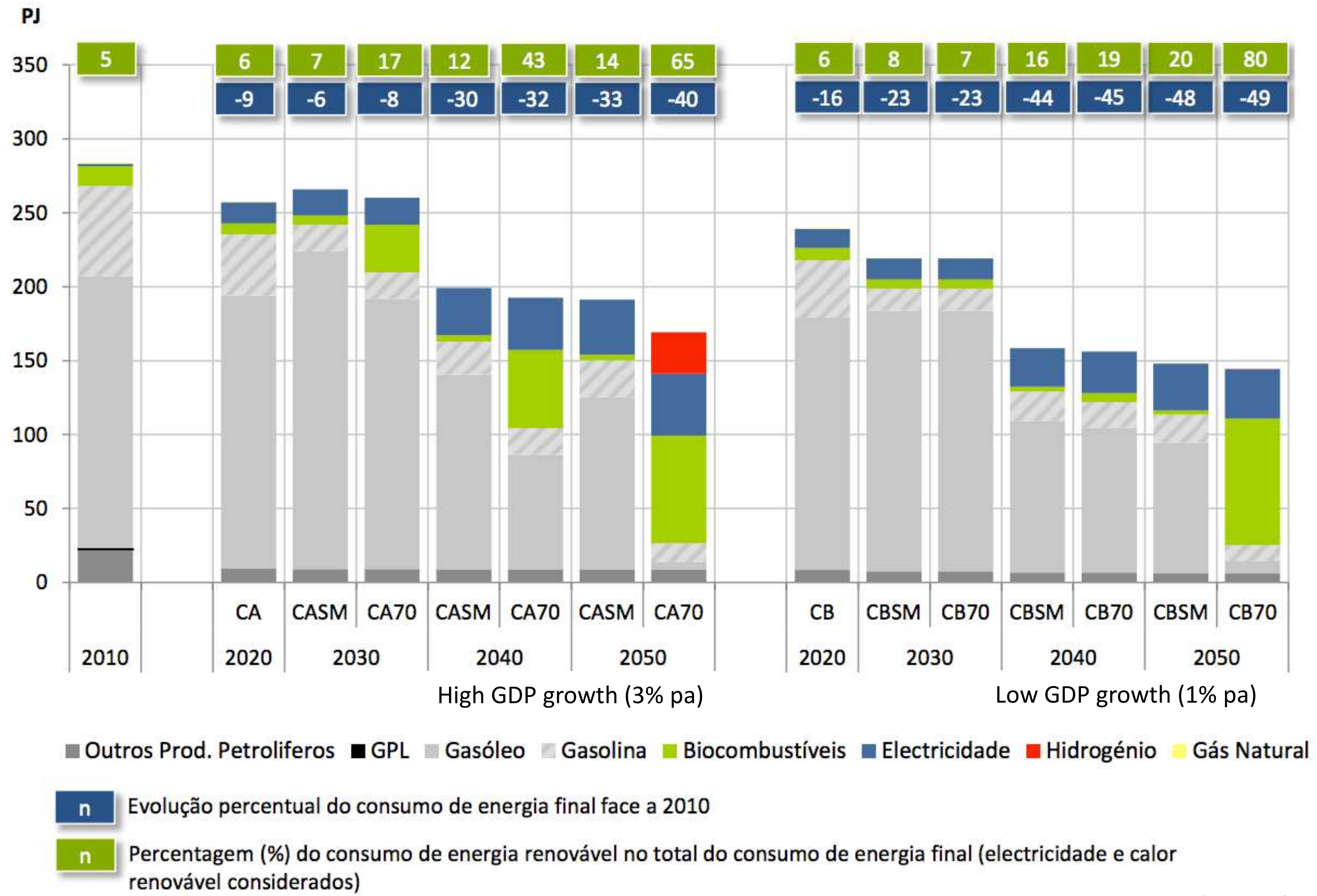
Primary energy consumption, endogenous resources as positive values and imported resources as negative values.



Seixas et al, 2013, RNBC

DETAILED RESULTS FOR THE ENERGY SYSTEMS: -70% GHG 2050/1990
INNOVATIVE TECHNOLOGIES APPEAR IN THE FUTURE

Final energy consumption in the transport sector



Seixas et al, 2013, RNBC

Additional costs for the energy system in a scenario with 70% reduction of GHG emissions, in comparison with a scenario with no CO2 restriction

Total system costs		Investments costs	
M€$_{2010}$	% PIB$_{2010}$	M€$_{2010}$	% PIB$_{2010}$
129	0.07	57	0.03
512	0.30	306	0.18

Additional costs (M€$_{2010}$) of imported primary energy for the energy system in a 70% reduction of GHG emissions, in comparison with a scenario with no CO_2 restriction.

2030	2040	2050
-78	-347	-542
-275	-358	-1 279

Seixas et al, 2013, RNBC

How limitative are bottom-up models?

1 – Do not consider the economy as a whole, and sub estimate the economic impacts of mitigation measures!

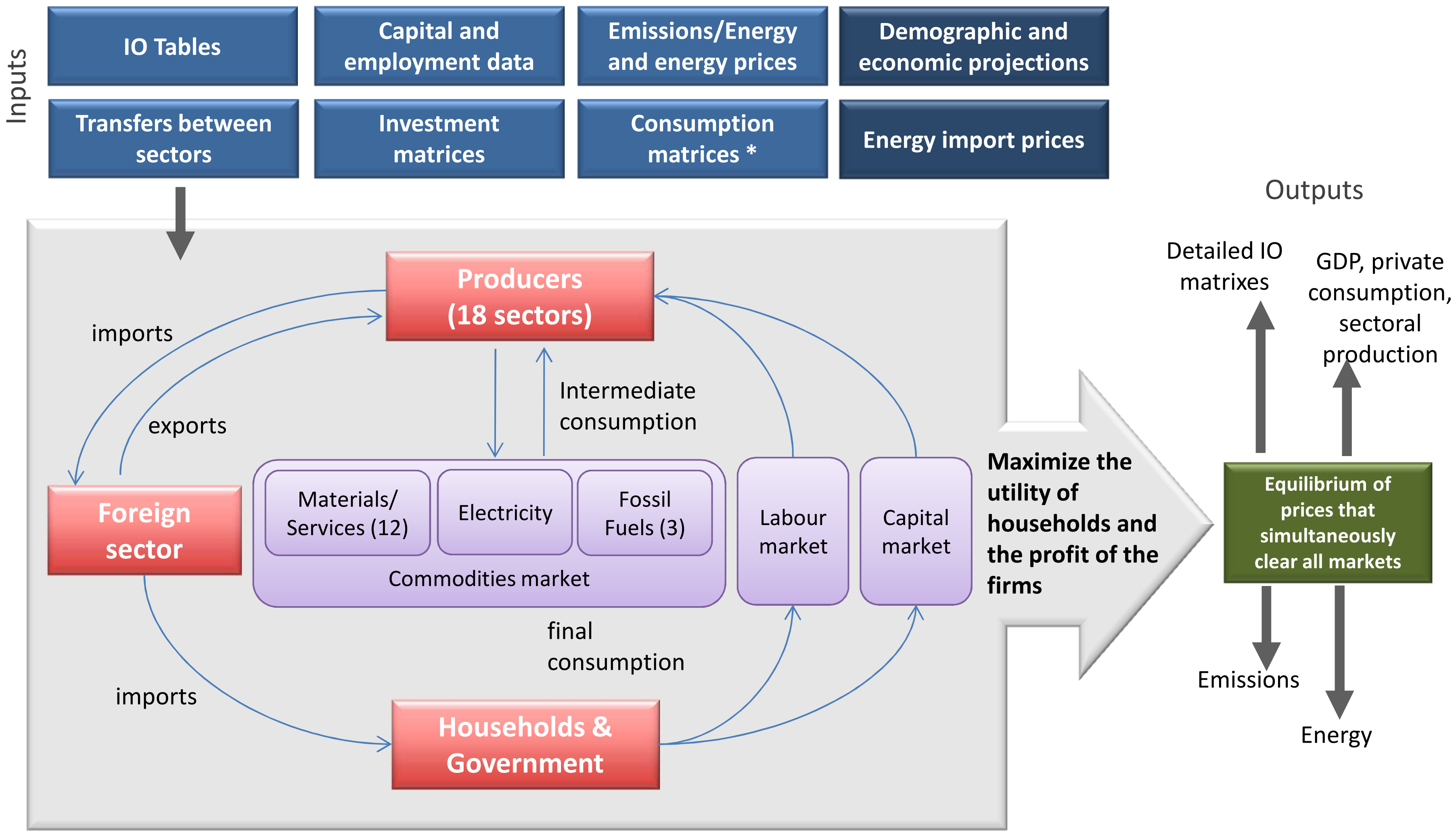
2 – Compute the most cost-effective solution, which may not represent the best solution in terms of economic welfare, economic growth or employment

3 - Do not consider limitations to investment

4 – Do not take into account agents behavior:

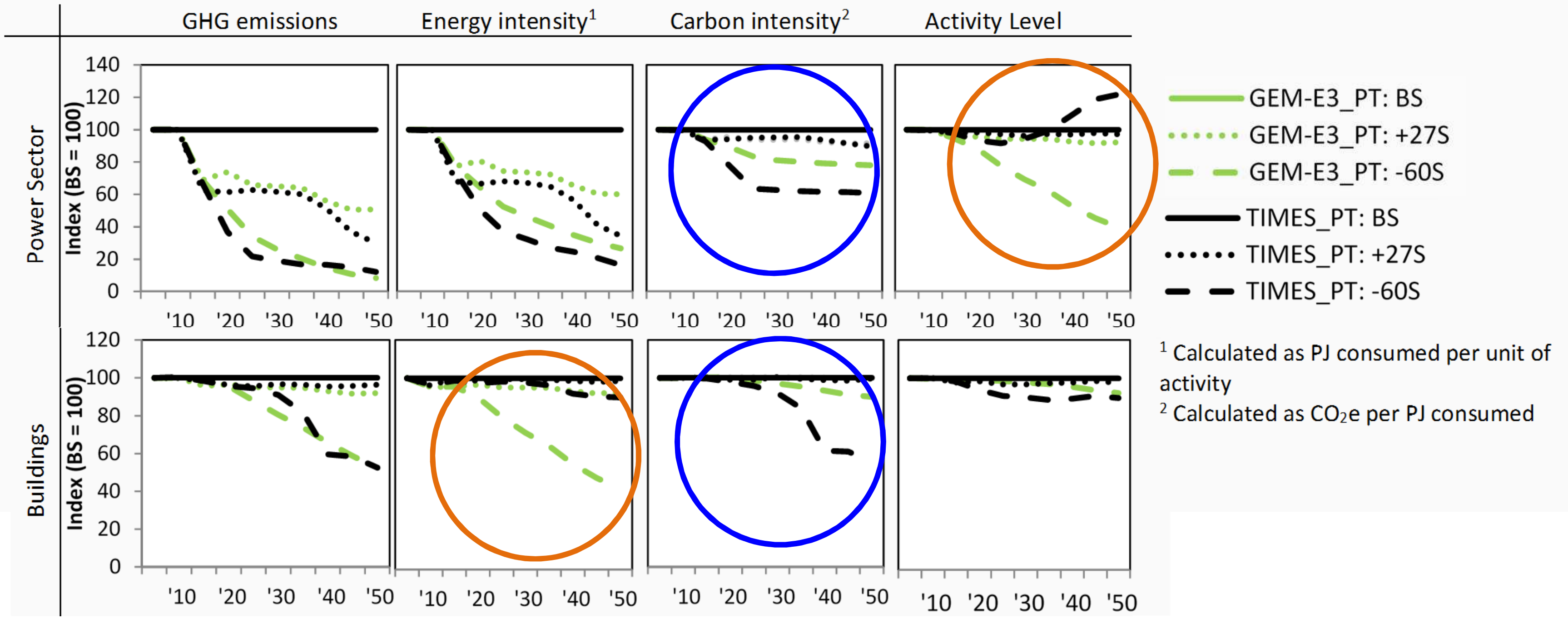
- two different technologies that satisfy the same demand, may not have perfect substitution for the economic agents (cultural and individual options), and inertia of agents
- demand as a function of prices can be accommodated through simple energy <u>services</u> -price elasticities

GEM-E3_PT



*13 households consumption categories   Government and Rest of the world with exogenous behaviour

- **Stringent GHG emissions** caps achieved
- **Strategy to reduce diverge (implying eventual different policies)**:
  - TIMES_PT → decarbonize power sector, with RES tech, and shift end-uses to electricity (low carbon techs)
  - GEM-E3_PT → energy savings reflected in power production decrease



[1] Calculated as PJ consumed per unit of activity
[2] Calculated as CO_2e per PJ consumed

Fortes et al, 2013, *Climate policy*

How limitative are top-down models?

1 – They do not consider technology date, or they assume very simpler technology data, overestimating the costs of changing the energy system

2- The substitution between energy sources/technologies are made by historic substitution elasticities, which may not reflect emergent technology options, as expected for the medium-long term (up to 2050).

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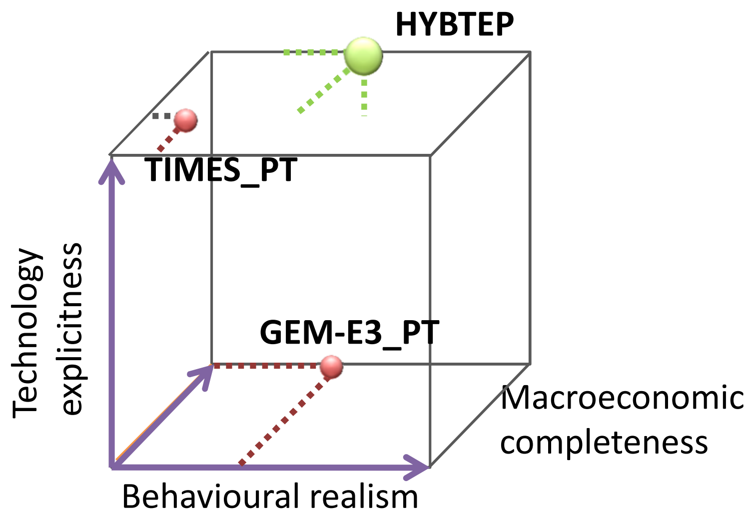
HYBTEP technological-economic platform

Policy makers need clear and consistent information concerning the real **impact of policies in the economy** and the most **cost-efficient technology portfolio** to achieve a low carbon future



Goal:

- Obtain a modelling platform with the detailed technological information of the BU TIMES_PT;
- Explicit representation of economy and its factors (production, consumption, labour) from the CGE GEM-E3_PT.

Methodologies linking energy systems models and economic models, IEA- ETSAP Workshop '14, Cork, http://www.ucc.ie/en/energypolicy/about/workshop14/

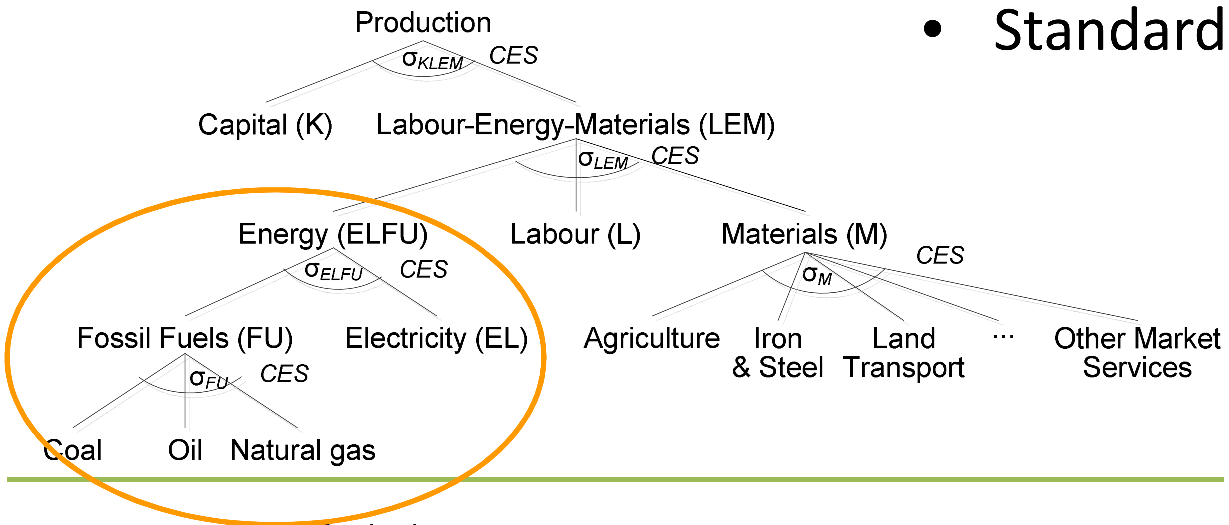
HYBTEP: Models Harmonization

	GEM-E3_PT		TIMES_PT		HybTEP
Activity sectors					
Private consumpt.	Households fuels and power	Demand Categories (energy services, materials and mobility)	Residential space heating and cooling, water heating, lighting, cooking, electric appliances	Economic Sectors	Residential
	Households operation of transport		Road car long distance and short distance, road moto		Private road transport
Production Sectors	Agriculture		Agriculture		Agriculture
	Ferrous and nonferrous metals		Iron and steel, nonferrous metals		Iron and steel and nonferrous metals
	Chemical		Ammonia, chlorine and other chemicals		Chemical
	Energy intensive industry		Cement, lime, glass, other non-metallic minerals, paper		Energy intensive industry
	Electric and other equipment goods, Transport equipment, Other Industries, Consumer goods, food and textile industries, Construction		Other industries		Other industry
	Land transport		Road heavy and light freight, rail freight; road urban bus; road intercity coach…		Land transport except private transport
	Other transport		Aviation, navigation		Other transport
	Services of credit and insurances, Other markets services, Non-market services		Commercial space heating and cooling, water heating, cooking, refrigeration, electric appliances, lighting and public lighting		Services
	Electricity	Supply sectors	Power sector		Power sector
	Oil		Oil refinery		Oil refinery
	Coal		Other supply sectors[a]		Other supply sectors[a]
	Natural gas				

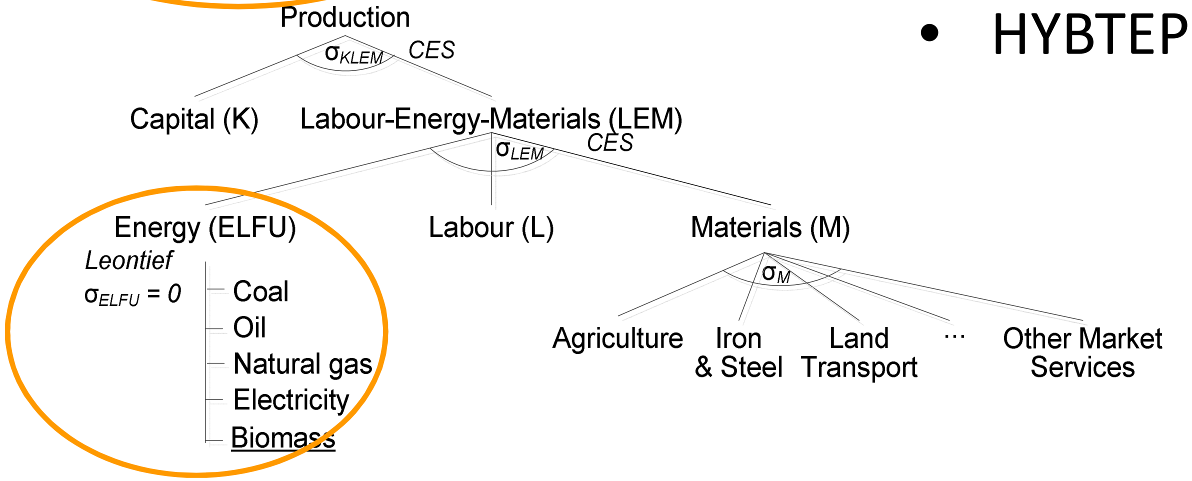
Fortes et al (2014) *Energy*

HybTEP: GEM-E3_PT changes

- Standard



- HYBTEP



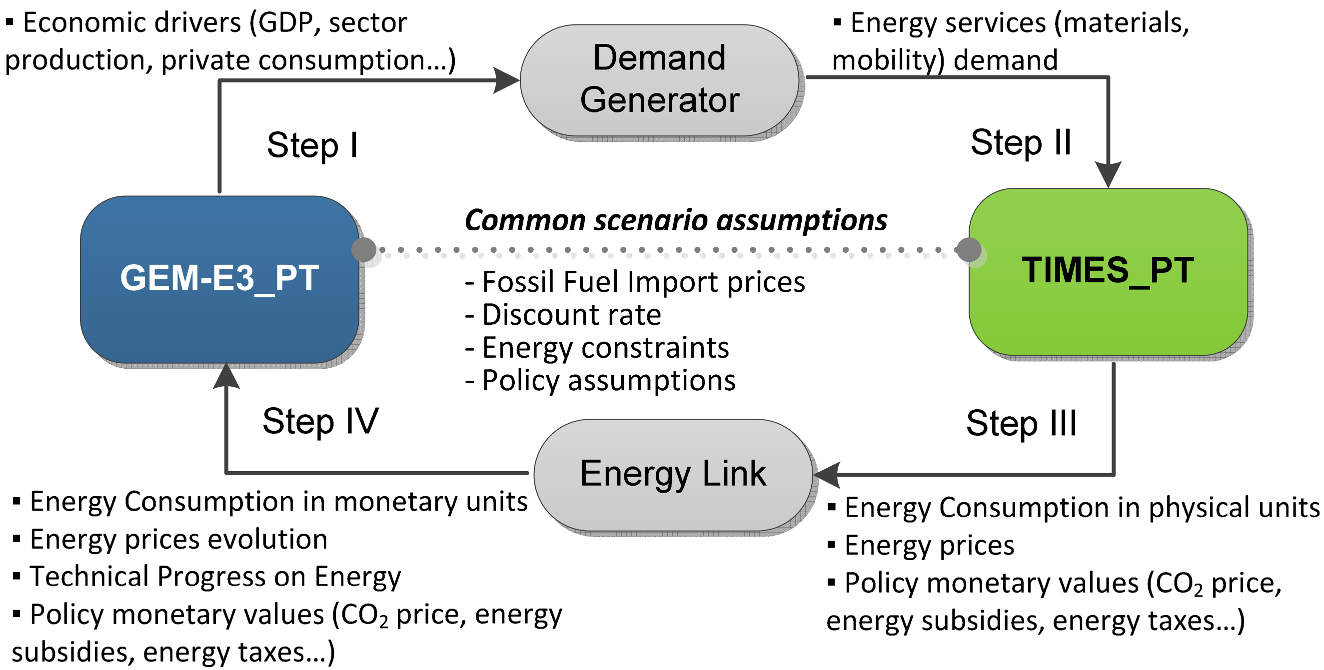
i. Energy consumption and fuel mix along the time defined exogenously (from TIMES_PT);

ii. Energy prices growth rate defined exogenously (from TIMES_PT;

iii. New energy commodity: biomass;

Fortes et al (2014) *Energy*

HYBTEP FRAMEWORK



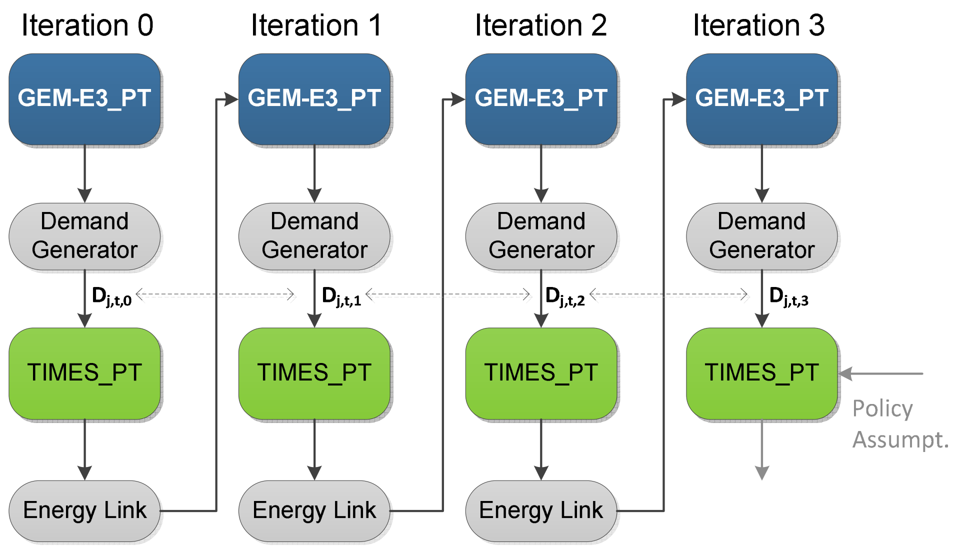
Each cycle represents 1 iteration → Convergence criteria: *Min* **energy services demand** difference (2%)

Fortes et al (2014) *Energy*

Calibration Scenario

- No policy

	2050		
Demand	It.0	It.3	Δ(%)
Residential (PJ)	123	130	6%
Services (PJ)	197	204	3%
Passenger.km	113 405	120 675	6%
Tonne.km	41 627	42 784	3%
Iron and Steel (Mt)	2.5	2.4	-3%
Cement (Mt)	11.6	12.1	5%
Paper (Mt)	3.3	3.5	8%
Ceramic (Mt)	37.3	40.6	9%
Other industries (PJ)	104	103	-1%



- TIMES_PT minimize energy system costs, inducing generally a reduction in energy costs, which are assumed by GEM-E3_PT with positive impacts on the demand for energy services.
- Without a soft-link, energy services demand would be underestimated.

Fortes et al (2014) *Energy*

Policy Scenarios

- Goal:
  - Evaluate the value added of HYTEP comparing with TIMES, including the effect of energy service-price elasticities

- Modelling tools:

Full economic feedback	No economic feedback	Effect of energy price on energy services demand		
		Commonly used	Sensitivity Analysis	
HYBTEP	TIMES_PT	TIMES_ED(-0.3)	TIMES_ED(-0.1)	TIMES_ED(-0.5)

- Assumption:
  - Revenue-neutrality: additional revenues are recycled to economy to reduce employers' social security tax.

Fortes et al (2014) *Energy*

Policy Scenarios

- **Global TAX**

	2020	2025	2030	2035	2040	2045	2050
CO_2 price (€$_{08}$/t CO2e)	25	39	62	69	100	218	370

EU Energy Roadmap, 2013

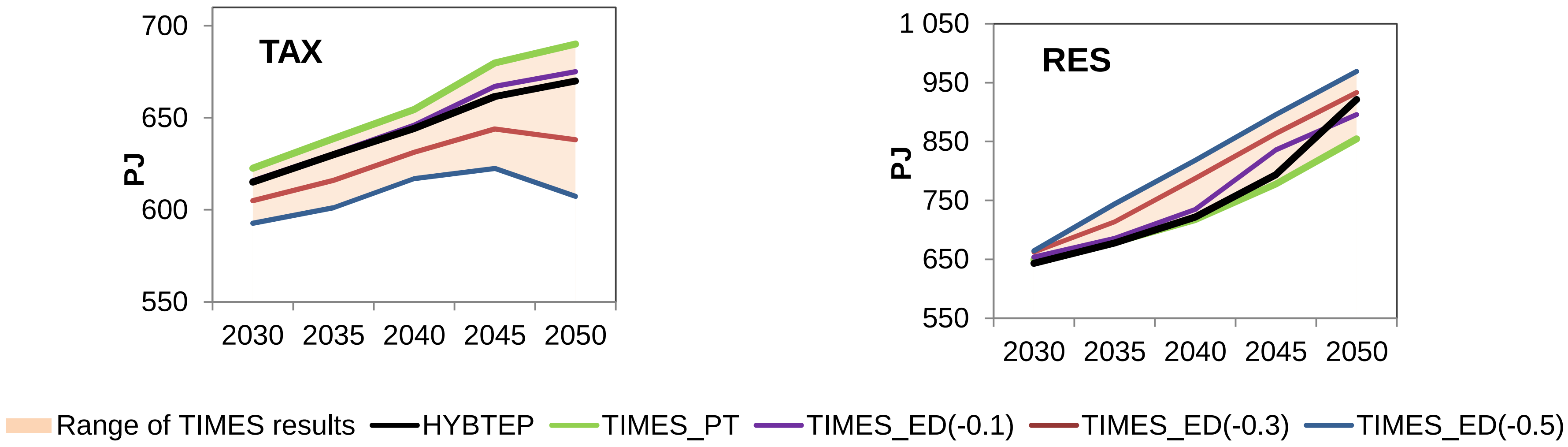
- **Subsidy to all RES**

50 €08/MWh in 2020 → 191 €08/MWh in 2050

EU Energy Roadmap, 2013

Fortes et al (2014) *Energy*

Final Energy Consumption



HYBTEP

- **CO_2 tax** → additional revenue to government, which is recycled to the economy → reduction in labor costs, partially offset the increase in energy costs in production.

- **RES subsidy**→ less available revenues to spend on public consumption and to reduce employers' social security tax. Reduction in energy prices, financed by an increase in labor costs, leads to small impact on production and demand

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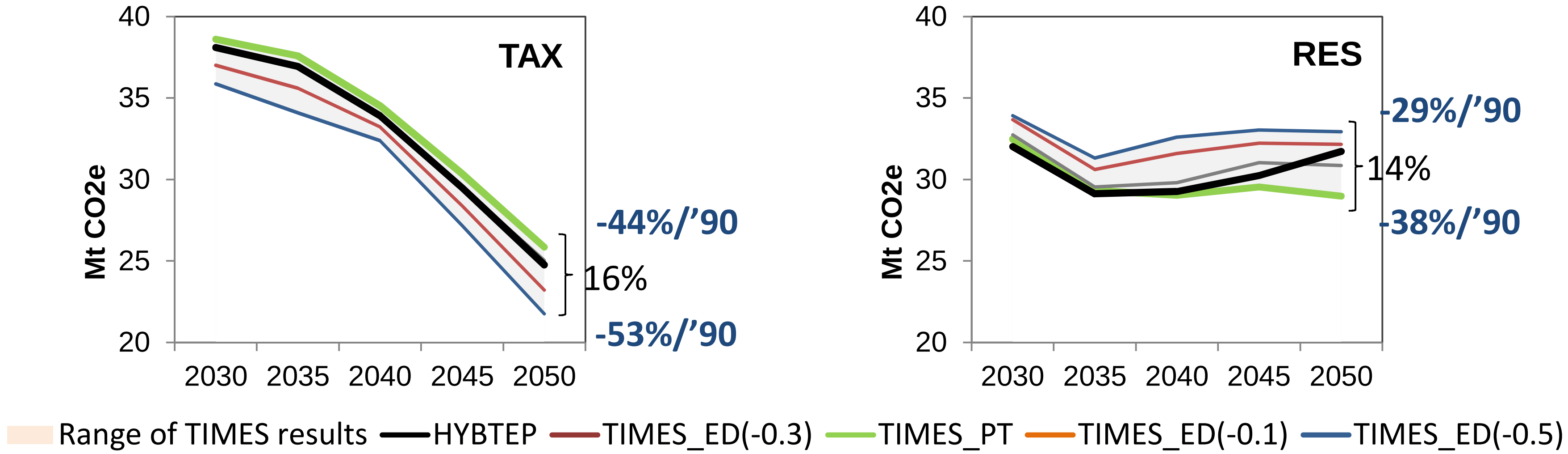
Greenhouse Gas Emissions



- **CO_2 tax** → Slightly higher reduction of GHG emissions with Hybtep than with TIMES technological model (no elasticities)
- **RES subsidy**→ TIMES technological model (no elasticities) induce higher GHG reductions than Hybtep
- TIMES elasticities are mostly homogenous across sectors, not capturing its specificities.
- TIMES presents a wide range of results.

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Economic Impacts

		2030			2050		
		Index (2005=1)	% change from CALIB		Index (2005=1)	% change from CALIB	
		CALIB (no policy)	TAX	RES	CALIB*	TAX	RES
GDP		1.3	-1.0	-0.9	1.7	**-2.4**	**2.8**
Private Consumption		1.3	-0.6	-0.4	1.9	1.1	1.3
Production		1.2	-1.0	-1.1	1.4	-2.4	2.9
Domestic demand		1.2	-0.3	0.0	1.7	-0.5	2.7
Exports		1.2	-2.3	-2.9	3.6	**-6.8**	**7.7**
Imports		1.2	-0.4	-0.7	1.5	1.6	2.5
Service	Production	1.2	-0.4	-0.3	1.6	-0.9	0.4
	Domestic demand	1.2	-0.5	-0.3	1.6	-1.0	0.6
	Exports	1.4	0.4	-1.0	1.7	1.1	-3.0
	Imports	1.4	-0.7	0.1	2.0	-1.4	2.0
Industry	Production	1.3	-1.4	-1.7	1.7	**-2.4**	**7.2**
	Domestic demand	1.3	-0.4	-0.2	1.8	**1.2**	4.3
	Exports	1.2	-3.0	-4.1	1.6	**-7.5**	**13.3**
	Imports	1.3	0.0	0.2	1.8	4.6	4.0

- The results are due to the balance between the financial instrument modeled and the revenue recycling scheme translated in a balance between energy and labor cost.

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AGENDA

I Low Carbon Energy and Climate are shocks for the economies?

II Modeling energy and climate: bottom-up TIMES_PT models and top-down GEM-E3_PT

III Hybrid modeling tool for the Portuguese case

IV **Final remarks**

- Planning the shift of energy systems to low carbon energy production is not a simple task, with important effects in the economy
- Modelling energy and/or climate policies with HYBTEP allows to:
  - Obtain the most cost-effective technology portfolio and simultaneously;
  - Examine the mechanisms driving changes in demand, namely those associated with the changes in domestic production

Maximization of households utility and firms profits in a context of the most cost-effective technology options

It is strongly recommended to deepen the research on linking technological and economic modeling tools

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“SCOPE do workshop:
In a global world, risks are inherent to the open nature of all systems. To address this global risk, countries need consider the capacity of the economic system to respond to the challenges posed by external shocks.

The world economic forum in the global risk report 2013 applies the concept of resilience to assess national preparedness to this global risk. External risks are defined as those beyond one’s capacity of influence or control (Kappla and Mikes, 2012).

The best way to deal with the exogenous nature of the external risk is to develop resilience. Resilience in economics might be described as the “nurtured” ability of the economy to recover from and adjust to the effects of adverse shocks to which it may be inherently exposed (Brigulio et al. 2014). Several approaches focus the resilience of the systems mainly at the economic and ecosystem’s level.
The current workshop extends the opportunity to discuss resilience to external shocks and the role of economic models to support the policy decisions.”

TIMES objective function: discounted total system cost

$$NPV = \sum_{r=1}^{R} \sum_{y \in YEARS} (1+d_{r,y})^{REFYR-y} \bullet ANNCOST(r,y)$$

where:

NPV	is the net present value of the total cost for all regions (the TIMES objective function);
ANNCOST(r,y)	is the total annual cost in region *r* and year *y*;
$d_{r,y}$	is the general discount rate;
REFYR	is the reference year for discounting;
YEARS	is the set of years for which there are costs, including all years in the horizon, plus past years (before the initial period) if costs have been defined for past investments, plus a number of years after EOH where some investment and dismantling costs are still being incurred, as well as the Salvage Value;
R	is the set of regions in the area of study, and