Final Report

A New Growth Path for Europe

Generating Prosperity and Jobs in the Low-Carbon Economy

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A study commissioned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

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Contents

1 Executive summary 5

2 Previous studies 9

3 The European power system 19

4 European import dependency on natural gas 28

5 Micro-costs and macro-benefits 35

6 Why Green Growth is possible 42

7 Modeling methodology 53

8 Simulations 73

9 Growth, jobs, and emissions 79

10 Measures 90

11 The Role of the New Member States 99

12 Green Growth and energy intensive industries 108

13 Historical context 124

List of Figures

Fig. 1: The impact of the EU 20/20/2020 package on welfare in 2020 for the EU27, in % . . . 12

Fig. 2: The cost of carbon inside and outside the EU ETS in 2020, in €/tCO$_2$ . . . 12

Fig. 3: Percentage change in output energy intensive industries EU in 2020 . . . 16

Fig. 4: Number of wind turbine plants built per decade . . . 20

Fig. 5: Number of solar plants built per decade . . . 21

Fig. 6: Electricity production by decentralized cogeneration 1982–2004 excluding district heating . . . 24

Fig. 7: Combined heat and power generation . . . 25

Fig. 8: Electricity prices for industrial consumers . . . 27

Fig. 9: Scenarios of EU27 gas demand . . . 28

Fig. 10: Map of conventional basins, wells and non-conventional deposits . . . 31

Fig. 11: Current export infrastructure from Southern Mediterranean and Iraq to Europe, 2010 . . . 34

Fig. 12: Micro vs. macro economic cost curves . . . 35

Fig. 13: Multiple equilibria of the Solow growth model in the labour-capital plane . 37

Fig. 14: Some interactions in the Lagom generiC model . . . 41

Fig. 15: Transitions between growth regimes in the Lagom generiC model . . . 41

Fig. 16: GEM-E3 economic circuit . . . 55

Fig. 17: GEM-E3 simulation procedure . . . 56

Fig. 18: GEM-E3 production nesting scheme . . . 57

Fig. 19: Changes at sectoral level (2020 – EU27) . . . 76

Fig. 20: GDP and equivalent variation in M30 simulations . . . 78

Fig. 21: Production in M30 . . . 78

Fig. 22: Two scenarios for Europe in 2020 . . . 79

Fig. 23: Production by sector, EU27 . . . 81

Fig. 24: A technology roadmap for the investment and development of low carbon technologies . . . 95

Fig. 25: Compare results Green Growth vs. business as usual Poland . . . 104

Fig. 26: Households' specific energy consumption (kWh/m^{2}a) scaled to EU average climate. Hungary vs. CEE Member States. Average 2000–2007 — 3CSEP2010 . . . 105

Fig. 27: Compare results Green Growth vs. business as usual Hungary . . . 107

Fig. 28: World GHG emission by sector . . . 109

Fig. 29: Industrial final energy use . . . 110

Fig. 30: CO_2 emissions by sector: EU27, excluding LULUCF . . . 111

Fig. 31: Varieties of crises: World aggregate, 1900-June 2010, composite index . . . 124

Fig. 32: Economic sentiment indicator and GDP evolution in the EU . . . 125

Fig. 33: Economic sentiment indicator and GDP evolution in Germany & Spain . . . 125

Fig. 34: Longer time perspective of the economic sentiment indicator . . . 126

Fig. 35: Employment rates in the EU, USA and Japan, 1975-2008 . . . 126

Fig. 36: Unemployment rate in the US and EU15, 1993-2009 . . . 127

Fig. 37: Greenhouse gas emissions, EU27, 1990-2008 . . . 128

Fig. 38: Greenhouse gas emissions by source sector, EU27 . . . 128

Fig. 39: Green growth stimuli commitments, selected nations, in $ bn . . . 131

Fig. 40: Global green growth stimuli, by sectors . . . 131

Fig. 41: Venture capital /private equity, by sector worldwide, in $ bn 2004-2009 . . . 132

List of Tables

Table 1: Range of energy scenario results EU27-2020 . . . 10

Table 2: Compliance cost EU27-2020 . . . 10

Table 3: CGE models used in the EMF study for M20 assesment . . . 11

Table 4: Comparison of macro assumptions of 2007 and 2009 baselines . . . 13

Table 5: Energy scenario results EU27-2020 . . . 14

Table 6: Effects of M30 in EU27 . . . 14

Table 7: Sectoral greenhouse gas emissions . . . 15

Table 8: Net investment in power generation capacity 2015-2020 . . . 15

Table 9: Main findings of CCS 2010 . . . 17

Table 10: Three strategies and 10 policy directions in Korea's 5-year green growth plan . . . 18

Table 11: Estimated effects of Korea's five year plan for green growth 18

Table 12: Nuclear power plants: Levelised costs of electricity in $ per MWh 22

Table 13: EU27 power mix in 2010 and 2020 26

Table 14: Historical learning rates for selected power producing technologies . . . 59

Table 15: Base year cost structure and market shares of power producing technologies EU27 . . . 60

Table 16: Base year electricity generation costs 61

Table 17: Estimation of GEM-E3 World MACC 68

Table 18: GEM-E3 activities linked to non-energy related GHG emissions 69

Table 19: Income elasticities 71

Table 20: Substitution elasticities 72

Table 21: Armington cities 72

Table 22: M20 EU27 macroeconomic aggregates 73

Table 23: GHG emission reductions compared to 2005 based on the COP-15 pledges 74

Table 24: Overview of M30 base case impact on key variables (EU27 % changes from reference case) . . . 76

Table 25: Macroeconomic features, EU27 80

Table 26: Macroeconomic features, EU15 82

Table 27: Macroeconomic features, EU12 83

Table 28: Macroeconomic features by country, EU15 84

Table 29: Macroeconomic features by country, EU12 85

Table 30: Main focus of climate policy making 90

Table 31: Eastern European energy system in the perspective of the EU27 averages 99

Table 32: Macroeconomic features, Poland 103

Table 33: Macroeconomic features, Hungary 107

Table 34: Energy-intensive industry market structure and economic significance . . 113

Table 35: Overestimation of the cost of compliance with new regulation 121

Table 36: GHG emissions (in thousend tons CO_2e-equivalent) in Europe 127

1

Executive summary

> *Josef Ackermann: "Make no mistake: a new world order is emerging. The race for leadership has already begun. For the winners, the rewards are clear: Innovation and investment in clean energy technology will stimulate green growth; it will create jobs; it will bring greater energy independence and national security."* [1]

> *Jean-Claude Trichet: "When the crisis came, the serious limitations of existing economic and financial models immediately became apparent. In the face of the crisis, we felt abandoned by conventional tools. [. . .] we need to develop complementary tools to improve the robustness of our overall framework [. . .] we may need to consider a richer characterization of expectation formation."* [2]

Post-crisis Europe can revitalize its economy by tackling the climate challenge. Raising the European climate target from 20% to 30% emissions reductions can open the way towards higher growth and increased employment. The financial crisis has reduced European GDP by several percentage points; if business as usual prevails, the EU growth path will proceed at a lower level than before the crisis. What is more, under business as usual it will be hard to even maintain the growth rate of the pre-crisis times. As a result, unemployment across Europe is likely to stay high, with major disparities between different regions. Sticking to the 20% target in a situation where this target has become too weak to mobilize innovations and to stabilize political will is the equivalent of digging deeper while being stuck in a hole.

It is time for boldness. Clear policies associated with a decisive move to a 30% target, can be doubly beneficial for the climate and the EU economy. The climate target must not be pursued in isolation, but be embedded in a comprehensive range of measures, setting expectations for growth of the European economy at a more ambitious level. What matters is to explicitly declare an ambitious growth target in the aftermath of the financial crisis and to pursue this target on a variety of fronts – including incentives for additional investment, growth-oriented fiscal policy, public procurement, and, of course, climate policy. With this strategy, Europe can define its role in the global economy by focussing on high-quality products where stable unit costs do not depend on low wages but on continuous learning-by-doing. European industry can then maintain and enhance its competitiveness by developing the low-carbon materials and technologies that will shape the future.

In the coming decade, Europe will need to accept the challenge of increasing economic growth while reducing both unemployment and greenhouse gas emissions. New model results show that these three goals can actually reinforce one another. Over the coming decade raising the EU's climate target from 20% to 30% can foster the following outcomes by 2020:

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[1] CEO of Deutsche Bank, December 2010 (Ackerman 2010).

[2] President of the European Central Bank, November 2010 (Trichet 2010).

- increase the growth rate of the European economy by up to 0.6% per year
- create up to 6 million additional jobs Europe-wide
- boost European investments from 18% to up to 22% of GDP
- increase European GDP by up to $\$_{2004}842$ bn
- increase GDP by up to 6% both in the old (EU15) and new (EU12) member states.

The economic opportunities of a European 30% reduction scenario are available independently of an international post-2012 climate agreement. The simulations performed for the present study assume domestic reductions of 30% and no international climate agreement that would go beyond the modest pledges made in the Copenhagen Agreement of 2009. If more ambitious goals should be pursued in the future by major economies, the positive impacts for Europe would be even larger.

Along the new growth path, all broad economic sectors – agriculture, energy, industry, construction, and services – increase production, with the largest increase in construction. The new growth path implies a major effort to retrofit buildings and enhance the built environment. This is advantageous in view of employment because people with very different vocational skills can operate in these sectors after a few months of on-the-job training (in construction, as in the industry, nowadays the majority of jobs are not centered around manual work - and there too, on-the-job training can be very effective).

Emissions are reduced by increasing energy efficiency and shifting from coal to renewables and gas. Energy efficiency is mainly, but not only, a matter of buildings. Over the next decade, renewables will be mainly wind, both on- and offshore. Carbon capture, photovoltaics, and nuclear cannot make much of a difference over this time span. Nevertheless, it will be important to prepare for the longer term too. The shift towards gas can raise concerns about energy security. European imports of natural gas, however, are reasonably diversified. The largest supplier, i.e. Russia, delivers just one third of total imports. Due to the expansion of shale gas in the USA and the Chinese determination to limit dependency on energy imports, Europe is a vital customer for Russia. However, Eastern European countries need improved transport and infrastructure for gas imported into Western Europe, and storage facilities need to be improved across Europe.

The key for this revitalization is a substantial increase of investment in Europe. Building wind turbines, implementing cogeneration of heat and electricity, insulating houses, modernizing the power grid, etc., all require substantial investment. If this green investment simply displaced investment in other sectors – tool-making, health, education, etc. – growth would not speed up and employment would only be re-allocated between sectors, without reducing the number of unemployed. However, in the coming years green investment can be part of a broader surge of investment. After the global crisis of 1929, such a surge of investment in Europe as elsewhere was initiated by the perspective of military armament. Nowadays, this is obviously not an option. However, after the financial crisis of 2007–08, the perspective of sustainable development can mobilize investment in a similar way for a worthier purpose. The new model results show that it is possible to increase the EU climate target to 30% while achieving investments 25% higher than in business as usual. The share of investment in GDP, which under business as usual would be 18%, will then be up to 4 percentage points higher.

The basic mechanism creating this opportunity for a new growth path is the mobilization of a virtuous circle of additional investment, learning-by-doing and expectation formation. It works as follows:

- If the EU announces and implements a new growth strategy including an ambitious target for emissions reduction, it can trigger additional investments that increase the share of gross investment in GDP by up to 4%.
- This substantial additional investment induces learning-by-doing across the economy as a whole, and at an even higher rate when it comes to new technologies like advanced construction materials, renewable energy and more.
- Learning-by-doing in turn increases competitiveness and thus spurs economic growth, thereby improving the expectations of investors.
- If the EU stabilizes the enhanced expectations of investors by policies consistently oriented to increasing sustainability, it can stabilize the new investment behavior and lead the European economy to a superior growth path.

The experience of the global financial crisis shows that the existing economic models were seriously limited. Against this background, a fundamental overhaul of European climate policy models is required. To identify and assess options for climate policy we need models that meet the challenges exposed by the financial crisis. For example, the models that were state-of-the-art before the crisis assumed that economic systems have a single stable equilibrium. Studies based on this kind of models imply that reducing greenhouse gas emissions creates extra costs in the coming years in order to avoid damages in the distant future – thereby win-win strategies are excluded by construction. A key problem of climate policy is, however, to balance the short-term view of businesses with the much longer-term view required from policy-makers aware of climate change. The financial crisis has exposed the fact that different expectations can lead to different investment behaviors, turning those expectations into self-fulfilling prophecies. Research has now started to take this into account in models used for policy advice.

For the first time in the academic climate modeling field, the present study has taken a state-of-the-art model of climate economics and enhanced it along those lines. The enhanced model includes:

- the fact that investments depend on subjective expectations, not on correct previsions of whatever future possibilities may arise
- the fact that higher investments trigger higher learning-by-doing, thereby reducing unit costs
- the resulting existence of different possible equilibria with different growth paths.

The new simulations show that 30% is achievable and can be economically beneficial by shifting the European Economy into a new, more advantageous equilibrium – a path of low-carbon growth. This result is consistent with upper bound green growth scenarios of previous studies. However, Europe is in danger of falling prey to a self-fulfilling prophecy of low growth. The 30% reduction target offers the opportunity to break out of this predicament. This phenomenon is well known: a new challenge can mobilise capabilities that could not be tapped without it. Similarly, economic systems have different possible regimes that can be activated in the face of different challenges.

To realise the win-win opportunity that comes with the 30% reduction target requires consistent policies and measures that reframe expectations in a broader framework of low-carbon growth. In addition to existing or proposed EU policies and measures, the present study considers that the move to 30% requires the following macro- and micro-economic measures:

- Macro-economic measures, e.g.:
  - Using part of the ETS auctioning revenue and resources from the structural funds to support mitigation efforts in Eastern European countries.
  - Incentivising entrepreneurial investment by tax relief balanced with marginal tax increases on capital incomes used for other purposes.
  - Building in low-carbon growth expectations in public procurement.
  - Managing growth expectations along the lines central banks manage inflation expectations.
- Micro-economic measures e.g.:
  - Enhancing building codes to foster investment in energy efficiency; enhancing standards for energy efficiency in transport.
  - Using part of the ETS auctioning revenue to foster energy efficiency and renewable energies.
  - Standardising smart grid infrastructures and smart household appliances.
  - Creating learning networks of businesses developing innovative solutions across Europe.

2

Previous studies

The debate about European climate policy has been shaped to a considerable extent by a series of modelling studies. We first give an overview of these. It shows that their design leads automatically to macro-economic costs of mitigation measures, with costs increasing as more stringent reduction goals are aimed for. This design, however, has become problematic with the financial crisis of 2008. The European economy has left its previous growth path and is now faced with very different possibilities: the rate of growth may decrease or increase both in the short and the long run. In order to capture these possibilities, the model architecture that was common before the crisis needs to be enhanced. This need is also highlighted by analyses of green growth opportunities that have been performed in the US and in South Korea. It forms the starting point of the present study.

2.1 Overview

The literature on the assessment of mitigation policies in Europe has been structured by the dynamics of EU climate policy and the outburst of a major financial crisis in 2007. A first series of analysis, summarized in (Tol 2010), have been produced during the process leading to the EU20/20/2020 package. These consist mainly in an impact assessment commissioned by the European Commission (Capros et al. 2008) and of its review by independent authors (Bernard and Vielle 2009; Boehringer et al. 2009; Boehringer, Rutherford and Tol 2009; Kretschmer, Narita and Peterson 2009). Part of these have been reassessed in view of the financial crisis (European Commission Staff 2010a). Finally, the most recent studies have been triggered by the political momentum to move beyond 20% greenhouse gas emission reductions in Europe (European Commission Staff 2010a). These studies consider mainly two effects: the substitution of fossil fuels by renewables and the reduction of energy use by energy efficiency measures. Both effects are assumed to involve social costs in the short run. Their only possible justification is seen in the avoidance of long-term costs from climate change. A simple linear dynamics is assumed by which social costs increase for every additional unit of greenhouse gas avoided. As a result, the reduction of 30% is seen as more costly than a reduction of 20% of the GHG emissions.

For brevity, in the present report the goal of -30% emissions is called M30 from now on; the goal of -20% emissions is called M20.

2.2 Climate policy before the financial crisis

2.2.1 The EU assessment study

The reference study on M20 before the financial crisis (Capros et al. 2008) was commissioned by the European Commission and performed using the PRIMES[3] equilibrium model of the European energy system. It analyzes the implementation of the EU20/20/2020 package under various scenarios on the flexibility mechanisms associated to the emission reductions and renewable energy sources (RES) constraints as well as the price of fossil fuels.

The intrinsic features of these scenarios can be described in terms of carbon price, emission reductions achieved internally and value of the energy supply from RES as reported in Table 1.

Table 1: Range of energy scenario results EU27-2020

	Lower bound	Upper bound
Internal GHG reduction vs 1990	−14.8	-20.0
RES share in Gross final energy	20.0	20.0
Carbon-price EU-ETS €/ton	30.0	47.0
Carbon value non-ETS €/ton	20.9	39.2
RES values energy supply €/MWh	44.5	53.0

Source: Capros et al. (2008) [Table 7].

The major lines of a sensitivity analysis are that the carbon value and the internal emission reductions decrease with the access to clean development mechanisms and that the value of RES energy supply decreases when member states are offered the possibility to trade guarantee of origins for RES[4].

The PRIMES model having been calibrated according to a BAU scenario without sustainability emissions and energy constraints, macroeconomic effects are then described in terms of compliance costs vis-à-vis this baseline. As reported in Table 2, these generically lie below one percent.

Table 2: Compliance cost EU27-2020

	Lower bound	Upper bound
% GDP in 2020	−0.48	-0.7
billion €2020	90	110

Source: Capros et al. (2008) [Table 8].

As for the carbon price and the RES energy value, the basic pattern of sensitivity is that compliance costs decrease with the extent of flexibility mechanisms. Two more specific findings are also highlighted. First, the joint implementation of the RES and emission targets is more efficient than that of the RES target alone (approximately €18 bn in 2020). Second, in case of high fossil fuel prices, the M20 package performs much better than the BAU scenario (0.4% vs. 1.8% GDP cost in 2020).

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[3] see http://www.e3mlab.ntua.gr/manuals/PRIMsd.pdf

[4] Based on http://www.swissgrid.ch/power_market/renewable_energies/guarantees_of_origin/

2.2.2 The Energy Modeling Forum review

An independent assessment (Boehringer, Rutherford and Tol 2009) of the EU20/20/2020 package has been performed in the framework of the energy modeling forum[5], using a series of computable general equilibrium models (whose taxonomy is presented in Table 3).

Table 3: CGE models used in the EMF study for M20 assesment

Model	M20 impact study references	Link to model description
Pace	Boehringer et al. 2009a	http://www.transust.org/models/pace/
DART	Kretschmer et al. 2009	http://www.narola.ifw-kiel.de/narola-models/dart/
Gemini E3	Bernard and Vielle 2009	http://gemini-e3.epfl.ch/
WorldScan	Boeters and Koornneef 2010	http://www.cpb.nl/eng/model/worldscan.html

Source: Boehringer, Rutherford and Tol (2009) - links last visited in Nov. 2010.

By design, these models evaluate climate policies in terms of costs vis-à-vis a business as usual scenario. They consequently phrase their results in terms of a carbon price and of an impact on welfare in 2020, which correspond to a marginal and an absolute version of the cost.

A comparative analysis of these studies is presented in (Tol 2010) whose main results are reported in Figures 1 and 2. The implementation of the package comes at a mean cost of 1.3% welfare loss in 2020 (with a standard deviation of 1.6%) through a mean carbon price of €75 per ton (with a standard deviation of €52). If the package is implemented optimally (in general equilibrium terms if there is an uniform carbon price among member states and among ETS and non-ETS sectors) the welfare loss goes down to 0.7% (with a standard deviation of 0.6%) and the carbon price to €44 (with a standard deviation of €22).

Moreover, if one discards a particular estimate which lies far out of the sample (Kretschmer, Narita and Peterson 2009), which assumes a 30% renewable target, the mean welfare loss falls to 0.7% (0.5% in the first-best case) and the standard deviation to 0.4 (0.15 in the first-best case).

As far as the sensitivity of these results is concerned, Tol (2010, p. 19) puts forward that an analysis based on CGE models implies that emission reductions costs increase if:

- Different countries, sectors, or emissions face different explicit or implicit carbon prices (Boehringer, Loeschel and Rutherford 2006; Boehringer, Hoffmann and Manrique-de-Lara-Penate 2006; Boehringer, Koschel and Moslener 2008; Manne and Richels 2001; Reilly et al. 2006).
- The carbon prices rises faster or more slowly than the consumption discount rate (Manne and Richels 1998; Manne and Richels 2004; Wigley, Richels and Edmonds 1996).
- Climate policy is used to further other, non-climate policy goals (Burtraw et al. 2003)

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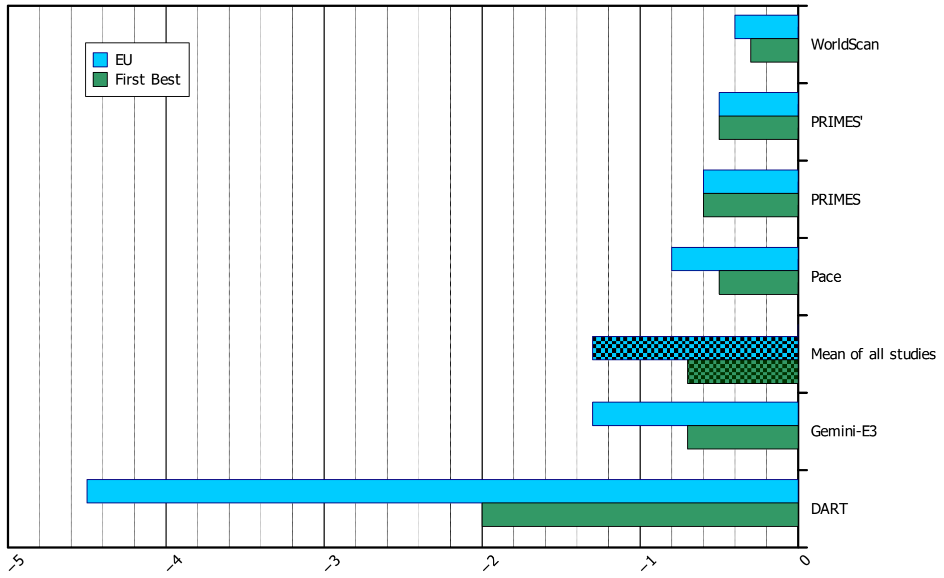
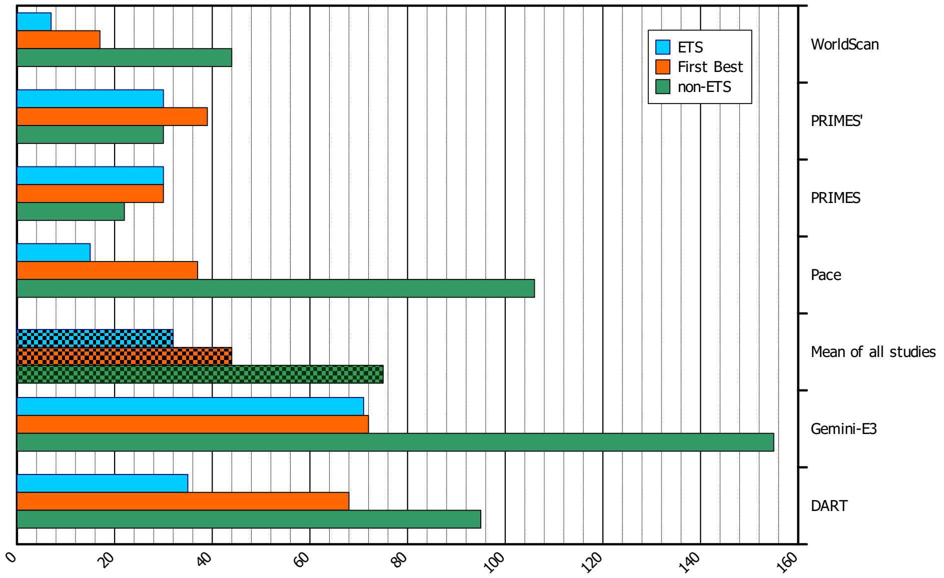
[5] see http://emf.stanford.edu/

Figure 1: The impact of the EU 20/20/2020 package on welfare in 2020 for the EU27, in %



Source: Tol (2010).

Figure 2: The cost of carbon inside and outside the EU ETS in 2020, in €/tCO$_2$



Source: Tol (2010).

- Climate policy adversely interacts with pre-existing policy distortions. (Babiker, Metcalf and Reilly 2003).

These conclusions hold in a framework where the business-as-usual scenario is, by construction, the optimal possibility as long as the long term costs of climate change are not internalized. The occurrence of the financial crisis is not part of this framework. As underlined below, when such a crisis actually occurs, the conclusions are radically different.

2.3 Climate policy after the financial crisis

The economic crisis led to a decrease of 5% of GDP in 2009 compared to 2007 in the EU27 (Eurostat 2010). As far as GHG emissions are concerned, the fall has been even sharper with a 9% decrease of emissions, the effect of the economic recession superimposing itself on the sustained trend of decrease in emissions since 2003 (European Environment Agency (EEA) 2010b). As a result, total GHG emission in 2009 were 17% below the 1990 level, almost reaching the M20 target.

These major developments led to a new assessment of the EU20/20/2020 package, in the process of elaborating the EU commission communication on options to move beyond 20% greenhouse gas emission reductions (European Commission Staff 2010a). This new assessment is also based on the PRIMES model (Capros et al. 2008) but uses a new baseline with macro-economic features consistent with the "sluggish recovery" scenario of the Europe 2020 strategy (Communication from the Commission 2010) and also takes into account up-to-date population projections (EUROPOP2008 convergence scenario from (Eurostat 2010)). As Table 4 underlines, this new baseline assumes a GDP loss of 10% (13% in per capita terms) in 2020 compared to the pre-financial crisis one. This is one order of magnitude larger than the estimates of costs associated with climate policies presented in the previous section.

Table 4: Comparison of macro assumptions of 2007 and 2009 baselines

	2005	2020 Baseline 2009	2020 Baseline 2007
Population (millions)	489	513	496
GDP (billion €2008)	11687	14963	16572
GHG emissions reduction (% from 1990)	-7.5	-13.8	-1.5
Coal import price $2008/boe	14	25.8	16
Gas import price $2008/boe	39.7	62.1	50

Source: European Commission Staff (2010a) [Table 4].

As a matter of fact, these macro-economic developments, as well as the increase in fossil fuel prices, considerably lower the estimates of the costs of the M20 package. According to simulations performed using the new baseline, the costs of the package come at €48 bn in 2020, or 0.3% of GDP.

This decrease in costs is also reflected in the evolution of the carbon price (Table 5) which falls to €17 in the ETS sector and €4 in the non-ETS sectors (ten Member States are projected to meet their non-ETS target already in baseline). However, the value of energy from renewable energy sources remains relatively high. The interpretation of these results is very clearcut:

Table 5: Energy scenario results EU27-2020

Internal GHG reduction vs. 1990	−20
RES share in Gross final energy	20
Carbon-price EU-ETS €/t	16.5
Carbon value non-ETS €/t	4
RES values energy supply €/MWh	50

Source: European Commission Staff (2010a) [Table 7].

> A major difference with the projections for the analysis under the Climate and Energy Package (Capros et al. 2008) is that the achievement of the renewables targets will go a longer way towards reaching the GHG reduction targets outside the EU ETS than originally modeled and there are much less additional carbon price incentives necessary to reduce GHG emissions so that the 2020 climate targets are reached. The lower economic growth forecast has made achievement of the GHG reduction targets easier whereas it does help less for the achievement of the renewables target, and the latter therefore dominates the efforts needed for target fulfillment. (European Commission Staff 2010b p. 33)

2.4 The goal of 30% emission reductions

The roughest estimates of the M30 target can be obtained through a linear extrapolation of the results surveyed in (Tol 2010). This leads to an estimate of 2% GDP loss in 2020. However, such an approximation is based only on studies performed before the financial crisis.

Much more detailed results are provided in (European Commission Staff 2010b) using the new 2009 baseline. The estimates of macroeconomic outcomes are summarized in Table 6. These estimates vary according to the assumptions made about the level at which Copenhagen pledges are implemented in the rest of the world, the access to international carbon credit markets, the modes of allocation of permits in the ETS sectors and the modes of recycling of revenues from the ETS.

Table 6: Effects of M30 in EU27

Variable	Lower Bound	Upper Bound
GDP (% change from M20)	−1.5	0.6
Employment (% change from M20)	−0.6	+0.7
Carbon price ETS (€per ton)	30	55
Energy consumption (% change from M20)	−3.5	-6.5
Renewables share in energy consumption (%)	20	22
Reduced oil and gas imports (billion €)	−9	-14

Source: European Commission Staff (2010a).

The overall picture suggests a relatively mild effect on employment and GDP with a carbon price between €30 and €55. If the revenues from ETS are recycled by reducing labour costs, M30 could create up to one million additional jobs (+0.7%). Other potential benefits are the decrease of the energy consumption and of the imports of fossil fuels.

As underlined by Table 7, the major contribution to emission reduction is found in the energy supply sector whose emissions should decrease by an additional 26% compared to M20. This reduction is performed through a shift in the power mix induced by massive investment in power generation capacity from renewable sources (Table 8).

Table 7: Sectoral greenhouse gas emissions

	M30 vs M20
% change CO_2 emissions Power and Distr. stream	-26
% change CO_2 emissions other sectors	-6
% change energy non-CO_2 emissions	-6
% change agricultural non-CO_2 emissions	-9
% change other non-CO_2 emissions	-8

Source: European Commission Staff (2010a) [Table 8].

Finally, the commission assessment gives a detailed analysis of the influence of the implementation of the M30 target on energy intensive industries. The results are very sensitive to access to international carbon markets and to pledges implemented outside the EU. Still, for almost all industries and all scenarios, the difference in output between M20 and M30 lies below one percentage point (Figure 3).

Table 8: Net investment in power generation capacity 2015-2020

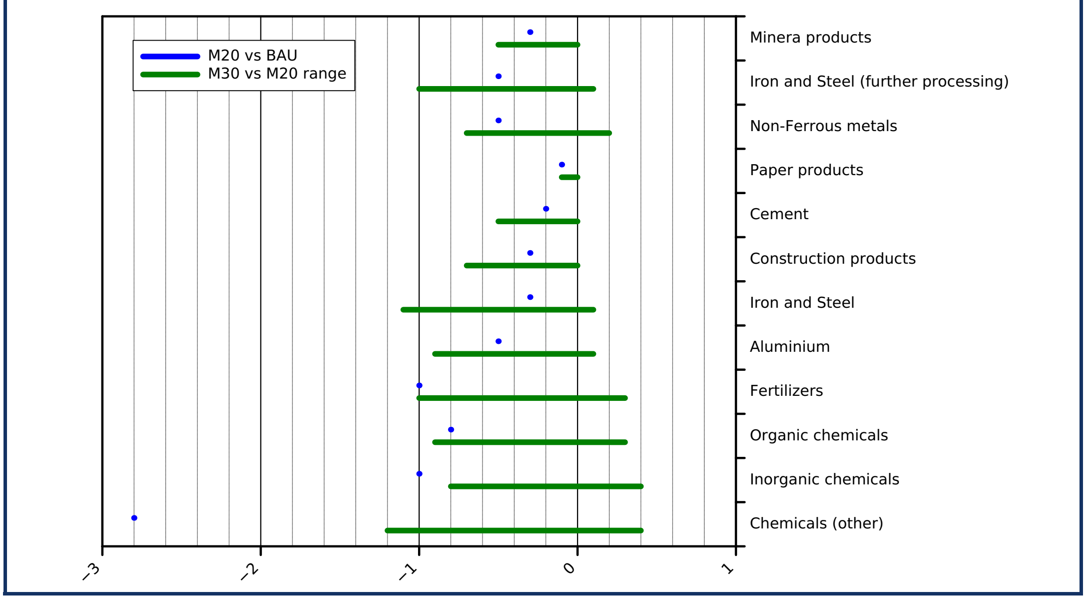
	M30 vs. M20
Nuclear energy	10.2
Coal and lignite	9.5
Petroleum products	3.5
Gas (including derived gases)	6.4
Biomass and waste	16.9
Hydro	3.3
Wind	84.2
Solar	27.9
Geothermal	3.6

Source: European Commission Staff (2010a) [Table 10].

2.5 Current limits of CGE modeling

The differences between the studies considered so far are relatively small (Kretschmer, Narita and Peterson 2009). If the assumptions made in these studies are incorporated in the GEM-E3 model used for the present study, very similar results are obtained. However, these assumptions neglect two major economic effects: the effect of investment on learning-by-doing and the effect of expectations on investment. These effects are well-established both on empirical and theoretical grounds. However, they are hard to implement in existing CGE models and have been neglected so far. The main point of the present study is to take them into account in order to reach a more realistic assessment. The necessity of this methodological updating is illustrated below by contrasting the results of the previous CGE analysis with those of two recent studies on green growth potential in the American (Center for Climate Strategies 2010) and the Korean (United Nations Environment Programme 2010) economy. Focusing on the economic stimulus triggered by a bold policy of green investments, they yield radically different results qualitatively and quantitatively.

Figure 3: Percentage change in output energy intensive industries EU in 2020



Source: European Commission Staff (2010a) [Table 29].

2.6 A complementary perspective 1: the Johns Hopkins study on the American economy

The report on "Impacts of Comprehensive Climate and Energy Policy Options on the U.S. Economy" of the Center for Climate Strategies at Johns Hopkins University (Center for Climate Strategies 2010) examines the impacts of the "implementation nationwide of climate policy measures based upon action plans developed in 16 [American] states."

This assessment is based on a microeconomic analysis of 23 climate policy measures proposed by stakeholders complemented by a macro-analysis performed using the "Regional Economic Models, Inc (REMI) Policy Insight Plus (PI+)", a structural economic model with 169 sectors.

Three scenarios, built upon the set of 23 climate policy measures, are considered. The first scenario considers the full implementation of these 23 measures leading to a 27% reduction of U.S. emissions in 2020 compared to 1990 (37% compared to 2010). The second scenario adds the feature of a limited cap-and-trade program and the third considers a scaled-down version leading to a reduction of 17% below 2005 levels (equivalent to 1990 levels).

As summarized in Table 9, the study (taking into account the effects of the economic crisis) shows that, if fully implemented, the climate policy measures could yield 2.5 million jobs and a $160 bn GDP expansion in 2020. Among the measures considered, "demand side management programs" in the energy sector is by far the most productive one, yielding the net creation of 0.9 million jobs and an increase in GDP of $90 bn in 2020 (Kannberg et al. 2003).

Table 9: Main findings of CCS 2010

Scenario	2020 GHG Reductions (BMtCO$_2$ e)[†]	2020 Direct Net Costs/Savings (billion $)[‡]	2020 Net New Jobs (million $)	2020 GDP Expansion (billion $)	Total 2020 New Gov't Revenue[*] (billion $)
23 Stakeholder Policy Recommendations at Full Implementation	3.2	-5.1	2.52	159.6	n.a.
23 Stakeholder Policy Recommendations at Full Implementation, plus Cap-and-Trade & Revenue Recycling	3.2	-5.1	2.13	116.9	19.2
23 Stakeholder Policy Recommendations at Congressional Economy-Wide Target levels, plus Cap-and-Trade & Revenue Recycling	1.7	-6.7	0.92	50.7	19.2

[*] *Direct revenues from Cap-and-Trade program allowance auction, not including use or distribution of revenues* [†] *Reduction from estimated business-as-usual 2020 baseline emissions of 7.7 BMtCO$_2$ e; BMtCO$_2$ e = billion metric tons of carbon dioxide equivalent* [‡] *Negative numbers in this column indicate net savings*
Source: Center for Climate Strategies (2010) [Table ES-1].

The main driver of these results is the reduction of production costs via improved energy efficiency: the majority of the measures have positive impacts even if implemented individually (the measures have been selected and assessed after a comprehensive analysis massively involving stakeholders). The other driver of the results is the stimulus on demand produced by increased investment. This explains in particular why the third scenario performs less well and that the major obstacles foreseen for the success of the policy are barriers to investment.

As far as sensitivity analysis is concerned, it is pointed out that the magnitude of the positive outcome increases as the capital costs decrease and the avoided energy costs increase.

2.7 A complementary perspective 2: the UNEP assessment of Korea's green growth plan

The Korean government has launched a five year plan for green growth over the period 2009-2013, with a commitment to spend 2% of gross domestic product for investment in areas such as green technologies, resource and material efficiency, renewable energies, sustainable transport, green buildings, and ecosystem restoration (Table 10). The plan has been reviewed by the United Nations Environment Programme (United Nations Environment Programme 2010) which is the main source for the present summary.

This plan is funded with $83.6 bn, representing 2% of GDP. It aims at reducing the greenhouse gas emissions by 30% in 2020 compared to the business-as-usual situation, increase the share of renewable energies from 2.7% in 2009 to 6% in 2020 and to enhance energy efficiency from 0.29 toe/$ in 2013 to 0.233 toe/$ in 2020.

According to two scenarios developed by the Presidential Committee on Green Growth (Table 11), and evaluated using input-output analysis (United Nations Environment Programme 2010),

Table 10: Three strategies and 10 policy directions in Korea's 5-year green growth plan

Strategies	Policy directions
Measures for climate change and securing energy independence	Reduce carbon emissions
	Decrease energy dependence and enhance energy self-suffice
	Support adaption to climate change impacts
Creation of new growth engines	Develop green technologies as future growth engines
	Greening of industry
	Develop cutting-edge industries
	Set up policy infrastructure for green growth
Improving quality of life and strengthening the status of the Country	Green city and green transport
	Green revolution in lifestyle
	Enhance global cooperation on green growth

Source: United Nations Environment Programme (UNEP) and New Energy Finance (2010).

the plan is expected to stimulate a yearly average production inducement of \$28.3 bn to \$31.2 bn, representing 3.5% to 4.0% of estimated 2009 GDP. The effects on employment amount to the creation of up to 1.8 million jobs in 2013.

Table 11: Estimated effects of Korea's five year plan for green growth

	Economic gains					
	Production inducement (billion \$)		Value-Added inducement (billion \$)		Job creation (thousand people)	
Indicator/period	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
2009—2013	141.1	160.4	58.4	73.9	1, 561	1, 805
Yearly average	28.3	32.1	11.7	14.8	312	362
Ratio of Yearly Average to GDP (%)†	3.5*	4.0*	1.5*	1.8*	34.4†	39.8†

* *Estimated 2009 GDP WON - 1,029.5 tr (= \$801.0 bn)* † *Number of unemployed in 1st quarter 2009 (908,000)*
Source: United Nations Environment Programme (UNEP) and New Energy Finance (2010).

Fiscal and financial incentives are recognized as keys in this transition towards green growth. Among the measures envisaged are tax benefits to individual investors, the issuance of long-term and low-interest green bonds and savings, and the creation of a green fund aimed at facilitating access to credit by small and medium-sized enterprises.

3

The European power system

After having discussed previous studies, we now ask what steps to decarbonise the European power system are feasible in the decade up to 2020. The main path to decarbonisation of the European power system comes from reducing energy consumption, while using less coal. The main substitutes for coal are natural gas, nuclear and renewables. While in the longer term renewables have the potential to become the main source of power due to their stronger cost reduction potential, over the next decade the pace of growth will be set by balancing the upscaling of production with the different learning curves. In this period nuclear is unlikely to be a big contributor to the replacement of coal, essentially due to high cost, low industry capacity and very long planning periods. Power from natural gas, with half the carbon intensity of coal, will therefore play an essential role for European climate policy in this decade.

3.1 Pacing renewables

Both investing too fast and too slowly in renewable technology is expensive in meeting the stated goal of 80% CO_2 reduction in 2050. The learning-by-doing rate depends on the ratio of investment to total capital in each sector, and is higher for successful new technologies than for established ones. European Climate Foundation (2010) estimates wind cost reductions at 5% and solar PV at 15% per doubling of the installed base, compared to a stable learning rate of 0.5% for mature technologies such as coal or gas.

The question whether renewable power technologies can function as baseload for the European system has been addressed comprehensively in the (European Climate Foundation 2010) study, with detailed simulations. The conclusion is that both technically and economically a system with nearly 100% renewable technologies is feasible, predicated on a substantial investment in the transmission backbone. The load balancing opportunities within the EU27 are sufficient to offset the intermittency of renewable power technologies, albeit with appropriate generation over capacity. The report states:

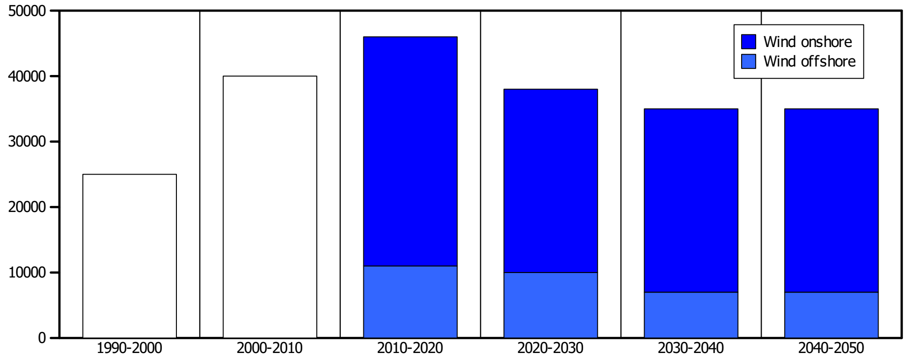
> A significant challenge is the provision of low load factor dispatchable capacity that can be available, for example in winter when there is less solar production and demand is higher. Roughly 10% to 15% of the total generation capacity would be needed to act in a backup arrangement with low load factors. The preferred technologies for the backup service are yet uncertain, and the attractiveness of the various options needs to be assessed in more depth. Currently, likely options include: extensions of existing flexible plants but limited to very low utilization rates; new gas-fired plants (e.g., open- cycle gas turbine plants without CCS); biomass/ biogas fired plants; and hydrogen-fueled plants, potentially in combination with hydrogen production for fuel cells. The implications for gas or hydrogen networks have not been studied in detail. Storage is optimized to create additional flexibility. The study has not assumed any additional large-scale storage capable of shifting large amounts of energy between seasons but with new technology this may become an economic alternative. Neither has vehicle-to-grid storage been as-

> sumed. If proven economic and feasible, this could enhance the balancing capability of the system.(European Climate Foundation 2010 pg. 12)

Significantly, the combination of solar and wind is more stable than wind alone. While this is a useful result, in practice this will only come about as a result of a series of decisions and investments over decades, enabling learning and correction along the way.

Within the longer-term context, our focus here is on the decade 2010–2020. Between 2000 and 2010, 40,000 wind turbines were installed. If in the following decade this pace is maintained, albeit with increasing size of turbines and higher off-shore proportion, this will put the share of wind at one fifth of the generation capacity in 2020. This assumes an average turbine size of 3–5 MW, for an added capacity of 140 GW with a load factor of 30%. This represents roughly a tripling of the cumulative installed base of 70 GW installed generation capacity over the decade.

Figure 4: Number of wind turbine plants built per decade



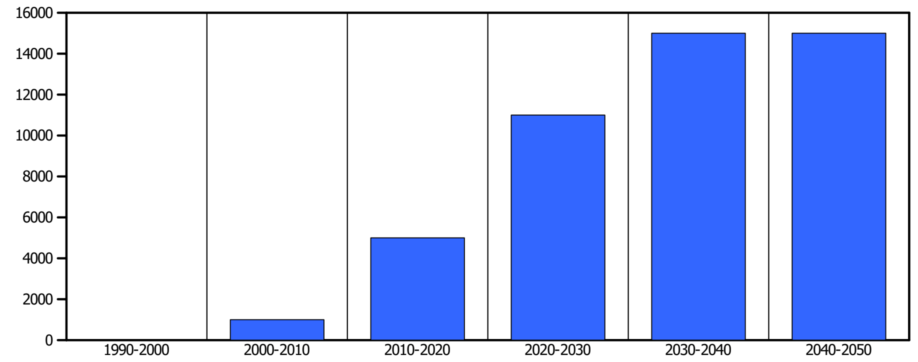
The new wind turbines are much larger and partly off shore
Source: European Climate Foundation (2010), page 30 of "Appendix A - Generation" in the 80% RES scenario.

Solar PV is growing from a smaller base and is assumed to grow 3–5 fold in production size over the decade. While this is a large absolute growth, it is less in relative terms than the growth over the previous decade. The result in 2020 is 60–120 GW of solar PV capacity. With a load factor of 10% to 15% this represents 6–15 GW of power. The cumulative installed base in 2010 is around 10 GW.

3.2 Practical constraints for nuclear

Nuclear is a particular case in being a technology at the intersection of escalating costs and permitting and construction delays. It is likely that permitting issues will all but prohibit a material expansion of the installed base by 2020. Paradoxically, through unlearning-by-not-doing, the historic cost trend is upward by more than 10% p.a., making nuclear increasingly unattractive over time (Cooper 2009).

Figure 5: Number of solar plants built per decade



Source: European Climate Foundation (2010), page 30 of "Appendix A - Generation" in the 80% RES scenario.

The IEA/OECD confirms the increasing costs of installing nuclear capacity in EU27 and USA, with ranges of \$4 bn/GW – \$7 bn/GW. At this price, nuclear becomes one of the most expensive sources of power. The cost in China and Korea is reported under \$2 bn/GW, which is competitive with other generation options. In the EU27 no more than a handful of nuclear plants were built in the decade 2000–2010, compared to almost 100 in the 1980's.

The combination of the reduced practical capacity of the European nuclear industry, spiraling costs and long permitting times implies that realistically no more than 2 GW to 5 GW of nuclear capacity can be built in the decade 2010–2020. Of course, with sufficient focus and determination a nuclear renaissance in the later decades is conceivable.

3.3 CCS – not yet a second wind for coal

CCS will hardly have a significant quantitative impact before 2020, beyond a selected number of trials at scale. Pilot projects will be modest in number, most will involve injection rates of 1 million metric tons per year (t/y) or less. In parallel the regulatory frameworks, funding strategy and long-term liability management will need to be settled.

The European Energy Programme for Recovery (EEPR) was adopted in July 2009. The EEPR funds projects in the field of gas and electricity infrastructure as well as offshore wind energy and CO_2 capture and storage. 12 CCS projects applied for assistance under the EEPR. In December 2009, the European Commission granted financial assistance to six projects that could make substantial progress with project development in 2010. These projects will receive overall funding of €1 bn under the EEPR. The demonstration projects would form the basis for a potential ramp-up in the decade post 2020.

Table 12: Nuclear power plants: Levelised costs of electricity in $ per MWh

Country	Technology	Net capacity	Investment costs*		LCOE	
			5%	10%	5%	10%
		MWe	$/MWh		$/MWh	
Belgium	EPR-1600	1,600	6,185	7,117	61.06	109.14
Czech Rep.	PWR	1,150	6,392	6,971	69.74	115.06
France†	EPR	1,630	4,483	5,219	56.42	92.38
Germany	PWR	1,600	4,599	5,022	49.97	82.64
Hungary	PWR	1,120	5,632	6,113	81.65	121.62
Japan	ABWR	1,330	3,430	3,940	49.71	76.46
Korea	OPR-1000	954	2,098	2,340	32.93	48.38
	AP-1400	1,343	1,751	1,964	29.05	42.09
Netherlands	PWR	1,650	5,709	6,383	62.76	105.06
Slovak Rep.	WER 440/V213	954	4,874	5,580	62.59	97.92
Switzerland	PWR	1,600	6,988	9,334	78.24	136.50
United States	Advanced Gen III+	1,350	3,814	4,296	48.73	77.39
Non-OECD Members						
Brazil	PWR	1,405	4,703	5,813	65.29	105.29
China	CPR-1000	1,000	1,946	2,145	29.99	44.00
	CPR-1000	1,000	1,931	2,128	29.82	43.72
	AP-1000	1,250	2,542	2,802	36.31	54.61
Russia	WER-1150	1,070	3,238	3,574	43.49	68.15
Industry Contribution						
EPRI	APWR. ABWR	1,400	3,319	3,714	48.23	72.87
Eurelectric	EPR-1600	1,600	5,575	6,592	59.93	105.84

* *Investment costs include overnight costs as well as the implied interest during construction (IDC).* † *The cost estimate refers to the EPR in Flamanville (EDF data) and is site-specific*
Source: International Energy Agency (IEA) (2010b) [Table 3.7a].

3.4 The lowest carbon fossil fuel

On average, natural gas has half the carbon footprint of coal, and gas fired generation is relatively straightforward to permit. Natural gas supply is still relatively plentiful and diverse. As such it is an important option for the European power system in the next decade.

For the foreseeable future, key issues with fossil fuels are relative price and volatility. As the capacity of the energy system is stretched and more expensive sources must be tapped, induced volatility will increase ahead of price level. Avoiding price volatility amounting up to half of the balance of payments has already been a major factor in Portugal's drive to reduce its dependency on fossil fuels by increasing the share of renewables from 17% to 45% from 2005 to 2010.

A similar effect occurs at the European scale, where the range of the fossil fuel bill is 4% of total trade. As the European balance of trade is roughly neutral, volatility in the fossil fuel imports has the potential to disrupt it. Renewables offer a hedge against both volatility and price, along with security of supply benefits. The major alternative fuel to coal is gas – in most European long-term contracts this is indexed to oil, and will thus suffer from additional volatility external to the power sector. While in the long term this price coupling is expected to weaken substantially, it will still dominate the dynamics over the decade under consideration here. The UK market has an independent gas index (NBP), must like the US (HH), but most gas contracts in continental Europe are oil indexed. Because of the interconnection of the UK gas market and the rest of Europe, the oil coupling is effectively extended into the UK, although more loosely.

In 2006 60% of natural gas was imported (vs. 40% of solid fuel and over 80% of oil), mostly from Russia, and this number is set to rise rapidly as Europe's internal supply dwindles. Shale gas is a potential game changer, as it has been in the US, but it is too early to tell whether this will also occur in Europe. In a decarbonising European power supply, the volume of gas will likely increase over the next decade, although the share could be stable to declining. This will come at the price of increased gas imports; the impact on the balance of trade could be somewhat mitigated by loosening the coupling to oil.

3.5 Cogeneration

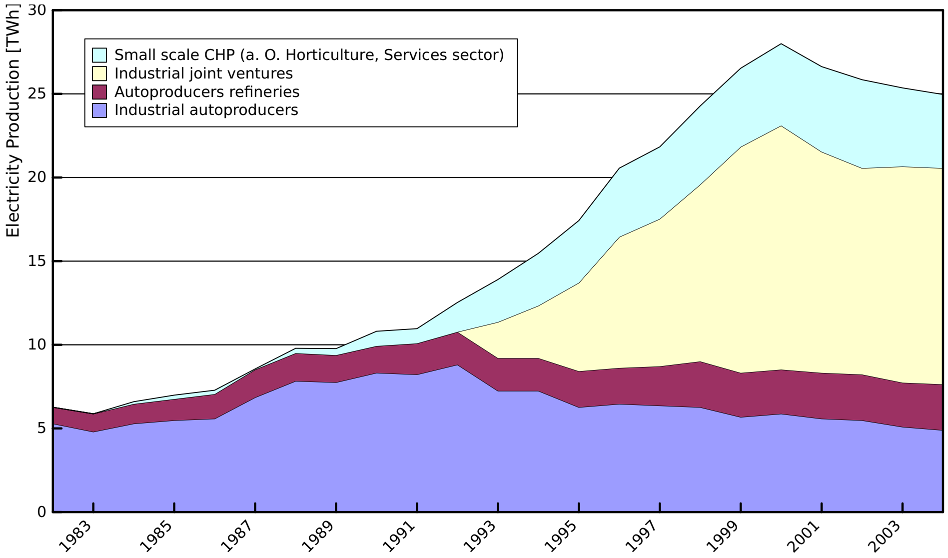
The degree of combined heat and power generation or cogeneration varies widely across the European Union. In four countries (Denmark, Finland, Latvia and the Netherlands) it represents more than a third of the total electricity production. The European average is 11% and Denmark is highest at 46%. Since cogeneration is essentially recovery of waste, it is an important and sizeable source of energy in a decarbonising system.

Waste heat in both power production and industrial processes can be recovered to use directly as heat or converted to electricity. A recent paper (Hekkert, Harmsen and de Jong 2007) describes the policies implemented in the 80's and 90's that led to cogeneration providing more than a third of the electricity in the Netherlands: "The figure below [see Figure 6] shows the development of electricity production by decentralized cogeneration in the Netherlands in the period 1982–2004. At the end of the 1990s, almost 30% of the total Dutch electricity production came from decentralized cogeneration, compared to 10% in the early 1980s. In absolute terms, the electricity production by decentralized cogeneration increased with more than a factor four."

It is instructive in this context that the slowdown observed after 2000 is due to changing market structure and deregulation. Hekkert, Harmsen and de Jong 2007 conclude as follows:

> The empirical conclusions are the following. We have seen a very successful government in the stimulation of cogeneration technology. The Dutch government has focused on many system functions to boost the diffusion of cogeneration, starting with guidance and creation of legitimacy and following up by market formation and resources mobilization. The activities of the government were well aligned with the needs of cogeneration adopters. Other actors in the cogeneration innovation system performed complementary activities (knowledge diffusion, innovative entrepreneurial activities, mobilization of resources) so that all system functions received sufficient attention. Thus, in this case study we observe a well functioning innovation system, which in turn leads to a successful diffusion of cogeneration technology. This observation is important since it backs the

Figure 6: Electricity production by decentralized cogeneration 1982–2004 excluding district heating

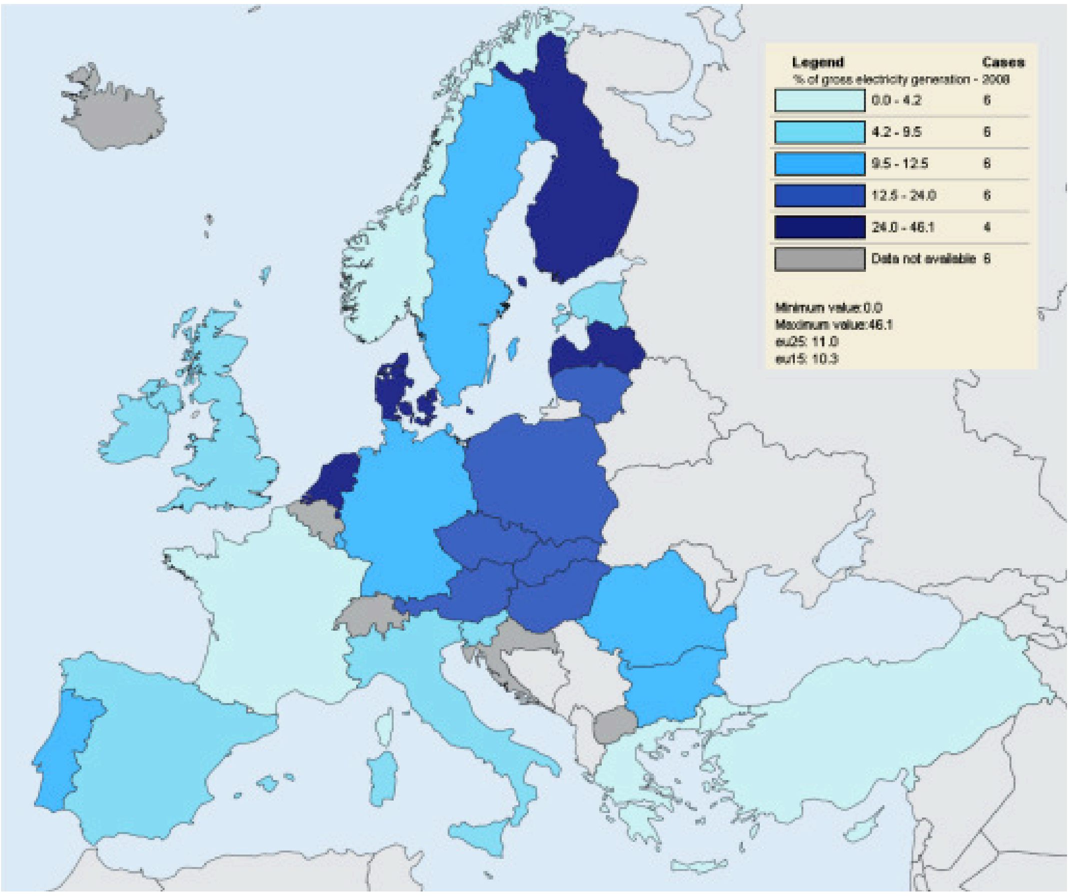


Source: Hekkert, Harmsen and de Jong (2007).

> functions of innovation systems framework. We also observe that a decline in system functioning directly has consequences for the diffusion pattern.
>
> This case study also shows that the institutional structure is an important explanatory factor for system functioning. The electricity act in 1989 and the voluntary agreements to reduce energy use around 1990, for example, were not intended to stimulate cogeneration but nevertheless had a major positive influence on the functioning of the innovation system. Without these often-unintentional changes (with respect to cogeneration stimulation), diffusion would not have taken place the way it did. Furthermore, structural changes in the institutional settings, like liberalization of the electricity market and high gas prices, also influenced the diffusion of cogeneration in a negative way in the period 2000–2006. Thus, innovation system functioning proved to be quite vulnerable for changes in institutional context. The reason for this seems to be the strong dependence of the innovation system on government actions. For emerging innovation systems around sustainable technologies this is unavoidable, but for full-grown innovation systems such as the cogeneration innovation system in the Netherlands, this is undesirable. (p. 4686)

The potential for cogeneration in Europe is substantial, as can be seen from the map below, as the mean value across the EU27 countries for cogeneration is 11%. The New Member States traditionally have high heat recovery rates, mainly for district heating. In turn the efficiency of the heat use and the state of maintenance represents an opportunity for improvement. Overall, cogeneration has the potential to be an important source of energy for the EU27.

Figure 7: Combined heat and power generation



Source: Eurostat (2010) [tsien030].

3.6 The EU power supply in 2020

The trends described above imply that over the decade of this study, the main question with regard to the power supply is how much of the coal capacity is replaced by gas and renewables respectively, and how quickly. Table 13 represents plausible ranges consistent with the M30 case, based on a balance of renewable cost reduction in the long run, with the shorter-term potential of gas-fired power, within the context of the constraints described above. Note that gas fired power capacity grows by 1% in absolute, but the relative share is reduced. Nuclear capacity only grows marginally, if at all. Renewables have the largest growth, but actual output is constrained by the lower load factor.

Cogeneration has substantial potential, starting from an 11% share of electricity production in 2009. With an assertive policy on cogeneration, a share of at least 15% is foreseeable across Europe. While there are substantial implementation issues, as cogeneration must be phased

Table 13: EU27 power mix in 2010 and 2020

Technology	Share of power capacity 2010 (in %)	Indicative share of power capacity 2020 (in %)
Coal	18	10
Gas	26	20
Nuclear	15	10
Hydro	21	15
Biomass	2	3
Wind	8	20
Solar	1	5
Cogeneration	10	15

Source: own analysis.

with shutdowns or refurbishments of industrial installations, the penetration rates in Denmark and the Netherlands demonstrate that a large increase is plausible.

The average wholesale price of electricity in Europe is €0.095/kWh (2009), with a variance of from €0.06/kWh, (Estonia) to €0.15/kWh (Malta). Figure 8 represents the distribution of electricity across the continent.

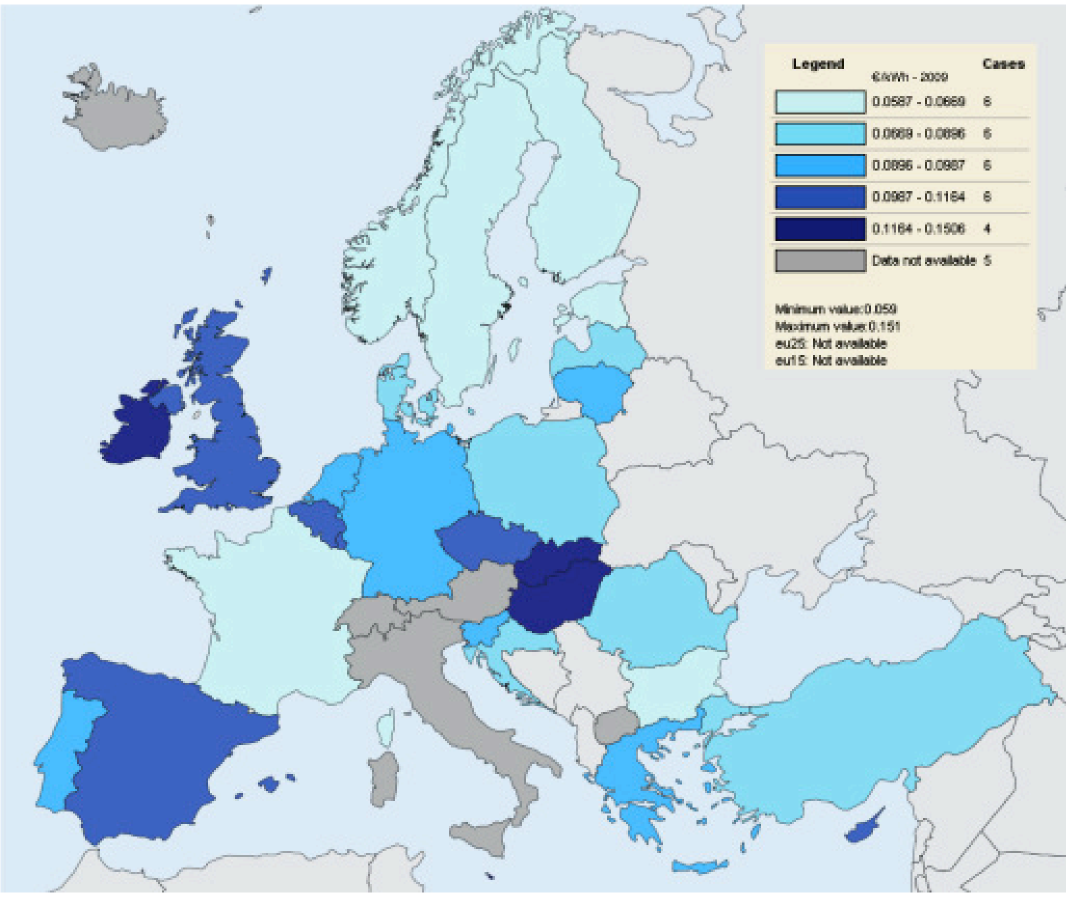
The Roadmap 2050 of the European Climate Foundation forecasts that decarbonisation will lead to a moderate increase in electricity prices. It is notable that the uncertainty range overlaps substantially with the BAU case:

> The unit cost of electricity in the baseline and the decarbonized pathways are compared using the "levelized cost of electricity" (LCoE) industry standard. The LCoE reflects the revenues that an investor would need to obtain to justify investments into power generation and grid. The levelized cost of electricity ("LCoE") is roughly the same in all three main pathways assessed, as a weighted average over the period between 2010 and 2050. The average LCoE for these three decarbonized pathways is about 10%–15% higher than the weighted average LCoE for the baseline over a period of 40 years, prior to applying any price for CO_2 emissions. Applying a price of between €20 and €30 per tCO_2 e would bring the baseline LCoE and the LCoE for these pathways roughly into equivalency with each other. The difference between the baseline and the decarbonized pathways is found to be slightly greater prior to 2030, but by 2050 the LCoE for the decarbonized pathways is within the range of LCoE for the baseline and trending lower. (European Climate Foundation 2010)

Until 2020, then, a cost increase of about 15% is to be expected.

In a market economy, the costs of one agent are the revenues of another one. Whether an 15% increase in electicity costs will translate into macro-economic costs for the economy as a whole requires a different kind of analysis, to which we turn in the next section.

Figure 8: Electricity prices for industrial consumers



Source: Eurostat (2010) [ten00114].

4

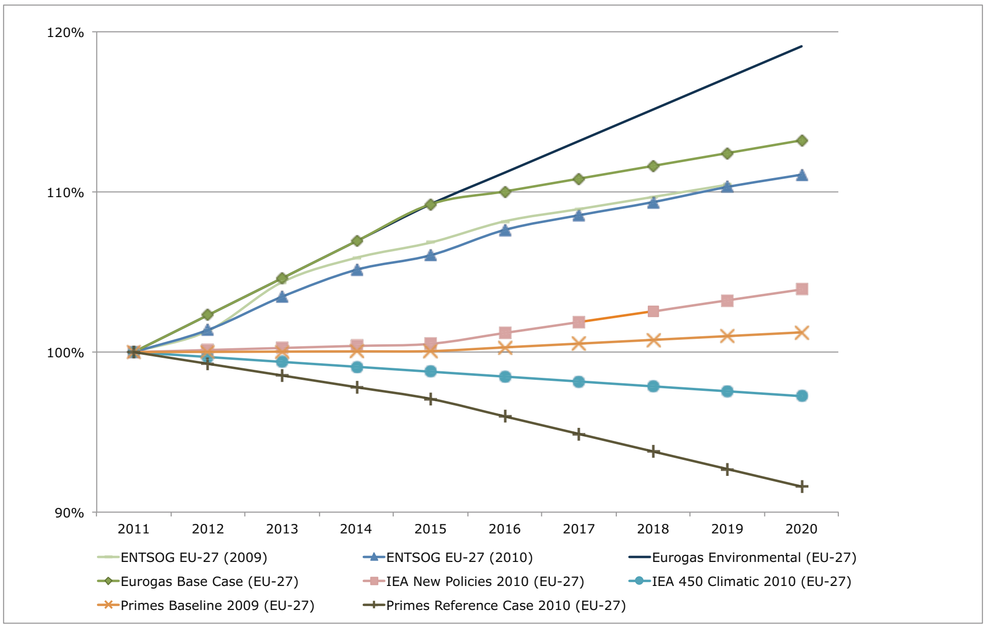
European import dependency on natural gas

4.1 European demand for natural gas

The significance of natural gas has been continuously increasing in the last 40 years in Europe. While the share of natural gas in primary energy demand was at 9.8% in 1973 in the OECD Member States of Europe (OECD-EU) (International Energy Agency (IEA) 2010a), this share reached 25.4% respectively 24% in the EU27 today (EuroGas 2010). The increasing use of natural gas in decentralized heating supply instead of coal in Western Europe has been one of the main reasons for this development. Regarding the new Member States, the political and geographical proximity to the former Soviet Union led to an expansion of their demand after the global oil crisis in the seventies. Approximately 27% of the natural gas demand is currently used in the energy sector in the EU27 while 39% is used in residential and commercial buildings (EuroGas 2010).

European policy on emission reduction will influence the future gas demand in the EU27. Uncertainties in the pace of implementation and the targets of this policy are reflected in the wide range of gas demand forecasts (see Figure 9).

Figure 9: Scenarios of EU27 gas demand



Source: PRIMES, International Energy Agency (IEA) 2009, EuroGas 2010, Entsog 2010.

Depicted models – EU PRIMES model (Energy Trends 2030, 2009), IEA World Energy Model (World Energy Outlook 209) and Industry models (ENTSO-G, Eurogas) – reflect an expected growth in gas demand from -5% to +15% between 2011 and 2020), whilst industrial associations as ENTSO-G and Eurogas expect an increase in gas demand even in an environmental scenario.

The base scenario of EuroGas 2010 reflects a projection of current economic development, business and regulation framework in the EU27. In contrast, the environmental scenario of EuroGas 2010 expects faster economic growth, more favorable policy towards natural gas and higher CO_2 prices. This leads to 12% growth in the base scenario and 18% in environmental scenario between 2010 and 2020.

IEA and PRIMES models take into account effects from strict CO_2 emissions policy in the EU27. They predict a slow growth and even a decline of the gas demand. The 450 (ppm) Scenario of IEA – which reflects a 20% emissions reduction in the EU27 (compared to 2007) – expects a reduction of gas supply by 0.7% until 2020 compared to 2007 (International Energy Agency (IEA) 2009, p.336) .

Our own results in a 30% emissions reduction policy scenario show a decrease in the EU27 gas demand by about 20% compared to 2010, while compared to the BAU scenario (20% emission reduction in the EU27) the gas demand decreases by 13%. The reduction in the New Member States is with 10% (compared to 2010) lower than in the EU15. In the 30% reduction scenario the share of natural gas in the power generation will decrease from today's 27% (share of finale consumption) to 22% in 2020. In contrast, the share in power generation increases from 38% in the base scenario to 55% in the environmental scenario of Eurogas over 2007-2030 (Zachmann G., Naumenko D. 2010).

The evolution of the global and European gas demand will be mainly influenced by the development of international climate regimes, price evolution of LNG, technical and economic development of non-conventional gases, economic development of China and development of Russian gas reserves.

4.2 Production, import and storage capacities

Norway is the major gas producer in the West Europe with an annual production of 105 bcm, followed by the Netherlands (78 bcm) and UK (62 bcm) (International Energy Agency (IEA) 2010a, p.42, II.4) .

For the indigenous natural gas production a decrease is expected. "The most pessimistic forecasts are those of Eurogas, which show EU gas output falling from 220 bcm in 2005 to 119 bcm in 2020 and 66 bcm in 2030.“ (Mott MacDonald 2010)

In 2010 only 36% of natural gas supply in the EU27 was covered by indigenous production. The two largest (pipeline) exporters into EU27 were Russia and Norway. 86% of gas imports into EU occurred by pipelines.

Beside the pipeline imports LNG imports increased over the last years. LNG terminals exist in Belgium, France, Italy, Greek, Portugal, Spain and UK. The capacities of European LNG terminals reached 169 bcm in 2009 and the volume of LNG imports into the EU increased by

21% from 2007 to 2009 (International Energy Agency (IEA) 2010a). Existing capacities are utilized at 36% in the EU27 (Hartley P. und Medlock K.B 2009, p.9) .

Germany is the largest importer of natural gas in the EU27 with an annual amount of 95 bcm, followed by Italy (65 bcm) and France (47 bcm) (International Energy Agency (IEA) 2010a, p.54, II.16) .

Europe is highly dependent on primary energy imports. In 2008 85% of TPES was covered by imports (crude oil, oil products, nuclear, gas, hydro renewables and electricity) (International Energy Agency (IEA) 2008a). Following Destatis 2010, Russia is the main exporter for European energy imports. In 2008 approx. 24% of coal, 29 % of crude oil and 32% of imported natural gas were supplied by Russia.

The import dependency differs among the EU27 Member States. While UK, the Netherlands, Sweden and Spain are able to cover their national demand by indigenous production (or alternative resources), the New Member States are highly depending on pipeline imports (Mott MacDonald 2010).

Over the last decade an European wide system of storage capacities has been established. The overall capacity reached 87.9111 bcm with a daily output of 1.6 bcm (International Energy Agency (IEA) 2010a, p.97) . With the existing capacities 15% of the annual gas demand in the EU27 is covered.

4.3 Assessment of import dependency

The dependency on Russian gas imports has been discussing extensively. Main arguments are the following (see e.g. (Lund Sagen E. 2006)):

- Political differences between Russia and the EU27 may led to the use of gas as instrument of political pressure.
- The existing transfer systems through the Ukraine and Belarus increase the risk of short-term supply shortfalls due to political and economic disputes between Russia and these countries.
- The level of resources of natural gas in West Siberia are not proved and the physical parameters in these fields are unknown.
- The age of existing transfer systems to Europe is outdated which makes investments for modernisation necessary.
- The outcome of the liberalisation of Russian gas industry is uncertain.
- The domestic demand will increase significantly in Russia.

A reduction of import dependency may become necessary for the EU27 if Russian gas deposits shrink rapidly due to increasing national consumption or faulty predictions of existing resources. On the other hand the EU27 has to be aware of self-fulfilling prophecies – an offensive politics of dependency reduction may lead to a realignment of Russian gas policy.

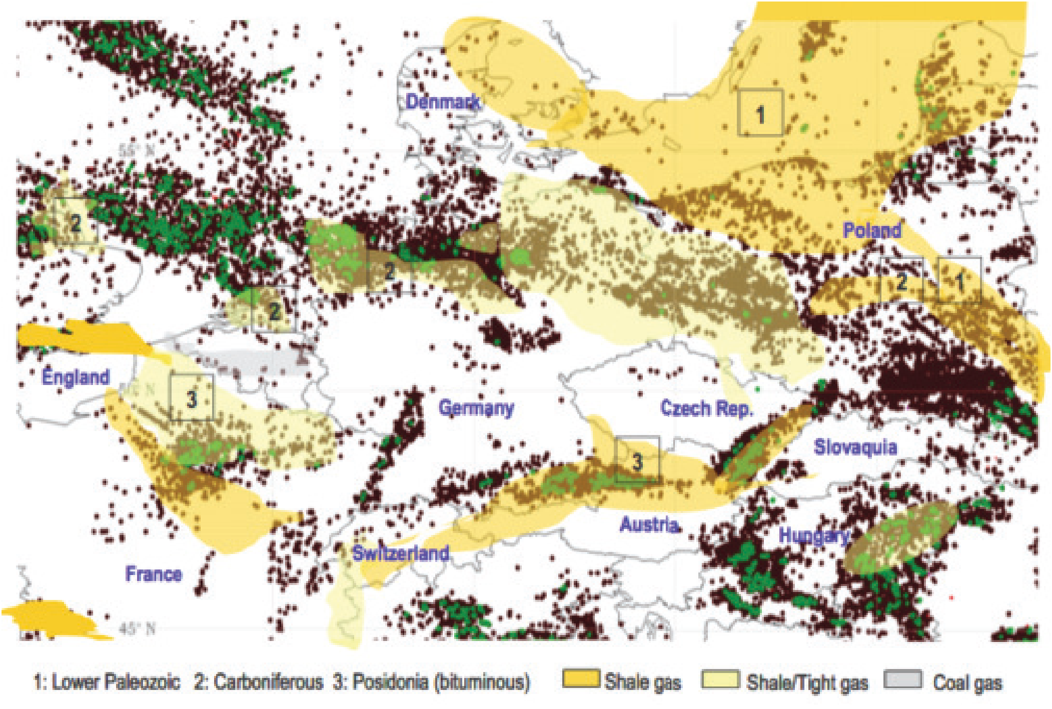
The reduction of European gas demand may help to reduce the risk resulting from import dependency. Nevertheless, a shrinking indigenous production increases this dependency.

4.3.1 Non-conventional gas

Non-conventional gas has been increasingly playing a role in the American gas production over the last decades. In Europe we face a significant will to follow this development especially in Poland.

Non-conventional gases (shale, tight gas and coal bed methane (CBM)) are distributed across Europe. Shale gas is represented in three major geological plays: Lower Paleozoic play (from Eastern Denmark and Southern Sweden to Northern and Eastern Poland), Carboniferous marine basin (North-West England, the Netherlands and North-West Germany to South Poland) and Lower Jurassic bituminous shales (South England, Paris Basin, Netherlands, Northern Germany and Switzerland) (Gény F. 2010, p.48) . The range of estimations is considerable. Advanced Resource International expects the amount of recoverable non-conventional gas resources with 5,600 bcm, while Wood Mackenzie estimates 4,200 bcm (Gény F. 2010, p.8) .

Figure 10: Map of conventional basins, wells and non-conventional deposits



Source: Gény F. 2010, Green dots represent active wells.

Significant resources outside the EU27 are expected in Ukraine. An unclear regulatory framework and technological barriers led to slow progress in this sector in Ukraine. Nevertheless, in the long run Ukraine may operate as an exporter for non-conventional gas into the EU27 (Meissner F., Naumenko D. 2011).

The activities regarding non-conventional gases in EU27 are most advanced in Poland, where national reserves are estimated within 1.5 to 3 tcm, but are currently unproved (Rumiński A. 2010). With non-conventional gas Poland will try to significantly reduce its dependency on domestic coal and Russian imports. Progress in this field is not expected during this decade, currently only exploration occurs and no production.

Fast progress in this sector – as seen in the USA – is unexpected in whole Europe due to the following reasons: The legal basis for mining non-conventional gases is weak in Europe and differs significantly from the US one. Currently only a few companies would be able to explore and produce non-conventional gas in Europe compared with a well established industry in the USA. One of the major obstacles for a fast progress in Europe is the stronger public awareness regarding environmental risks. Such risks resulting from water and land consumption and the need of several highly risky chemicals for exploration and production of non-conventional gas. Moreover, geological differences between the USA and Europe are responsible for the weak development.

Summarizing, non-conventional gas may play a role in the European gas supply, but not before 2025.It is not clear today if the demand for this resource enable a business-case for industries. Developments in mining techniques will also be necessary to reduce the enormous environmental impacts. Moreover, EU27 climate policy has to take into account that the emission from non-conventional gas seems to be higher than the emission from coal, “Compared to coal, the footprint of shale gas is at least 20% greater and perhaps more than twice as great on the 20-year horizon and is comparable when compared over 100 years.“ (Howarth R.W., Santoro R., Ingraffea A. 2011). A trade-off between reduction of import dependency and emissions reduction targets will become necessary.

4.3.2 LNG

LNG has traditionally been an option for a reduction of pipeline dependency in Europe. On the demand side Europe competes with Asia – e.g. Japan/Korea – which have used LNG for decades for diversification reasons. LNG is generally competitive with pipeline gas today, over longer distances (Wingas 2007).). Cost differences with piped gas come from trading off pipeline cost with liquefaction and shipping. Europe would be able to import three times more LNG than today (assuming Europe is willing to buy for security of supply). According to Mott MacDonald 2010,the capacities of LNG could cover 450 bcm of European gas demand until 2030. Clingendael 2008 highlights the importance of following two points for the LNG imports into the EU27:

- Suppliers of LNG prefer far-east type long-term contracts for financing the expansion of production capacity. While Southern Europe has traditionally used LNG for base security of supply, Nothern Europe has tended to consider it as a hedge against pipeline uncertainty.

- The tight coupling of oil and gas prices in Europe is an essential dynamic in the arbitrage between US HH based prices, the far east oil indexed prices and the spot market. An independent gas index will have a profound effect on market dynamics, but requires acceptance by the suppliers.

The political development of LNG suppliers in North Africa and Arabia will further determine the success of LNG in Europe – but this holds for all energy imports from this region and is not a specific problem of LNG.

4.4 Alternative distribution

In a mid- and long-term perspective the risk of supply shortfalls in the Ukrainian and Belorussian pipeline system will be reduced by the North- and South-Stream projects which will deliver Russian gas to Europe. After completion, North-Stream will have an annual capacity of 55 bcm (North Stream 2011) and will deliver gas from Jamal Region to Europe. This will reduce the transport through Belarus (Jamal-Europe Pipeline with a capacity of 33 bcm (Hett F. 2007)) and Poland.

The South-Stream pipeline will further have a capacity of 63 bcm (South Stream 2011) and will deliver Russian natural gas through the Black-Sea from West-Sibiria.

Beside the reduction of supply shortfall risk the development of new relationships to producers in Asia and North-Africa may reduce the dependency on Russian gas.

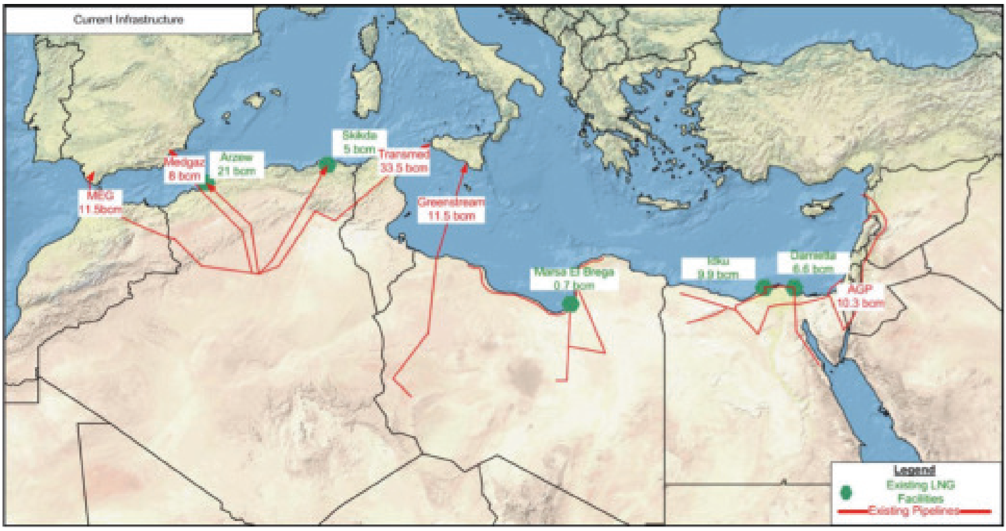
The Nabucco Pipeline will deliver natural gas from Azerbaijan, Turkmenistan and Iran after 2016. Risks regarding the role of Turkey have to to be taken into account for this option.

Further efforts of EU27 exist in development relations to states in North-Africa. Following Mott MacDonald 2010 annual export volumes until 2030 may become possible: Algeria: 90 bcm, Egypt: 60 bcm, Libya: 40 bcm, and Iraq: 30 bcm 11).

Algeria disposes of an infrastructure for annual export volumes of 70 bcm, which is about 26 bcm more than export volumes in 2009 (Mott MacDonald 2010). The Libyan export capacities for delivery to Europe enriched 12.5 bcm in 2009. Egypt is one of European LNG export partners. Beside LNG pipeline capacities of the Arab Gas Pipeline through Syria, Jordan and Lebanon exist for 10 bcm natural gas (Mott MacDonald 2010, p.10) . The current export volume reached one third of the capacities.

According to Mott MacDonald 2010 three options exist for an increasing of gas imports from North-Africa: (1) expansion of the national LNG infrastructure, (2) development of a Mediterranean Gas Ring (Medgas Ring) and (3) development of a direct pipeline to Spain or/and Italy. A forth option is the connection of existing pipelines to Nabucco.

Figure 11: Current export infrastructure from Southern Mediterranean and Iraq to Europe, 2010



Source: Mott MacDonald 2010.

The outcome of the started political process in North-Africa and several Arabic countries will mainly influence the options for import-export relationships with this region for Europe. Nevertheless, except LNG, gas exports from this option is only plausible in the long-run and beyond the year 2020.

5

Micro-costs and macro-benefits

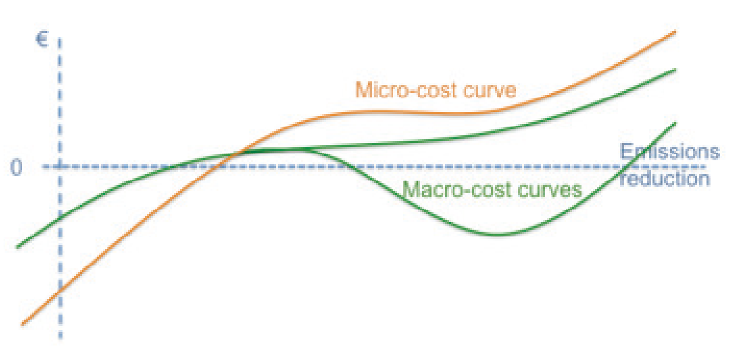
The results of the present study imply that there is a win-win strategy for the EU in terms of climate and overall economic activity. It is possible to increase the incomes of households and firms in such a way that the moderate increase in energy prices will be more than offset. The opportunities for such a strategy at the European level were not identified, up until today, by other studies because their analysis neglected two important and interrelated features of the contemporary economy: i) learning-by-doing and ii) expectation management.

This lacuna is not a problem as long as one is studying marginal changes in the neighborhood of a given economic equilibrium, because then these two features can be captured implicitly by fixed parameters of suitable models. The financial crisis of 2008, however, has created a situation where different growth paths, i.e. different dynamic equilibria, are possible. Neglecting the effects of and interactions between learning-by-doing and expectation management now leads to a blind spot in which opportunities for win-win strategies remain invisible. The blind spot, however, can be overcome by paying attention to the difference between micro- and macro-costs and benefits. Intuitively, it is easy to see that at the micro level what is a cost for one agent is by definition a revenue for some other agent, while no such symmetry obtains for society as a whole. Technically, it is important to look at this difference in more detail.

The difference is illustrated in Figure 12. There, the micro-cost curve represents the carbon prices that are needed to make different technologies for emissions reduction competitive – the higher the emission reduction, the higher the carbon price. This curve can only be identified in a situation where the prices of many other products and services are given, i.e. in the environment of a given economic equilibrium. By contrast, the macro-cost curve represents the changes in GDP that are compatible with different levels of emission reductions.

At the current level, there are several reduction opportunities that can be realized by smart entrepreneurs and households who save energy costs at current prices. This is represented by the fact that the micro-cost curve has negative values in the neighborhood of the current level of emission reductions. If these low-hanging fruits are reaped, society as a whole gains as well, as represented by the negative values of the macro-cost curve in the same neighborhood of emission reductions. Macro- and micro-costs

Figure 12: Micro vs. macro economic cost curves



Source: own analysis.

differ, because the energy saving comes with a redistribution of resources (most likely in favour of the agents that have the opportunity and the will to realize it).

Higher levels of emission reduction imply higher micro-economic costs, simply because economic agents are not so dumb as to systematically switch to more expensive technologies before they have exploited the potential of the cheaper ones. The economy as a whole, however, may well switch to another equilibrium where the additional revenue generated is higher than the additional costs incurred for emission reductions. This is represented by the bifurcation of the macro-cost curve.

The economy is a complex system, and the difference between micro- and macro-costs is one aspect of this complexity. Human beings are familiar with complex systems – each family is one. Or consider soccer teams. If such a team plays a national championship for several years and then gets qualified for the champions league, this clearly requires an additional effort from each individual player. But it is well-known that the new challenge can mobilize capabilities that could not be tapped without it – whether a given team will do so or not may well decide its current success or failure. This is not a gradual process, and there are limits to it, but it is a key fact of human life that social systems have different possible states that can be activated in the face of different challenges. In the case of an economy faced with a resource constraint, this means that there are multiple equilibria with very different macro-cost curves.

5.1 General equilibrium theory and its applications

To overcome the blind spot mentioned above, in the current study the GEM-E3 model has been extended to incorporate learning-by-doing as well as expectation management. As a result, we are able to represent the multi-equilibrium structure that leads to the difference between micro-costs and macro-costs. More specifically, the micro-costs are computed as prices of carbon dioxide, while the macro-costs are computed as differences in GDP – with the result that with an appropriate policy they can in fact be macro-benefits.

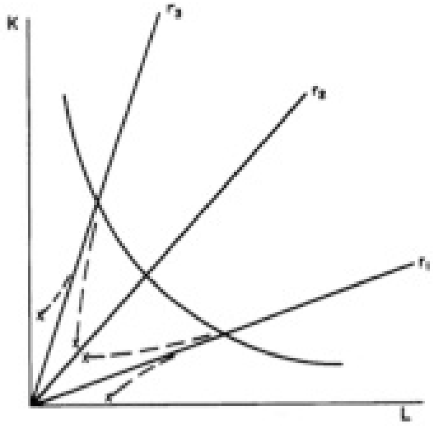
Although the model behaves well in view of the stylized facts we are interested in here, extensive research should be done in order to evaluate the new properties of this modelling approach. This research can start with the observation that CGE models, such as the GEM-E3 model (Capros et al. 1999; Kouvaritakis, Paroussos and Van Regemorter 2003) used in the present study, provide a partial implementation of the theory of general equilibrium (originally developed by Arrow and Debreu) in view of policy analysis. The implementation is partial in the sense that whereas the theory provides a global picture allowing in particular the existence of multiple equilibria (a consequence of the Sonnenschein-Mantel-Debreu theorem), the state of the art implementation only provides a local view: it considers the variations induced by policies in the neighbourhood of a given equilibrium. For the present study, the model has been modified so as to overcome this limitation.

A good example is the treatment of the so-called “super Cobb Douglas Economy” by Sue Wing (2004). He states that this model

> has nice properties that guarantee a unique equilibrium once there are no taxes or subsidies (Mas-Colell et al. 1991). Furthermore, if there are exogenous distortions the equilibrium will still be unique (Kehoe and Levine 1985), but this result is not assured in the presence of distortions that are endogenous. . . .
>
> However, it is tempered by evidence that distortions can have the effect of inducing multiple equilibria, even in models with a representative consumer and convex production technologies(Foster and Sonnenschein 1970; Hatta 1977). Although this finding seems to turn on the fact that at least one commodity is an inferior good (Mas-Colell et al. 1991), a rarity in applied work. . .
>
> Research in this area is ongoing, focusing on translating theoretical results into numerical diagnostic tools (e.g., Dakhlia 1999). But without the ability to test for or remedy the problem of multiple equilibria, most applied modelers proceed on the assumption that the solutions generated by their simulations are unique and stable.

It is this assumption that has been shown to be so dangerous by the global financial crisis. Ultimately, the research aiming to overcome the blind spot implied by the assumption of a unique and stable equilibrium may result in models that represent explicitly the heterogeneity of economic agents together with the key features of the complex networks they form. For practical purposes, what matters here is to recognize the difference between micro-costs and macro-benefits in view of the choices Europe is faced with after the global financial crisis of 2008.

Figure 13: Multiple equilibria of the Solow growth model in the labour-capital plane



The three rays are trajectories for capital accumulation corresponding to three different equilibria in the Solow growth model

5.2 History and current trends in computable general equilibrium modeling

The distinguishing features of general equilibrium modelling derive from the Arrow-Debreu economic equilibrium theorem (Arrow and Debreu 1954) and the constructive proof of existence of the equilibrium based on the Brouwer-Kakutani theorem (Kakutani 1941).

The Arrow-Debreu theorem considers the economy as a set of agents, divided into suppliers and demanders of different goods, interacting in several markets for an equal number of commodities. An arbitrary good or bundle of goods is chosen as numeraire, i.e. the unit of account in which prices are expressed. Each agent is a price-taker and individually defines his supply or demand behaviour by optimising his own utility, profit or cost objectives.

The theorem states that, under a set of well-specified conditions, there exists a set of prices that bring supply and demand quantities into equilibrium, and at which all agents achieve their individual optimum under given conditions. The Brouwer-Kakutani existence theorem is constructive in the sense of implementing a sort of tâtonnement process around a fixed point where an equilibrium vector of prices sits. The models known as computable general equilibrium models follow such a process.

It has been demonstrated that the Arrow-Debreu equilibrium can also be obtained from global (economy-wide) optimisation that implements Pareto optimality and uses the equilibrium characterisation introduced by Negishi (1962). Models that follow this methodology have the form of mathematical programming and are sometimes called optimisation equilibrium models. A major advance has been the introduction of stochastic optimisation techniques, leading to dynamic stochastic general equilibrium (DSGE) models. They have become a key tool in modelling rational expectations.

If there are goods for which no production technology is specified, a so-called "closure rule" is needed. This problem arises, e.g., if one wants to model an open economy without specifying the production structure of the rest of the world. But it also arises if one wants to model money created by banks – be they central banks or private ones – rather than using an arbitrary numeraire. An example of a closure rule for money consists of incorporating an IS-LM mechanism, which has been traditionally used in Keynesian macro-models, into computable general equilibrium models.

Some authors used the term "generalised equilibrium modeling" to underline the flexibility of the computable equilibrium paradigm, e.g. regarding the extensions aforementioned, but also the possibility to represent and even mix different market clearing regimes within a single model. In general, these possibilities enrich the analytical capability of the model regarding structural change and its relation to market distortions, for example price regulations, cost-depending price setting, etc.

The extensions that allowed the introduction of alternative market clearing regimes gave the possibility for introducing elements of the new trade economic theory within CGE models. From the simple static open economy models of the 70s, it was now possible to develop sophisticated multi-country models where benefits from the exploitation of the potential for economies of scale and from the intensification of competition due to trade liberalisation are explicitly represented.

Similar methodological approaches have also lead to the incorporation of mechanisms reflecting endogenous technology evolution dynamics. This issue, however, is at the frontier of current research activities and although the theoretical literature is expanding, few attempts have been made to include endogenous growth in a full-scale applied CGE model.

5.3 M30 as a deviation from the optimal path

Most studies in the existing literature (European Commission Staff 2010a; Prognos AG 2010; Tol 2010) on the assessment of M30 policies have analyzed these as a deviation from the business-as-usual (BAU) scenario. That is, taking BAU as the unique focal point, these studies compute the potential cost of implementing the reduction target. The models used in this respect are structured in such a way that the reference scenario is, by assumption, the optimal trajectory except for the climate externality. Mitigation policies are hence seen as a deviation from the optimal path: by construction, they induce social costs in the short run.

How is one then to interpret the results of these studies? They should be seen as providing an upper-bound for the risk (or equivalently a lower bound for the benefit) associated with the implementation of the target.

5.4 M30 as a focal point

In order to get a more comprehensive assessment, one should dually analyze the issue taking M30 itself as a focal point. In particular, one should take into consideration that well-designed climate policy can internalize the positive external effects of additional investment on technical progress.

The implementation of this alternative perspective requires to encompass recent advances in endogenous growth theory and agent-based modeling: whereas the determinants of growth are exogenously given when a BAU scenario is chosen as a focal point, shifting the focus on M30 as such requires to represent them endogenously. This amounts to constructing a self-contained model of economic dynamics which encompasses the feedback links between investment, learning-by-doing, and expectations of agents. The theoretical basis for these advances comes from the endogenous growth literature (see Aghion and Howitt 1998, Romer 1994). Their implementation in policy models is made possible today by advances in multi-agent modeling.

5.5 Expectation management

The positive feedback between investment and expectations stems from what Keynes (Keynes 1936, Chapter 12) labels animal spirits:

> Even apart from the instability due to speculation, there is the instability due to the characteristic of human nature that a large proportion of our positive activities depend on spontaneous optimism rather than mathematical expectations, whether moral or hedonistic or economic. Most, probably, of our decisions to do something positive, the full consequences of which will be drawn out over many days to come, can only be taken as the result of animal spirits – a spontaneous urge to action rather than inaction, and not as the outcome of a weighted average of quantitative benefits multiplied by quantitative probabilities.

However, the feedback between investment and expectations is by no means restricted to Keynesian models. It is well known that multiple equilibria arise in rational expectations models (Driskill 2006a). The coordination of expectations then gives rise to different investment behaviour that may in turn reinforce a given pattern of expectations. In the context of this study, animal spirits are modeled as growth expectations. They are endogenously linked to investment decisions of firms so as to ensure consistency with the new investment patterns triggered by M30 policies. We discuss more extensively the expectation management issue in section 9.

5.6 Endogenous growth theory and learning-by-doing

Economic growth is induced in standard CGE models by embedding exogenously given labour productivity growth patterns. Lacking a representation of technological change, they hence implement the basic features of a Solow-type growth model (see Solow 1956). This strongly contrasts with the findings, by Solow himself, that 87.5% of growth in output in the United States between the years 1909 and 1949 could be ascribed to technological improvements alone (known as the Solow residual). These findings gave rise to an important literature trying to endogenize the representation of technological progress. The guideline of these inquiries has been the relation between fixed capital, investment and productivity. Kaldor initially put forward such a relation :

> it gives more explicit recognition to the fact that technical progress is infused into the economic system through the creation of new equipment, which depends on current (gross) investment expenditure. Hence the 'technical progress function' has been redefined so as to exhibit a relationship between the rate of change of gross (fixed) investment per operative and the rate of increase in labour productivity on newly installed equipment. (Kaldor and Mirrlees 1962 p. 174)

The relationship was then developed by Arrow (1962, p. 157) – "I therefore take instead cumulative gross investment (cumulative production of capital goods) as an index of experience" – who put forward the existence of increasing returns related to the positive externalities brought by experience or learning-by-doing: "I advance the hypothesis here that technical change in general can be ascribed to experience, that it is the very activity of production which gives rise to problems for which favorable responses are selected over time." (p. 156). Further literature went on to specify the micro-economic dynamics of these externalities, inquiring the role of research and development (Grossman and Helpman 1991; Barro and Sala-i-Martin 1995), specialization (Romer 1987), public spending (Barro 1990), Schumpeterian creative destruction (Aghion and Howitt 1992), or the accumulation of human capital (Lucas 1988). Though diverse, these approaches all build on the fundamental relationship between investment and labour productivity.

5.7 Insights from agent-based modeling

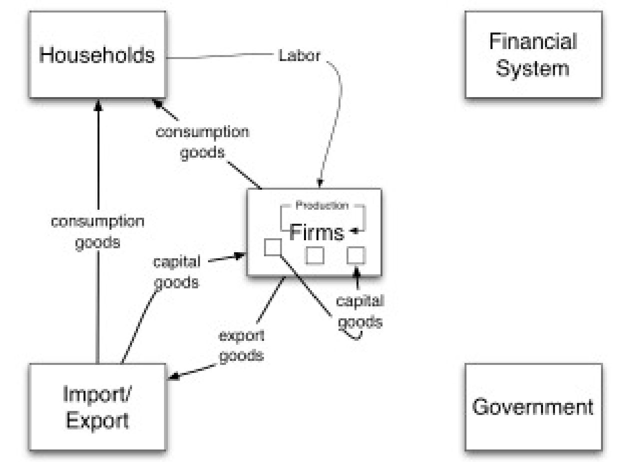
Agent-based models represent economic systems as emergent properties of networks of interacting agents (see Figure 14).

On the basis of a specification of the agents' micro-economic behaviour (e.g. pricing and investment behaviour of firms, savings and consumption behaviour of households), they determine the dynamics of macro-economic aggregates (e.g.: output, GDP, unemployment, savings). They hence provide the opportunity to test micro-foundations specified outside the representative agent paradigm (see Kirman 1992) and can serve as a virtual laboratory to qualitatively assess the effects of economic policy.

This methodology has been applied to analyze a wealth of issues: organization of electricity markets (Li and Tesfatsion 2009), regional policy (Deissenberg, Vanderhoog and Dawid 2008), business cycles (Dosi, Fagiolo and Roventini 2010), the interactions between micro-economic behaviour and macro-economic dynamics (Gatti et al. 2008, Mandel et al. 2009) and equilibrium selection processes (Gintis 2006).

The micro-macro approach provides us with two robust stylized facts. On the one hand, the models have demonstrated, from the bottom-up, that very robust relationships exist between the agents' expectations and the growth pattern of an economy. They hence provide micro-foundations for the Keynesian emphasis on the role of animal spirits. On the other hand, they have demonstrated the consistency of agents' micro-economic behaviour with the sustainment of growth by endogenous mechanisms such as learning-by-doing.

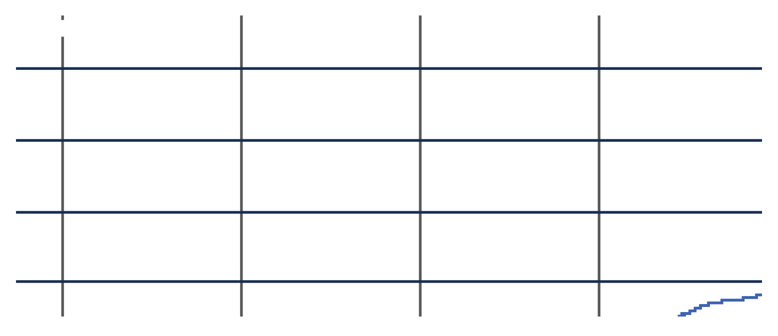
Figure 14: Some interactions in the Lagom generiC model



Source: own analysis.

Finally, the analysis of equilibrium selection processes (Gintis 2006, Mandel et al. 2010) emphasizes the conventional nature of prices and puts forward the possibility of transitions between different equilibria and/or growth patters (see Figure 15). With this background we now consider simulations of various scenarios for European climate policy.

Figure 15: Transitions between growth regimes in the Lagom generiC model



Source: own analysis based on Lagom generiC model.

6

Why Green Growth is possible

In the past decades, a canonical type of economic growth models has emerged. It is often dubbed the neoclassical growth model, and it provides the backbone of much research in climate economics. An excellent presentation is given by Barro and Sala-i-Martin (2003), the best application in climate economics is due to Nordhaus (2008).

This model type has its problems, and there are strong reasons to look for models of a different kind, especially in light of the recent financial crisis (Farmer and Foley 2009). However, existing models embody considerable empirical knowledge about past patterns of economic growth and provide a common language currently used by most analysts and policy makers. Therefore, we take the neoclassical growth model as our starting point. The starting point, however, is what we will leave behind step by step.

Neoclassical models express the familiar view of a market economy as organized by an ’invisible hand’ in such a way as to achieve a unique equilibrium. In growth theory, this is a unique growth path. In climate economics, this path is then seen as causing massive damages in the future because of greenhouse gases emitted now. In order to avoid these damages, present emissions must be reduced, leading to lower GDP now. The problem of climate policy then is to find some mechanism of sharing that burden among the various relevant actors. More climate protection then means lower growth: the idea of green growth as a way to protect the environment while enhancing economic growth would be an illusion.

We start by rehearsing a model of this type. Then we introduce three modifications that lead to the possibility of green growth.

6.1 A single growth path

6.1.1 Time and agents

There is a single representative household and a single representative firm operating through a finite number of moments in time. Despite being only one of its kind, both agents mimic a situation of perfect competition in the sense that they react to price signals over which they have no influence. It is customary to assume that the firm only takes decisions about the present moment while all inter-temporal decisions are taken by the household.

If one lets the number of moments in time grow very large, one may approximate decisions over infinite time (in numerical simulations, when considering a period of a decade one may run the program for a century - longer runs usually do not yield different results anymore). If one lets the number of moments in time be small, say two or three, one can build overlapping generations models (see Gerlagh and van der Zwaan 2000 and Michel and de la Croix 2000, for a discussion in view of climate economics).

We use the following notation:

$$\begin{aligned} t &= 0, 1, .., T \\ i &: \text{firm} \\ h &: \text{household} \end{aligned} \tag{1}$$

The time index will be written as superscript, the agent index as subscript (exponents will be put outside of brackets).

6.2 Firm

At each moment in time, the representative firm produces output of a single good q_i^t by using capital k_i^t, labor l_i^t and an emissions generating resource e_i^t. The firm's technological production possibilities are represented by a CES production function with exogenous technical progress (represented by the variable π^t). The parameters of the function are chosen so as to roughly match the most recent estimates for the U.S. (Raval 2009). The firm chooses its (non-negative) inputs so as to maximize the difference between revenues and costs, where costs include interest i^t and depreciation δ on the capital stock, wages w^t for labor, and a price p_e^t for the emissions generating resource. To keep things simple, we assume that the resource is imported from the outside world and paid for by exporting the good produced by the representative firm. We treat the price of the resource as set exogenously, so as to be able to analyze the impact of climate policies via changes in that price. These changes may result from technical standards, taxes, tradable permits, etc.

$$\begin{aligned} \max_{k_i^t, l_i^t, e_i^t} \quad & q_i^t - k_i^t \cdot (i^t + \delta) - l_i^t \cdot w^t - e i_i^t \cdot p_e^t \\ \text{s.t.} \quad & q_i^t = \left(0.3 \cdot (k_i^t)^{-1} + 0.65 \cdot (l_i^t \cdot \pi^t)^{-1} + 0.05 \cdot (e_i^t)^{-1}\right)^{-1} \\ & k_i^t, l_i^t, e_i^t \in I\!R_{>0} \end{aligned} \tag{2}$$

6.3 Household

At each moment in time, the representative household earns an income y_h^t composed of the wage w^t for its labor l_h^t and the interest i^t on its assets s_h^t. The household consumes a fraction c_h^t of its income and saves the rest by lending it to the firm as credit and keeping one unit of financial asset per unit of good lent. The initial endowment of financial assets s_h^0 is given. At each moment, the household is capable of delivering at most one unit of labor. The labor it actually supplies then is a number between 0 and 1. The household chooses sequences of consumption fractions and fractions of labor units so as to satisfy its preferences. These can be represented by a standard utility function with a discount factor and a bequest function for the final moment T (in the illustration chosen here, the household tries to achieve a bequest that is a fixed multiple α_h of its final income).

$$
\begin{aligned}
\max_{c_h, l_h} \quad & \sum_{t=0}^{T} (0.97)^t \cdot \left(\log\left(y_h^t \cdot c_h^t\right) + \frac{1}{l_h^t - 1} \right) - (0.97)^{T+1} \cdot \left(s_h^{T+1} - \alpha_h \cdot y_h^T\right)^2 \qquad (3) \\
\text{s.t.} \quad & y_h^t = l_h^t \cdot w^t + s_h^t \cdot i^t \\
& s_h^{t+1} = s_h^t + y_h^t \cdot (1 - c_h^t) \\
& c_h, l_h : I\!N \to [0,1]
\end{aligned}
$$

6.4 System properties

It is well known that in neoclassical models the accumulation of capital is insufficient to explain actual growth rates. The problem is that labor in industrialized countries shows only little growth and sometimes none at all. To explain growth rates of 2% and more in a neoclassical framework, capital would need to grow much faster than that, which it does not. The missing residual, which is in the order of half of total growth, is then explained by invoking technical progress. The long-term dynamics of industrialized countries can be described quite well by assuming an exogenous rate of growth for labor productivity in the order of 2% as well.

$$
\begin{aligned}
\pi^{t+1} &= \pi^0 \cdot \exp(0.02 \cdot t) \qquad (4) \\
\pi^0 &= \bar{\pi}^0 \\
p_e^t &: I\!N \to I\!R_{>0}
\end{aligned}
$$

For our present purposes, the price on emissions generating resources is exogenous as well. One may then consider price increases due to increasingly stringent climate policies.

6.5 Equilibrium conditions

In the neoclassical tradition, the invisible hand of the market is assumed to balance supply and demand so smoothly that one can focus on the situations where they are equal. This is the economic concept of equilibrium. It is quite important to distinguish this notion from other equilibrium concepts like critical point of dynamical systems of Nash equilibria in game theory. In specific situations, such notions may or may not coincide. In the present case, we simply require that supply and demand match at each moment in time. This means that the output of the firm minus the depreciation of capital is equal to the income of the household, labor demanded by the firm is equal to labor supplied by the household, capital used by the firm is equal to the assets owned by the household and the tax raised on emissions generating resources is equal to the subsidy handed out to the household. Other incentive schemes to avoid emissions can be investigated, but for our present purposes this one will suffice:

$$\begin{aligned} q_i^t - k_i^t \cdot \delta &= y_h^t \\ l_i^t &= l_h^t \\ k_i^t &= s_h^t \end{aligned} \tag{5}$$

6.6 The critical property

Because the representative firm solves only a static optimization problem at each moment in time, it can be incorporated into the intertemporal optimization problem of the household. The optimization problem of the household then involves a goal function – call it U for utility – and a domain over which it is to be maximized – call it A for action space. We can define:

$$A = \{(c_h^0, l_h^0, .., c_h^T, l_h^T) \mid c, l \in [0,1] \subset I\!R\} \tag{6}$$

This set is bounded, convex, and closed. If the goal function is continuous, it will assume a maximum at least once over A, so the economy under consideration has at least one equilibrium. If the goal function is strictly concave, the problem will have exactly one solution. Otherwise, a set of equilibria may result. To check concavity of the goal function, it is useful to rewrite it as a function of total consumption $C_h^t = c_h^t \cdot y_h^t$:

$$\begin{aligned} U(C_h^0, l_h^0, ..., C_h^T, l_h^T, s_h^{T+1}) &= \sum_{t=0}^{T} \beta^t \cdot (u_c(C_h^t) + u_l(1 - l_h^t)) + \beta^{T+1} \cdot u_T(s_h^{T+1}) \quad (7) \\ \text{where} & \\ u_c(C_h^t) &= \begin{cases} \log(C_h^t) & \text{for } C_h^t > 0 \\ -\infty & \text{for } C_h^t = 0 \end{cases} \\ u_l(l_h^t) &= \begin{cases} \frac{1}{l_h^t - 1} & \text{for } l_h^t \in [0,1) \\ -\infty & \text{for } l_h^t = 1 \end{cases} \\ u_T(s_h^{T+1}) &= -(s_h^{T+1} - \alpha_h \cdot y_h^T)^2 \\ \beta &= 0.97 \end{aligned}$$

Each of the three functions is continuous and strictly concave. U is additively separable into time steps. Notice that the value of β is irrelevant here, because multiplication with a constant does not alter the concavity of a function. At each time step $0, .., T$, the goal function is additively separable into u_c and u_l, at time $T+1$ it just involves u_T. So, U is strictly concave except where it converges towards $-\infty$ because either $c_h^t = 0$ or $l_h^t = 0$ or both. Values of $-\infty$ can be disregarded when looking for maxima. For our purposes, then, strict concavity of U can be taken for granted.

However, the transformation of the goal function transforms the action space, too. Using the equilibrium condition $k_i^t = s_h^t$, the new action space can be parametrized on given sequences $\hat{e}_i$, i.e. sequences of emissions generating resources as follows:

$$\begin{aligned} A^*(\hat{e}_i) \quad = \quad & \{\ (C_h^0, l_h^0, .., C_h^T, l_h^T, s_h^{T+1})\ | \\ & \quad l_h^t \in [0,1] \subset I\!R, \\ & \quad C_h^t \in [0, f(l_h^t \cdot \pi^t, k_i^t) - k_i^t \cdot \delta], \\ & \quad s_h^{T+1} = f(l_h^T \cdot \pi^T, k_i^T, \hat{e}_i^t) - C_h^T \\ & \} \end{aligned} \tag{8}$$

where

$$\begin{aligned} k_i^{t+1} \quad &= \quad f(l_h^t \cdot \pi^t, k_i^t, \hat{e}_i^t) - C_h^t, \\ \pi^{t+1} \quad &= \quad \pi^0 \cdot \exp(0.02 \cdot t), \\ f \quad &: \quad I\!R_{\geq 0} \times I\!R_{\geq 0} \times I\!R_{\geq 0} \rightarrow I\!R_{\geq 0}, \\ f \quad & \quad\ \ \text{differentiable, strictly concave} \end{aligned}$$

The values for l_h^t stay within $[0, 1]$, but the upper bound of C_h^{t+1} now depends on $(l_h^t, s_h^t, \hat{e}_i^t)$ via production at time t. Moreover, the action space is enlarged by the variable s_h^{T+1}. However, $A^*(\hat{e}_i^t)$ is still closed and bounded, because given the situation at time t there is always a maximal value of output that can be reached at time $t+1$. As the goal function is continuous, the optimization problem has a solution and the economy has at least one equilibrium.

To show convexity of $A^*(\hat{e}_i^t)$, and thereby uniqueness, one must show that if $\tilde{x} = (\tilde{C}_h^0, \tilde{l}_h^0, ..., \tilde{c}_h^T, \tilde{l}_h^T, \tilde{s}_h^{T+1})$ and $\bar{x} = (\bar{C}_h^0, \bar{l}_h^0, ..., \bar{c}_h^T, \bar{l}_h^T, \bar{s}_h^{T+1})$ both belong to $A^*(\hat{e}_i^t)$, any convex combination $\lambda \cdot \tilde{x} + (1-\lambda) \cdot \bar{x}$ (with $0 < \lambda < 1$) also belongs to $A^*(\hat{e}_i^t)$.

Let t^* be the first moment in time where the two differ. If they differ in $C_h^{t^*}$ only, any convex combination of $\tilde{C}_h^{t^*}$ and $\bar{C}_h^{t^*}$ will also be feasible. If they differ in $l_h^{t^*}$, any convex combination of $\tilde{l}_h^{t^*}$ and $\bar{l}_h^{t^*}$ will be feasible. Because of the strict concavity of f, any such convex combination will lead to an output q_i^{t*} that will be higher than the corresponding convex combination of $\tilde{q}_i^{t*}$ and $\bar{q}_i^{t*}$. Therefore, whatever consumption levels $\tilde{C}_h^{t*}$ and $\bar{C}_h^{t*}$ may occur at time t^*, their convex combination will be feasible as well.

If $\tilde{s}_h^{t^*+1} = \bar{s}_h^{t^*+1}$, the same reasoning applies for time $t^* + 1$. Now suppose $\tilde{s}_h^{t^*+1} \neq \bar{s}_h^{t^*+1}$. *Because* π^{t^*+1} *does not depend on the choices of the agents*, this is the only way decisions at time t^* can affect $\tilde{x}$ and $\bar{x}$ at time t^*+1 . The strict concavity of f then implies that any convex combination of $\tilde{s}_h^{t^*+1}$ and $\bar{s}_h^{t^*+1}$ will allow for a maximal output (i.e. with $l^{t^*+1} = 1$) that will be higher than the corresponding convex combination of the maximal outputs of $\tilde{x}$ and $\bar{x}$ at time $t^* + 1$. The strict convexity of f so ensures that step by step convex combinations of $\tilde{x}$ and $\bar{x}$ are elements of $A^*(\hat{e}_i^t)$. This reasoning can be iterated up to time T, and it holds for s_h^{T+1} as well.

The strict concavity of U also ensures that there is a one-to-one correspondence between sequences of quantities $\hat{e}_i^t$, $t = 0, .., T$, and sequences of prices p_e^t: any optimal solution must fulfill the central tenet of neoclassical thinking, $p_e^t = \frac{\partial U_i^t}{\partial \hat{e}_i^t}$, and strict concavity implies a monotonic relation between the quantity $\hat{e}_i^t$ and its marginal utility.

If the neoclassical growth model captures the key features of the actual economy that matter for climate policy, it has severe consequences. The problem that climate policy seeks to address is a situation where emissions in the present lead to suffering in the future. Reducing present emissions in this model type, however, means reducing present incomes, and thereby either returns on investment or wages or both. It is obvious that this makes the implementation of an effective climate policy an arduous task. The task becomes even harder when different governments have to find a way to allocate those income reductions among themselves.

6.7 Alternative growth paths

Taking the neoclassical model as our starting point, we now introduce some features that are relevant to think about European climate policy. The European economy is charactized by persistent unemployment and less than spectacular growth, and under these conditions proposals for climate policy that imply reductions in income are likely to receive more rhetorical than practical support. Recent advances in economic modeling suggest that there are better possibilities, however. Moreover, the recent financial crisis provides strong reasons for an overhaul of existing models. In this spirit, we now introduce a few amendments to the neoclassical model.

6.8 Time and agents

We consider a number N_i of firms and a number N_h of households:

$$\begin{aligned} t &= 0, 1, .., T \qquad (9) \\ i &= 1, .., N_i \\ h &= 1, .., N_h \end{aligned}$$

Once the implications of heterogeneous agents and their interaction networks have been investigated, their aggregate behavior may sometimes still be approximated by representative agent models. There can be little doubt, however, that this cannot be done in general (Kirman 1992).

6.9 Firms

We leave the firm nearly unaltered, except for the important fact that now there is more than one. The one change is the introduction of a sales tax ζ in order to finance unemployment benefits. The sales tax is just a simple way of doing so, other tax schemes can be introduced without changing the main finding.

$$\begin{aligned} \max_{k_i^t, l_i^t, e_i^t} \quad & q_i^t \cdot (1-\zeta^t) - k_i^t \cdot (i^t + \delta) - l_i^t \cdot w^t - e_i^t \cdot p_e^t \\ \text{s.t.} \quad & q_i^t = \left(0.3 \cdot (k_i^t)^{-1}, 0.65 \cdot (l_i^t \cdot \pi^t)^{-1}, 0.05 \cdot (e_i^t)^{-1}\right)^{-1} \\ & k_i^t, l_i^t, e_i^t \in I\!R_{>0} \end{aligned} \tag{10}$$

6.10 Households

We keep many features of households unchanged (again except for having more than one). However, households now must reckon with the possibility of a stochastic shock, namely finding themselves unemployed. This means that expectations become crucial for economic dynamics, as present decisions now depend on what economic agents expect from an uncertain future. Therefore, in (11), it is the expectation E induced by the probabilities m^t that is maximized.

In the past years, the prevalent style to model such situations has been shaped by the rational expectations hypothesis, according to which all agents are assumed to have common expectations, corresponding to the probabilities implied by the economists model. As with the neoclassical growth model, there is much to be said against this hypothesis (Evans and Honkapohja 2001). For our present purposes, however, it is sufficient. The model implies that households get unemployed with probabilities m^t (introduced below) and that they share expectations based on these probabilities. Employment status is represented by a random variable: $\mu_h^t = 1$ for employed, $\mu_h^t = 0$ for unemployed. When a household is unemployed, it gets unemployment benefits z^t.

Because the intertemporal optimization problem now involves stochastic shocks, its solution cannot be a sequence of consumption demands and labor supply - deciding today whether to carry an umbrella two months in advance is an inferior strategy to choosing a decision rule and taking the actual decision in two months on the basis of additional information that will be available then. Therefore, the households search for a decision rule ψ that yields the fraction of income to be consumed and the amount of labor to be offered as a function of their financial assets and their employment status.

$$\begin{aligned} \max_{\psi_i} \quad & \mathrm{E}\left[\sum_{t=0}^{T}(0.97)^t \cdot \left(\mathrm{oog}\ (y_h^t \cdot c_h^t) + \frac{1}{l_h^t \cdot \mu_h^t - 1}\right.\right. \\ & \qquad\qquad\qquad \left.\left. -(s_h^{T+1} - \alpha_i \cdot y_h^T)^2\right)\right] \qquad (11) \\ \text{s.t.} \quad & y_h^t = l_h^t \cdot w^t \cdot \mu_h^t + z^t \cdot (1 - \mu_h^t) + s_h^t * i^t \\ & s_h^{t+1} = s_h^t + y_h^t \cdot (1 - c_h^t) \\ & \psi_i : \ I\!R_{\geq 0} \times \{0,1\} \rightarrow [0,1] \times [0,1] \\ & \psi_i(s_h^t, \mu_h^t) = (c_h^t, l_h^t) \end{aligned}$$

6.11 System properties

A major advance in climate economic modeling has been the introduction of endogenous technical change (Edenhofer et al. 2006). It is a well-established fact that productivity increases with production thanks to learning by doing, and to some extent it is possible to quantify this link. Careful empirical research (e.g. Alberth 2008, Nagy et al. 2011) provides strong evidence to the effect that unit costs fall, and labor productivity increases, in line with the expansion of cumulative production. We therefore replace the exogenous dynamics of (4) with the endogenous dynamics of (12).

The endogenous productivity dynamics matters for the probability of unemployment, m^t, too. The debate about how much unemployment is voluntary, how much an inevitable consequence of time-consuming search processes on the labor market, and how much due to various departures from the neoclassical idea of market equilibrium will hardly be settled anytime soon. But it is widely accepted that unemployment can rise to levels where deflationary processes set in, and that it can fall to levels where runaway inflation becomes a serious danger. Somewhere in between lies a rate of unemployment that is sometimes emphatically called "natural", sometimes labelled more technically as the non-accelerating inflation rate of unemployment, aka NAIRU. However, empirical research has shown that the NAIRU itself moves in the course of time, and a major factor affecting its dynamics is the rate of productivity growth (Ball and Mankiw 2002).

Ormerod, Rosewell and Phelps (2009) provide evidence suggesting that since more than a century industrialized economies move back and forth between two kinds of equilibria, one characterized by higher one by lower unemployment. The differences in inflation between the equilibria are remarkably small, while the historical record shows that differences in productivity growth are substantial. A third constellation of very high unemployment seems relevant mainly for the years of the great depression after 1929, and the world came dangerously close to it again in the financial crisis of 2007-2008. In view of the possibility of green growth this hypothesis may become quite important. For our present purposes we stick to a weaker hypothesis that remains agnostic about the number of possible equilibria by simply letting the probability of unemployment decrease with productivity growth in a way that is consistent with broad patterns of growth in industrialized countries.

The price of the emissions generating resource stays exogenous as before, and the unemployment benefits are set exogenously, too.

$$\begin{aligned}
\pi^{t+1} &= \pi^t \cdot (1 + \frac{q^t}{Q^t}) \\
q^t &= \sum_{i=1}^{N_i} q_i^t \\
Q^t &= Q^0 + \sum_{i=0}^{t} \sum_{i=1}^{N_i} q_i^t \\
\pi^0 &= \bar{\pi}^0 \\
m^t &= \text{Prob}(\mu_h^t = 1),\ \forall h \\
m^{t+1} &= 0.0012 \cdot \left(\frac{\pi^{t+1} - \pi^t}{\pi^t} \right)^{-1} \\
m^0 &= \frac{\sum_{h=1}^{N_h} \mu_h^0}{N_h} \\
p_e^t, z^t &: \ I\!N \to I\!R_{>0}
\end{aligned} \tag{12}$$

6.12 Equilibrium conditions

The equilibrium conditions need only two amendments, both needed to deal with unemployment. First, the labor actually employed is equal to the labor offered on the market minus the unemployed. A more sophisticated treatment could represent vacancies, too, but it would not change the argument. Second, the sales tax is set at the level needed to finance unemployment benefits.

$$\begin{aligned}
\sum_{i=1}^{N_i} (q_i^t - k_i^t \cdot \delta) &= \sum_{h=1}^{N_h} y_h^t \\
\sum_{i=1}^{N_i} l_i^t &= \sum_{h=1}^{N_h} l_h^t \cdot \mu_h^t \\
\sum_{i=1}^{N_i} k_i^t &= \sum_{h=1}^{N_h} s_h^t \\
\sum_{i=1}^{N_i} \zeta \cdot q_i^t &= \sum_{h=1}^{N_h} (1 - \mu^t) \cdot z^t
\end{aligned} \tag{13}$$

6.13 Sunspots with externalities

At each moment in time, the household is faced with two possibilities. The application of the decision function then can be analyzed as a binary tree (see Olson and Roy 2006 for a related analysis of policies as sequences of conditional probabilities). As in (7), the goal function for the economy as a whole can be rewritten in separately additive form and shown to be continuous and strictly concave. The action space is again a bounded closed set, so the problem has at least one solution and the economy at least one equilibrium.

The proof of convexity, however, breaks down because of endogenous productivity dynamics. Financial assets are no more the only way for decisions at time t^* to influence the decision problem at time $t^* + 1$. If in period t^* policy ϕ leads to higher growth than policy ψ, in period $t^* + 1$ policy ϕ can take advantage of a higher level of labor productivity. As a result, at time $t^* + 1$, the maximal output that can be generated by a convex combination of ϕ and ψ – call it χ – may be smaller than the corresponding convex combination of maximal outputs from ϕ and ψ at time $t^* + 1$. In this case, the convex combination of the consumption and investment decisions implied by ϕ and ψ at time $t^* + 1$ is impossible for χ if the latter is to fulfill the specification of the action space. So, χ does not belong to the action space and the latter is not convex.

Non-convexity of the action space means that there may be several equilibria. In view of endogenous technical progress, this possibility has been analyzed by Benhabib and Farmer (1999), who notice: "An interesting feature of endogenous models is their ability to generate multiple balanced growth paths in conjunction with indeterminacy" (p.424, see also Mino 2001). Multiple equilibria are a pervasive property of economic models with more than two goods (remember that in dynamic models with only one sector the output of each period counts as a different good). In particular, rational expectations are possible for an arbitrary large set of equilibria (Driskill 2006b).

In the present case, an individual household can only form expectations about the future by assuming what the other households will expect. If all expect low productivity growth with the associated high NAIRU, that is what they will get. Of course, not any conceivable set of expectations leads to a possible equilibrium, but there is definitely more than one possibility. As a result, economic agents may be trapped in a situation of low productivity growth and high unemployment, and they can only overcome this situation if they find some way to jointly shift their expectations. This is what a well designed green growth strategy can achieve.

In the presence of several possible equilibria, neither rationality nor the forces of supply and demand can explain equilibrium selection. This has led to the concept of sunspot equilibrium and the vast literature that has grown around it (Shell 2008). A sunspot equilibrium is selected by coordination of expectations via events taking place outside of the market place, like sunspots.

Sunspot equilibria can arise in models that fulfill all the conditions of a general equilibrium of the Arrow-Debreu type. In the present case, they are linked to a double externality: the one of productivity increase and the related one of high unemployment linked to low productivity growth. This means two things: first, not all possible equilibria are Pareto optimal. And second: a Pareto improvement can be reached by coordinating expectations towards a new growth path. Such is the historical opportunity of green growth.

7

Modeling methodology

7.1 Overview of the GEM-E3 model

The model we have used for quantitative assessments of different possible equilibrium paths is the computable general equilibrium (CGE) model GEM-E3.[6] The GEM-E3 model is a multi-region multi-sector model that covers the interactions between energy, economy, and environment. The design of the GEM-E3 model has been developed following four main guidelines:

1. Model design around a basic general equilibrium core in a modular way so that different modeling options, market regimes and closure rules are supported by the same model specification.
2. Fully flexible (endogenous) coefficients in production and in consumers' demand.
3. Calibration to a base year data set, incorporating detailed Social Accounting Matrices as statistically observed.
4. Dynamic mechanisms, through the accumulation of capital stock.

The GEM-E3 model starts from the same basic structure as the standard World Bank models[7]. Following the tradition of these models, GEM-E3 is built on the basis of a Social Accounting Matrix (Decaluwe, Martens and Monette 1987; Decaluwe and Martens 1988) and explicitly formulates demand and supply equilibrium. Technical coefficients in production and demand are flexible in the sense that producers can alternate the mix of production not only regarding the primary production factors but also the intermediate goods. Production is modeled through KLEM (capital, labor, energy and materials) production functions involving many factors (all intermediate products and two primary factors – capital and labor). At the same time, consumers can also endogenously decide the structure of their demand for goods and services. Their consumption mix is decided through a flexible expenditure system involving durable and non-durable goods. The specification of production and consumption follows the generalized Leontief type models[8] as initiated in the work of Jorgenson.

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[6] The GEM-E3 model was initially built under the auspices of EC (DG-RTD) by a consortium involving ICCS-NTUA, BUES, ERASME, KUL, PSI and ZEW. It is presented in detail by Capros et al. 1999. The version of the GEM-E3 used in this study has been developed by ICCS-NTUA within the EC(DG-RTD) funded project 'MODELS'.
The model code is owned by the EU and we are not in a position to share it. An open source code for a CGE model is included in Löfgren, Harris and Robinson 2001).

[7] The World Bank type of models constitutes the bulk of equilibrium modeling experiences. This type of models is usually used for comparative statics exercises. These models however do not use full scale production functions but rather work on value added and its components to which they directly relate final demand.

[8] The generalized Leontief type model was first formulated empirically in the work of D. W. Jorgenson who introduced flexibility in the Leontief framework, using production functions such as the translog function. The

The model is not limited to comparative static evaluation of policies. It is recursive dynamic (see Babiker et al. 2009 for a discussion in view of climate policy). Its properties are mainly manifested through stock/flow relationships, technical progress, active population growth, capital accumulation and agents' (backward looking) expectations[9] and the Quest model used in (Conte et al. 2010).

The model is calibrated to a base year data set that comprises a full Social Accounting Matrix for each EU country that is built by combining input-output tables (as published by EUROSTAT) with national accounts data. Bilateral trade flows are also calibrated for each sector represented in the model, taking into account trade margins and transport costs. Consumption and investment are built around transition matrices linking consumption by purpose to demand for goods and investment by origin to investment by destination. The initial starting point of the model, therefore, includes a very detailed treatment of taxation and trade. Total demand (final and intermediate) in each country is optimally allocated between domestic and imported goods, under the hypothesis that these are considered as imperfect substitutes (the "Armington" assumption, see Armington 1969).

GEM-E3 explicitly considers market clearing mechanisms, and related price formation, in the economy, energy and environment markets. Following a micro-economic approach, it formulates the supply or demand behaviour of the economic agents regarding production, consumption, investment, employment and allocation of their financial assets. Prices are computed by the model as a result of supply and demand interactions in the markets.

By simultaneously representing all markets of an economy, the model is able to capture their multiple interactions providing insights into the factors determining the allocation of resources and distribution of incomes. Figure 16 provides a sketch of the different decision steps and transactions represented in the model. The version used in the current study covers the whole world aggregated to 37 regions (27 of which are the EU member states). In each region the economy is aggregated to 25 activities represented by one typical firm that operates within a perfect competition market regime. Regarding the power generation sector a bottom-up approach has been adopted enabling to discretely identify 8 power producing technologies. All regions are linked through endogenous bilateral trade flows of goods and services following Armington (1969). Household consumption and leisure are derived through utility maximisation. In addition to the voluntary unemployment (as this is captured by the choice for leisure) the model computes involuntary unemployment by adopting the efficiency wages approach originated by Shapiro and Stiglitz (1984).

Institutional regimes, that affect agent behaviour and market clearing, are explicitly represented, including public finance, taxation and social policy. All common policy instruments affecting economy, energy and environment are included. The model is general and complete,

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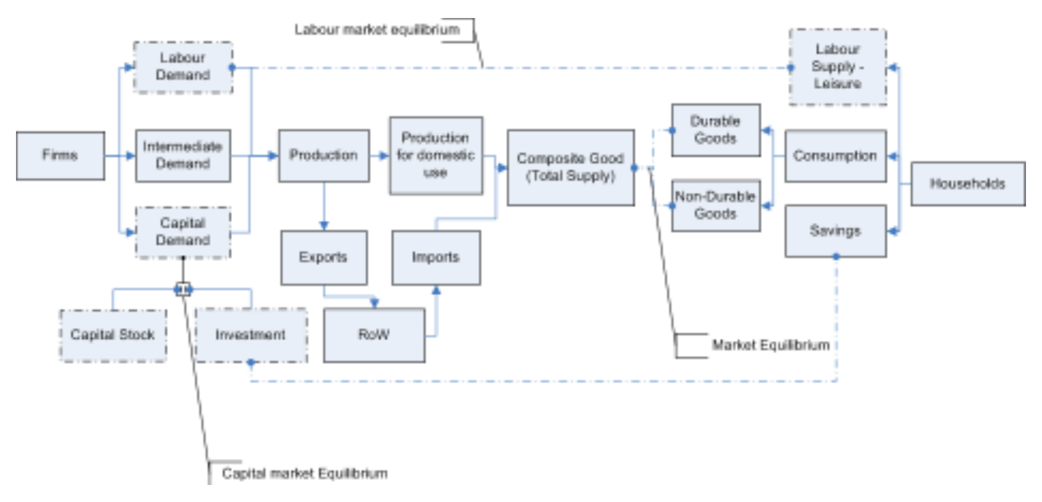
work of D. W. Jorgenson inspired many modeling efforts, in which particular emphasis has been put on energy. For example, such models have been developed in France by P. Capros and N. Ladoux, by the OECD (the GREEN and WALRAS models), in Sweden by L. Bergman and in Germany by K. Conrad.

[9] A recent generation of general equilibrium models involve rational expectations where the model is solved inter-temporally i.e. for all time-periods together. Recent examples of such models are the G-Cubed model (McKibbin and Wilcoxen 1995).

Figure 16: GEM-E3 economic circuit



Source: E3M-Lab.

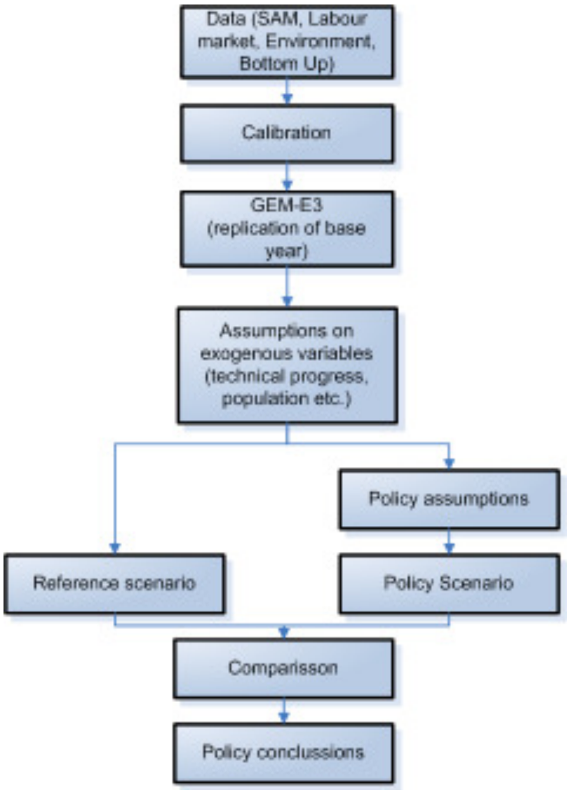
in the sense that it includes all agents, markets and geographic entities that affect European and World economic equilibrium. The model attempts also to represent goods that are external to the economy as for example damages to the environment.

The internalisation of environmental externalities is conveyed either through taxation or through global system constraints, the shadow costs of which affect the decisions of the economic agents. The current version of GEM-E3 links global constraints to environmental emissions, changes in consumption or production patterns, external costs/benefits, taxation, pollution abatement investments and pollution permits. It evaluates the impact of policy changes on the environment by calculating the change in atmospheric emissions and damages, and determines costs and benefits through an equivalent variation measurement of global welfare (inclusive environmental impact). The recent awareness about the greenhouse problem motivated the emergence of several empirical models for the analysis of economy-environment interactions. For example, the works of Nordhaus (2005); Jorgenson, Slesnick and Wilcoxen (1992); Manne and Richels (1997); Proost and Van Regemorter (1992) have focused on the economic conditions for obtaining CO_2 emission reductions by means of a carbon-related tax. Such a policy issue needs to be addressed by ensuring consistent representation of the interactions between the economy, the energy system and the emissions of CO_2.

The recursive dynamic model extends up to 2030 with a five year time step. The main drivers of economic growth, technical progress, agents' expectations and active population are assumed exogenous in the model. These exogenous variables are calibrated so as to produce a reference projection that is consistent with official economic and demographic projections (Brown et al. 2009; European Commission (DG ECFIN) and the Economic Policy Committee (AWG) 2009). Thus the analysis with the GEM-E3 model starts by constructing a reference projection of economic growth for the 37 regions with which the world is represented in the model. The reference projection, named baseline scenario, serves as a basis of comparison for the policy scenarios (Figure 17).

Within the current study the GEM-E3 model has been modified so as to incorporate learning-by-doing mechanisms and semi-endogenous energy efficiency improvements. In the following subsection the specification of the main part of GEM-E3 is provided (for a full specification of the model see Capros et al. 1999) and the mechanics of the newly incorporated mechanisms are detailed.

Figure 17: GEM-E3 simulation procedure



Source: E3M-Lab.

7.1.1 Firms

The production function of firms involves 16 intermediate inputs and two primary production factors (capital and labor). The aggregate production function used in the model is the neoclassical constant elasticity of substitution (CES, see Arrow et al. 1961). In order to capture the different substitution possibilities among the production factors, the nesting scheme of the CES presented in Figure 18 was adopted.

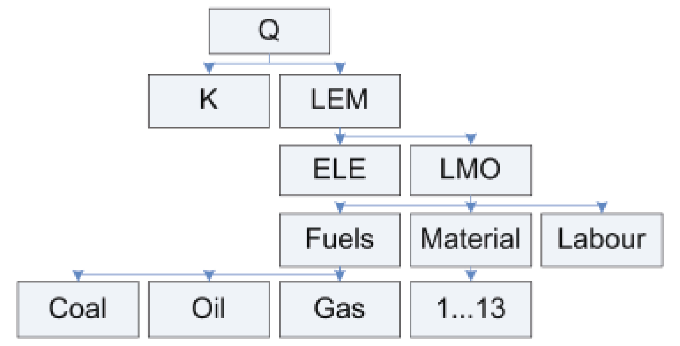
Firms seek to maximize their profits by employing the optimum amounts of intermediate and primary production factors. The firms' optimization problem is given by (14) and (15).

$$\max \Pi_i = P_i \cdot Q_i - PK_i \cdot K_i - PLEM_i \cdot LEM_i \tag{14}$$

$$\text{where } Q_i = \left(e^{tgk} \cdot d_i^k \cdot K^\rho + d_i^{lem} \cdot LEM_i^\rho\right)^{\frac{1}{\rho}} \tag{15}$$

and i is the number of firms $i = \{1 \text{ to } 25\}$, Π is profit, P_i is the unit cost of production, Q_i the volume of production; $PLEM_i$ is the unit cost of production of the bundle of labor, energy, and materials, and LEM_i the volume of this bundle; PK_i is the user cost of capital, K_i the volume of capital employed; ρ is the parameter that relates to the elasticity of substitution s as follows $s = \frac{1}{1+\rho}$ (the elasticity of substitution is indexed to i but for presentation reasons

Figure 18: GEM-E3 production nesting scheme



`Q` is production, `K` is capital, `LEM` is the energy material labor bundle, `ELE` is electricity, and `LMO` the fuel material labor bundle
Source: E3M-Lab.

this is skipped here); d_i^k and d_i^{lem} are the calibrated share parameters for capital and the LEM_i bundle respectively; and tgk is the technical progress of capital. From the first order conditions, the optimum demands for K, LEM production factors are derived (similarly for all other nestings the optimum factor demands can be derived)

$$\frac{d\Pi}{dK} = 0, \quad K_i = Q_i \cdot \left(e^{tgk} \cdot d_i^k\right)^s \cdot \left(\frac{PK_i}{P_i}\right)^{-s} \tag{16}$$

$$\frac{d\Pi}{dLEM} = 0, \quad L_i = Q_i \cdot \left(d_i^{lem}\right)^s \cdot \left(\frac{PLEM_i}{P_i}\right)^{-s} \tag{17}$$

Substituting the derived demands into the production function, the function of the unit cost of production can be derived. This is the supply function of the firm and serves as the zero profit[10] condition for the model.

$$P_i = \left[e^{-tgk \cdot s} \cdot \left(d_i^k\right)^s \cdot (PK_i)^{1-s} + \left(d_i^{lem}\right)^s \cdot (PLEM_i)^{1-s}\right]^{\frac{1}{1-s}} \tag{18}$$

Similar derivations apply for all levels of the CES nesting scheme. The respective productivities found in each level are: energy productivity (tge), materials productivity (tgm) and labor productivity (tgl).

7.1.2 Learning-by-doing

The learning-by-doing or experience curve has been studied extensively. It represents technical progress as a function of some cumulative experience indicator. Dasgupta and Stiglitz

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[10] By applying the Euler equation (due to the homogeneity of 1^{st} degree in quantities of the CES) we get $\Pi \equiv \mathrm{K} \cdot \frac{d\Pi}{dK} + LEM \cdot \frac{d\Pi}{dLEM}$, that is, if each production factor is paid its marginal product then profits are zero, that is, all revenues are used for the compensation of the production factors.

(1988) assume that the size of the productivity increase through learning-by-doing is a positive function of the capital intensity of production. One should note that this type of productivity growth is not embodied in machinery and equipment, but it is not strictly disembodied either, since it needs the machinery and equipment as the object of learning. According to Lieberman (1987), a typical empirical study of the learning function, learning is found to be a function of cumulative investment rather than calendar time. Similarly Christensen (1997) uses the cumulative capacity as a measure of the knowledge accumulation occurring during the manufacturing and use of a technology.

In the version of the GEM-E3 model used in this study, learning rates in power producing sectors were introduced. A rather comprehensive review of learning curves for energy technology and policy analysis can be found in Jamasb and Köhler (2007). The usual form of learning curve measures how much the costs of a given power producing technology are reduced due to its increased capacity (Equation 19):

$$c_i = a \cdot Cap_i^{lr} \tag{19}$$

where c_i is the cost per unit of production, Cap_i is capacity and lr the learning elasticity. The learning effect is then measured in terms of percentage cost reduction for each doubling of the cumulative generation capacity or of production (equation 20):

$$LRE_i = 1 - 2^{lr} \tag{20}$$

where LRE_i is the learning effect. Thus learning by doing rates are assumed to reduce overall production costs (see also McDonald and Schrattenholzer (2001), Pizer and Popp (2007)). In the GEM-E3 model, learning rates are assumed to increase labor productivity and hence reduce labor costs. Learning in GEM-E3 has been assumed to be a function of the ratio of investment to installed capacity (i.e. capital stock). The exact specification is given in Equation 21:

$$\Omega_i = \left(\frac{INVV_i}{KS_{i,t-1}} - d + 1 \right)^{period} \cdot \Omega_{i,t-1} \tag{21}$$

where Ω_i is the learning productivity rate, $INVV_i$ is investment by firm, $KS_{i,t-1}$ is the capital stock of the previous period/year and d is the capital stock depreciation. Ω then increases the exogenous labor productivity *tgl* (*tgl* is computed during the development of the reference projection) which enters in the derived demand for labor in Equation 22:

$$\frac{d\Pi}{dL} = 0, \quad L_i = LMO_i \cdot \left(e^{tgl \cdot \Omega_i} \cdot d_i^l \right)^{s3} \cdot \left(\frac{PL_i}{PLMO_i} \right)^{-s3} \tag{22}$$

where L_i is the firms demand for labor, LMO_i is the labor, material, energy bundle, PL_i is unit cost of labor, $PLMO$ is the unit cost of the LMO bundle, d is a share parameter and $s3$ the elasticity of substitution. Jamasb and Köhler (2007) provide a survey of historical learning rates in energy-related sectors, see Table 14.

Since learning-by-doing exhibits increasing returns to scale, it was not endogenised in the GEM-E3 model (a fully endogenous specification would lead to non-convergence problems).

That means that agents (in our case power producing sectors) are not aware of the learning-by-doing effect prior to their decision to select the optimal production factor mix. The cost reduction occurs once their investment decision is made. A shortcut to semi-endogenise the learning-by-doing effect would be to follow an iterative approach (not currently modeled).

Table 14: Historical learning rates for selected power producing technologies

Technology	Learning rate	Reporter	Period
Hydro	1.4	OECD	1979-1993
Nuclear	5.8	OECD	1975-1993
Coal	3.7	US	1960-1980
GTCC	34	OECD	1984-1994
Biomass	15	EU	1980-1999
Wind	18	EU	1980-1995
SPV	35	EU	1985-1994

Source: Adapted from Jamasb and Köhler (2007), McDonald and Schrattenholzer (2001), Kouvaritakis, Soria and Isoard (2000).

That is, at the first iteration firms will decide on their optimum production factor mix without knowing the learning by doing effect. Once the mix is decided the learning productivity effect can be computed (outside the 'solve' loop of the model). Then in the subsequent iteration firms will decide on the optimal factor mix knowing the potential learning-by-doing effect (as this was computed in the previous iteration).

7.2 Bottom up representation of the energy sector in the GEM-E3 model

CGE models have been criticized for their simplified modeling approach of the energy system. The usual CGE representation of energy production by means of aggregate production functions fails to capture crucial characteristics of the sector reducing the credibility of simulations related to energy policies and technology dynamics. The bottom up models employed instead, ignore the feedbacks from the interaction of the energy sector with the wider economy within which it operates. The development of a modeling framework that encompasses the multi market equilibrium of top down models with an engineering consistent representation of power producing technologies constitutes a long-standing challenge in applied energy policy analysis since the hybrid CGE model of (Manne 1977). Many different approaches have been employed to link bottom up and top down models and can be classified, following Boehringer and Rutherford (2005), in two main categories: (i) hard link approach, that is, integrating both bottom-up and top-down features in a consistent modeling framework. Such an integrated framework is provided by the specification of market equilibrium models as mixed complementarity problems (see Boehringer (1998) , Frei (2001), Kumbaroglou and Madlener (2001), Kumbaroglou and Madlener (2001), McFarland, Reilly and Herzog (2004), Wing (2006)). (ii) soft-link or decomposition approach where bottom-up and top-down models are run independently of each other (Boehringer and Rutherford 2005, Hudson and Jorgenson 1974). In this case results from one model are fed into the other, and vice versa. The GEM-E3 model adopts the hard link approach and identifies the following power producing technologies: i) Coal fired, ii) Gas fired, iii) Oil fired, iv) Nuclear, v) Biomass, vi) Hydro electric vii) Wind and viii) PV. The market shares and cost characterisation of power producing technologies is based on engineering databases and energy balances such as the TECHPOL database, the ENERDATA database and the PRIMES model database. The cost structure and market shares (at the EU27 level) are depicted in Table 15.

Table 15: Base year cost structure and market shares of power producing technologies EU27

Technology	Capital	Labour	Fuel	Market
Coal fired	46	26	28	31
Oil fired	22	11	66	6
Gas fired	21	10	69	25
Nuclear	78	22	–	24
Biomass	35	13	51	3
Hydro	87	13	–	9
Wind	92	8	–	2
PV	98	2	–	0

Source: E3M-Lab model parameters.

The shares of each technology in power generation in the base year are introduced from energy balance statistics. Some of the potential technologies that may develop in the future are not used in the base year. Since the production function for power generation is calibrated to the base year, it is necessary to introduce artificially small shares even for the non existing technologies in order to allow for the possibility of their penetration in the future under market conditions.

The input-output tables represent the electricity sector as an aggregate of two activities, namely the power generation and the transmission and distribution of electricity. This is not convenient for the bottom up model, and so it is necessary to split the Input-Output column and row in different activities, some corresponding to power generation by technology and the rest corresponding to transmission and distribution of electricity. The split was performed by combining data from energy balances and company-related economic data about generation and transmission and distribution activities by country. The aggregate data were based on Eurostat, IEA and USA DOE statistics. For example, the disaggregation shows that the generation cost accounts for over half of total cost, and in most EU countries they account for over 60 %. In order to disaggregate the power sector a mapping was specified between the entries of the Input-Output table and the engineering information retrieved from the technical databases. For this purpose the following cost elements were derived from the engineering database: (i) capital cost (ii) fixed operating and maintenance cost (iii) fuel cost and (iv) other variable operating and maintenance costs, related to the energy producing technologies to be incorporated in the model. Subsequently these unit costs are associated with the corresponding cost elements of the Input-Output statistics, according to the following principles: a) annualized capital costs correspond broadly to operating surpluses, b) fuel costs correspond to the fuel input, c) fixed operating and maintenance cost correspond to non energy inputs (materials), d) variable operating and maintenance costs are associated with wages and salaries paid to employees in power generation. Since the entire GEM-E3 model is calibrated on the social accounting matrices it is reasonable to keep the macroeconomic data constant and adjust the market and cost shares of the technologies. The purpose of the calibration is to depart as little as possible from the flows suggested by the engineering information while respecting exactly the totals appearing in the original input output table. Toward this end a cross entropy method was applied. This calibration technique cannot be applied uniformly since each country has specificities that must be respected. For example there are cases where the input output data do not register a flow from agriculture to electricity (biomass fuel), or the engineering data suggest such capital allocations that lead to unrealistic investment to capital ratios by technology. Adjustments of data were made in order to cope with these difficulties.

Table 16: Base year electricity generation costs

Technology	Cost relative to Coal fired technology
Coal fired	1
Oil fired	1.6
Gas fired	1.3
Nuclear	1.2
Biomass	1.7
Hydro	2.1
Wind	1.3
PV	4.1

Source: E3M-Lab model parameters.

The production function in GEM-E3 follows a nested scheme, involving capital (K), labor (L), energy (E) and materials (M) and is based on a CES neo-classical type of production function.

At the top level of the production function there is a CES aggregation of capital and the LEEM (labor, Energy, Electricity, Material) bundle. The elasticity of substitution at this level is 0.1. At the second level there is CES aggregation of Electricity (incl. T&D) and the LEM bundle with 0.2 elasticity of substitution. At the fourth level transmission and distribution (T&D) bundle and the power generation bundle (GEN) are aggregated through a CES function. At this level the elasticity of substitution chosen is 0.1 since these activities are considered to be complementary to each other. The power generation bundle is then a C.E.S. aggregate of a set of discrete power technologies. At the fifth nesting level a higher elasticity of substitution is chosen allowing for shifts in the technology mix of power production. The CES formulation for each level is shown below:

$$El_i = \left(d_i^{ren} \cdot (\frac{REN_i}{\overline{REN_i}})^{\rho} + d_i^{nc} \cdot (\frac{NC_i}{\overline{NC_i}})^{\rho} \right)^{\frac{1}{\rho}} \tag{23}$$

$$REN_i = \left(d_i^{hyd} \cdot (\frac{HUD_i}{\overline{HYD_i}})^{\rho 1} + d_i^{wnd} \cdot (\frac{WND_i}{\overline{WND_i}})^{\rho 1} + d_i^{pv} \cdot (\frac{PV_i}{\overline{PV_i}})^{\rho 1} + d_i^{bms} \cdot (\frac{BMS_i}{\overline{BMS_i}})^{\rho 1} \right)^{\frac{1}{\rho 1}} \tag{24}$$

$$NC_i = \left(d_i^{nuc} \cdot (\frac{NUC_i}{\overline{NUC_i}})^{\rho 2} + d_i^{cov} \cdot (\frac{COV_i}{\overline{COV_i}})^{\rho 2} \right)^{\frac{1}{\rho 2}} \tag{25}$$

$$COV_i = \left(d_i^{coa} \cdot (\frac{COA_i}{\overline{COA_i}})^{\rho 3} + d_i^{oil} \cdot (\frac{OIL_i}{\overline{OIL_i}})^{\rho 2} + d_i^{gas} \cdot (\frac{GAS_i}{\overline{GAS_i}})^{\rho 3} \right)^{\frac{1}{\rho 3}} \tag{26}$$

The output of the power producing technologies is a CES aggregate of: capital labor and fuels. A parameter is introduced reflecting the capital equipment technical progress of each technology. This parameter is used to calibrate the production cost of each technology depicted in table below.

$$Q = \left(ent_con \cdot d^k \cdot (\frac{K}{\overline{K}})^{\rho 4} + d^{lf} \cdot (\frac{LF}{\overline{LF}})^{\rho 4} \right)^{\frac{1}{\rho 4}} \tag{27}$$

$$LF = \left(d^l \cdot (\frac{L}{\overline{L}})^{\rho 5} + d^{fuel} \cdot (\frac{Fuel}{\overline{Fuel}})^{\rho 5} \right)^{\frac{1}{\rho 5}} \tag{28}$$

7.2.1 Energy efficiency

In the standard version of the GEM-E3 model energy efficiency improvements are simulated through the exogenously specified energy productivity (*tge*). Based on the methodology developed in previous works (Capros et al. 1998; Capros et al. 1999), energy efficiency cost curves were introduced in the model. In this specification, agents are able to use part of their income in order to increase energy efficiency. To achieve this, an additional factor was introduced, namely the stock of energy saving technology. Then energy productivity (*tge*) was formulated as a positive function of the stock of energy saving technology.

$$EFIst_{i,t} = (1 - dloss_{i,t})^{period} \cdot EFIst_{i,t-1} + \left(\frac{1 - (1 - dloss_{i,t})^{period}}{dloss_{i,t}} \right) \cdot EFIfl_{i,t} \tag{29}$$

$$EFfl_{i,t} = ac_i \cdot (EFIst_{i,t})^g \tag{30}$$

where $EFIst$ is the stock of energy saving technology, $dloss$ is the decay parameter for the energy efficiency improvements, $EFfl$ is the expenditure for energy efficiency, and ac and g are calibrated parameters of the energy efficiency cost curve.

It is important to underline the three distinctive features of the stock of energy saving technology: i) it does not increase the productive capital stock of the firm. Accumulation of the energy saving technology increases only energy productivity and hence provides energy efficiency improvements. ii) Expenditure in energy saving technology is essentially additional demand for goods and services such as equipment goods, electrical goods, construction, market services, and iii) the accumulation of energy saving technology has permanent effects on energy productivity. Energy efficiency improvements are modeled so as to exhibit decreasing marginal returns (saturation effect). It should be noted that in the current setup expenditures in energy efficiency ($EFfl$) are assumed exogenous. This approach could be further improved by including the expenditure on energy efficiency as an endogenous choice of the agents (households and firms).

7.2.2 Government

Government behaviour is set exogenously in the model. Government income is generated through tax collection, property income and dividends received by firms. The world version of GEM-E3 identifies the following fiscal instruments: indirect taxes, direct taxes, subsidies, social security and duty rates. These receipts are coming from product sales (i.e. from branches) and from sectors (i.e. agents).

7.2.3 Households and labor market

GEM-E3 identifies a representative household per region that maximizes its utility under its budget constraint. Household budget is composed of: i) income from labor supply ii) dividends received from firms iii) public transfer payments.

The utility function is a LES (Linear Expenditure System - Stone Geary Stone 1954) type extended (Extended Linear Expenditure System) according to (Lluch 1973)[11].

$$U\left(CV, LJV\right) = \left(\beta_{\mathrm{H}} \cdot \ln\left(CV - CH\right) + \beta_{L} \cdot \ln\left(LJV - CL\right)\right) \tag{31}$$

where CV is total consumption, CH is the subsistence minimum consumption, LJV is leisure, CL is the subsistence minimum leisure, β_{H} is the LES budget share parameter (households consumption pattern), β_{L} is the leisure share parameter. The total and disposable incomes of the consumer are calculated as:

$$M = PL \cdot L + W^{oth} \tag{32}$$

$$YDISP = \mathrm{M} - S \tag{33}$$

where $PL \cdot L$ is the income from labor supply, and W^{oth} the non labor income (i.e. dividends, unemployment benefits, property income), $PLJ \cdot LJV$ is the value of leisure and S are the savings. The objective function of the household is the maximization of its intertemporal utility function subject to its intertemporal budget constraint.

$$max_{CV,LJV} \int_{t=0}^{\infty} e^{-stp \cdot t} U\left(CV, LJV\right) \tag{34}$$

$$\text{s.t. } \dot{w}\left(t\right) = YDISP\left(t\right) - PCI\left(t\right) \cdot CV\left(t\right) - PCI\left(t\right) \cdot CH\left(t\right) - PLJ\left(t\right) \cdot LJV\left(t\right) - PLJ\left(t\right) \cdot CL\left(t\right)$$

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[11] Lluch extended LES so as to incorporate saving decision of households

where stp is the social time preference or subjective rate of discount. The solution to the above problem[12] is given by the optimal demand for consumption and leisure (35), (36).

$$CV = ch + \mu \cdot \frac{bh}{PCI} \cdot (YDISP + PLJ \cdot LJV - PLJ \cdot CL - PCI \cdot CH) \tag{35}$$

$$LJV = cl + \mu \cdot \frac{bl}{PLJ} \cdot (YDISP + PLJ \cdot LJV - PLJ \cdot CL - PCI \cdot CL) \tag{36}$$

where μ is an approximation to the marginal rate of consumption $\mu = \frac{stp}{r}$, r is the interest rate (Lluch 1973). Once the household has decided on its overall consumption and leisure, it has to allocate this consumption to specific goods and services (fn). These goods and services are distinguished into durable goods (DG) and non durable goods (NDG; below, $fn = \{DG, ND\}$). At this stage the GEM-E3 model adopts the approach developed by Conrad and Schroeder (1991) where the demand system of durable and non-durable goods is a function of their price, the stock of durable goods and total expenditure. The demand for durable goods is:

$$HCFV_{DG} = chcfv_{DG} + \frac{bhcfv_{DG}}{PDUR_{DG}} \cdot \left(PCI \cdot CV - \sum_{i:nd} PHCFV_i \cdot chcfv_i \right) \tag{37}$$

where $HCFV$ is consumption by purpose, $chcfv$ is the subsistence minimum, $bhcfv$ is the LES share parameter (related to the Household consumption pattern), $PHCFV$ is the price that refers to the consumption by purpose, and $PDUR$ is the user cost of the durable good:

$$PDUR_{DG} = PHCFV \cdot (r + d) + PHCFV \cdot (mincons + DISPCONS) \tag{38}$$

Consumption of durable goods is linked with the consumption of non-durable goods (LND) (e.g. fuel for the operation of transport vehicle). This consumption is calculated as:

$$LLNDC_{LND,DG} = HCFV_{DG} \cdot (mincons_{LND,DG} + DISPCONS_{LND,DG}) \tag{39}$$

where $MINCONS$ is the minimum consumption of non durable goods required for the consumption of one unit of durable goods and $DISPCONS$ is a factor of proportions adjusted according to the variation of the relative prices:

$$DISPCONS_{LND,DG} = alphdisp_{lnd,dg} \cdot \left(\frac{PCI}{PHCFV_{lnd}} \right)^{etadisp_{lnd,dg}} \tag{40}$$

where $alphdisp$ is a share parameter, and $etadisp$ is price elasticity.

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[12] The derivation follows (Lluch 1973).

Consumption of non durable goods is linked to durables, and the consumption of non-durable goods is calculated as:

$$\begin{aligned} HCFV_{LND} = chcfv_{lnd} + \frac{bhcfv_{lnd}}{PHCFV_{lnd}} \cdot \left(PCI \cdot CV - \sum_{i:lnd} PHCFV_i \cdot chcfv_i \right) \\ + \sum_{dg} LLNDC_{LND,DG} \end{aligned} \tag{41}$$

$$HCFV_{ND} = chcfv_{nd} + \frac{bhcfv_{nd}}{PHCFV_{nd}} \cdot \left(PCI \cdot CV - \sum_{i:nd} PHCFV_i \cdot chcfv_i \right) \tag{42}$$

Thus the consumer decides upon the consumption of durable goods not only according to their price but also according to the cost of goods and services linked to the consumption of durable goods. The consumption by purpose is translated to demand for consumption products through the consumption matrix. GEM-E3 uses fixed factor coefficient consumption matrices. Thus the final consumption demand by households is calculated from:

$$HCV_{pr} = \sum_{fn} tchcfv_{pr,fn} \cdot HCFV_{fn} \tag{43}$$

with $tchcfv$ representing the fixed factor coefficient consumption matrices.

Unemployment in pure competitive general equilibrium models is usually voluntary and it is the result of the households decision for leisure. A way of simulating involuntary unemployment relates to the assumption that there is a negative correlation between wages and unemployment. This approach is consistent with the efficiency wages theory of Shapiro and Stiglitz (1984) which states that productivity/quality of labor has a positive correlation with wages. In periods with high unemployment, firms are not motivated to offer high wages to attract higher quality labor or to increase productivity of existing workers. On the other hand, at low unemployment rates it is efficient for firms to offer wages above their equilibrium level, because they seek for increases in labor productivity and for reducing the probability of someone quitting the job and hence reducing costs from the recruitment of new personnel (Phelps 1998; Campbell and Orszag 1998). In the GEM-E3 model the efficiency wage approach is adopted for representing involuntary (equilibrium) unemployment.

This modeling approach was preferred because of its empirical validation, by using for example Blanchflower and Oswald (1994), its simplicity, and the fact that it is parsimonious in parameters. The specification of efficiency wages in GEM-E3 is shown below and it is based on Shapiro and Stiglitz (1984) and Annabi (2003):

The utility function of a "shirker" worker U_s is defined as:

$$r \cdot U_s = w - (q + b) \cdot (U_s - U_u) \tag{44}$$

where q is an efficiency related parameter, b is a quit-job-rate, r the interest rate, w the wage and U_u the utility function of the unemployed. The utility function of a "non-shirker" is:

$$r \cdot U_n = w - e - b \cdot (U_n - U_u) \tag{45}$$

where $e \geq 0$ is the disutility from working (for the "shirker" $e = 0$). The utility function of the unemployed is:

$$r \cdot U_u = \overline{wr} + a \cdot (U_n - U_u) \tag{46}$$

where $\overline{wr}$ is the unemployment benefit and a the probability to get a job.

A worker decides not to be productive when $U_n \geq U_s$. This is the efficiency condition. Replacing the utility functions of the shirker and non-shirker, the efficiency condition can be rewritten as:

$$w \geq \overline{wr} + e + \frac{e \cdot (a + b + r)}{q} \tag{47}$$

Thus, the efficiency wage is an increasing function of the quit rate, the probability of finding a job, the interest rate, and the unemployment benefit. In equilibrium, the number of workers that are unemployed should equal the number of workers that fill a vacancy

$$b \cdot L = a \cdot (LS - L) \tag{48}$$

The unemployment rate is defined as

$$u = \frac{LS - L}{LS} \tag{49}$$

Thus the efficiency condition (unemployment wage function) becomes:

$$w = \overline{wr} + e + \frac{e}{q} \cdot \left(\frac{b}{u} + r\right) \tag{50}$$

This equation serves as the labor supply function in GEM-E3. The condition was adjusted so as to incorporate real wages. This replaces the previous labor market equilibrium condition, i.e. $LAV^s = LAV^D$ from which the equilibrium wage rate was derived. PCI is the consumer price index and eg an adjustment parameter to reflect the different labor market flexibility conditions that prevail in each country.

$$w \cdot \frac{PCI}{\overline{PCI}} = \overline{wr} + e + \frac{e}{q} \cdot \left[\left(\frac{b}{u}\right)^{eg} + r\right] \tag{51}$$

7.2.4 Environment

The GEM-E3 model incorporates all GHG emissions and their associated marginal abatement cost curves. There are three mechanisms that affect the level of actual emissions in the GEM-E3 model:

- End-of-pipe abatement (process related GHG emissions and pollutants SO_2, NO_x, VOC, PM): end-of-pipe abatement technologies are formulated explicitly by bottom-up derived abatement cost functions. These cost functions differ between sectors, GHGs and countries.

- Substitution of fuels (all fuels): as the production of the sectors is specified in nested CES-functions, there is (at least for a substitution elasticity greater than 0) some flexibility in the decision of intermediate consumptions. Input demand is linked to the relative prices of these inputs. Hence, if there is an extra cost on energy inputs, there will be a shift in the intermediate demand away from 'expensive' energy inputs towards less costly inputs. Any cost of emissions therefore drives substitution towards less emission intensive inputs, e.g. from coal to gas or from energy to materials, labor or capital.
- Decline in production: in a general equilibrium system that reflects the interdependency of agents' decisions, imposing an environmental constraint (through standards, taxes or other policy instruments) entails additional costs of production (which is linked to the costs of substitution or abatement installations). The resulting increased output price implies a decrease in demand of these goods even if this demand is relatively inelastic to price changes, because of budget constraints. This further implies a lowering in production and accordingly lower demand for intermediate consumption. Hence, there is an emission reduction due to a demand driven decline in production.

The abatement activities are modeled so as to increase the user cost of the polluting input (for example the price of energy or the unit cost of production for process related GHG emissions) which influences the decision process of the firm. The price of energy, including of abatement cost and taxes, is used in the decision of the firm about the choice of production factors (at the energy level and implicitly at the level of aggregates); it represents the user's cost of energy. Upwards sloping marginal abatement cost curves are incorporated for all non-energy related GHG emissions. When an environmental tax is imposed, the firm causing the pollution pays to the government.

In the modeling of the abatement activities, installing abatement technologies (i.e. the demand for goods and services that implement the technology) entails additional costs which have been considered as corresponding to inputs to production and not as an investment. The major advantage of this formulation is its simplicity, especially as the available abatement cost functions are in terms of annualized costs, and because, with this framework, the abatement costs do not directly increase GDP as it would be the case if modeled as investment in which case a depreciation and replacement mechanism would have to be introduced. The user's cost of the abatement equipment would have to be added to the capital income, avoiding however any double counting. The input demand for abatement is modeled in the following way:

- the demand for abatement inputs is allocated to the delivery sectors through fixed coefficients;
- the total delivery for abatement is added to the intermediate demand and these inputs are valued as the other intermediate deliveries.

The total abatement cost for the firm is:

$$TCA_i = AA_i \cdot AC_i\,(AA) \cdot Ef_i \cdot Q_i \tag{52}$$

where AA is the degree of abatement, AC the average cost of abatement, Ef the emission factor and Q_i level of production of activity i.

The average cost is:

$$AC_i\left(AA\right) = \frac{TCA_i}{AA_i{\cdot}Ef_i \cdot Q_i} \tag{53}$$

The firm minimizes its cost subject to its production function (w is the real wage, L is labor, r is the user cost of capital and K capital flow):

$$\min TC_i = w_i \cdot L_i + r_i \cdot K_i + \left(1 - AA_i\right) {\cdot} Ef_i \cdot T_i \cdot Q_i + AC_i\left(AA\right) \cdot AA_i{\cdot}Ef_i{\cdot}Q_i \tag{54}$$

$$\text{s.t. } Q_i = \left(e^{tgk} \cdot d_i^k \cdot K^\rho + d_i^{lem} \cdot LEM_i^\rho\right)^{\frac{1}{\rho}}$$

From which the marginal cost is derived as:

$$T_i = \frac{MC_i}{Ef_i \cdot Q_i} \tag{55}$$

$$MC_i = mc_i(AA) \cdot Ef_i \cdot Q_i \tag{56}$$

Thus the optimal degree of abatement is derived from equating marginal cost with taxed emissions. The marginal cost function for abatement in GEM-E3 is $mc_i = c_i \cdot \left(e^{AA} - 1\right)$ and the total cost (integral of the marginal cost) is $CABAVV_i = c_i \cdot \left(AA_i - e^{AA}\right)$. The coefficient c was estimated for each greenhouse gas, activity and sector available in (United States Environmental Protection Agency 2005). Table 17 presents the estimations of the world Marginal Abatement Cost Curves (MACCs) of GEM-E3 based on the EPA data.

Table 17: Estimation of GEM-E3 World MACC

Activities	GHG	Estimation (C1)
Agriculture	CH_4	230.14
Agriculture	N_2O	97.20
Solvents	HFC	152.71
Semiconductors	PFC	26.00
Refrigeration	HFC	349.00
Oil	CH_4	180.79
Gas	CH_4	150.16
Nitric Acid	N_2O	26.13
Magnesium	SF_6	16.06
Landfills	CH_4	127.75
HCFC	HFC	22.86
Foams	HFC	115.09
Electric T&D	SF6	26.62
Coal	CH_4	89.87
Aluminum	PFC	114.37
Adipic Acid	N_2O	15.48

Source: E3M-Lab estimations.

The EPA report provided data for the following countries/regions: Africa, Annex I, Australia and New Zealand, Brazil, Canada, China, CIS, Eastern Europe, EU15, India, Japan, Latin America/Caribbean, Mexico, Middle East, Non-EU Europe, Non-OECD Annex I, OECD, OPEC, Russian Federation, South & SE Asia, South Korea, Turkey, Ukraine, United States, World. Marginal abatement costs were available for the years 2010 and 2020.

Each GHG emitting activity is linked to the GEM-E3 production sectors according to Table 18.

To simulate GHG mitigation policies the user of the model has two options either to impose an energy/environmental tax or to impose

an emission reduction constraint. A binding emission reduction constraint generates a dual value which in equilibrium will be equal to the marginal cost of abatement. Permits can be auctioned or freely allocated (based for example on grand-fathering). Public revenues from auctioned permits can be recycled into the economy through the following channels: i) reducing employers' social security contributions, ii) support households' income through lump-sum transfers iii) finance carbon free technologies. The firms' revenues from permit sales can be redirected to firms' capital income or to reduce overall production costs.

Table 18: GEM-E3 activities linked to non-energy related GHG emissions

No	Activity	GHG
1	Agriculture	CH_4, N_2O
2	Coal	CH_4
4	Natural Gas	CH_4
5	Electricity	SF_6
6	Ferrous and non ferrous metals	PFCs, SF_6
7	Chemical industry	HFCs
8	Rest of energy intensive industries	CO_2
9	Electrical goods	HFCs
10	Equipment manufacturing	PFCs, SF_6
11	Transport	N_2O
12	Waste disposal (Non market services)	CH_4

Source: E3M-Lab.

7.3 Investment

The basic methodology approaches for modeling investment behaviour relate to the accelerator model AM[13] and to Tobin's Q (Tobin 1969) [14]. GEM-E3 is based on these two approaches. It starts from Ando et al. (1974) according to which investment is defined as $I_t = \hat{k}_t \cdot \Delta X_t^c$ where $\hat{k}_t$ is the capital to output ratio and ΔX_t^c is the net change in firms productive capacity. In GEM-E3 the optimum derived demand for capital K^* is a function of the capital to output ratio and of the relative prices. The capital stock update is provided by the following motion equation:

$$KAVC_t = (1-d)^t \cdot KAVC_{t-1} + INVV_t \tag{57}$$

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[13] The AM model assumes that the optimal demand for capital is a function of output $K_t^* = \mu_t \cdot Q_t$. Prices, wages and interest rates do not affect capital demand. The AM assumes instantaneous capital adjustment to its optimal level hence $I_t = K_t^* - K_{t-1}^* = \mu \cdot (XD_t - XD_{t-1})$. A variation of this approach relates to the non-instantaneous adjustment of capital: $I_t = \lambda \cdot (K_t^* - K_{t-1}^*)$.

[14] According to which net investment depends on the market price of capital and on its replacement cost.

Thus investment is equal to the change in the productive capacity of the firm plus capital depreciation:

$$INVV_t = \Delta X_t + d \cdot KAVC_{t-1} \tag{58}$$

Change in productive capacity ΔX_t is derived from the comparison of previous year capital stock $KAVC_{t-1}$ with the optimum demand of current year K_t^*. Using the average Tobin Q (Hayashi 1982), firms take into account both the cost of capital and its replacement cost $\frac{PK}{PINV \cdot (r+d)}$, which leads to:

$$INVV_t = K_t^{:} \cdot \left(\frac{PK}{PINV \cdot (r+d)} - 1 + d \right) \tag{59}$$

Since GEM-E3 is not a fully dynamic model, firms' expectations for next period growth $stgr$ are defined exogenously, hence the investment function of the model becomes:

$$INVV_t = K_t \cdot \alpha 0 \cdot \left[\left(\frac{PK}{PINV \cdot (r+d)} \right)^{s1 \cdot \alpha 1} \cdot (1 + stgr) - (1 - d) \right] \tag{60}$$

where $\alpha 0$ and $\alpha 1$ reflect the adjustment cost of capital and the price elasticity, respectively. (α^0 is analogous to λ of the accelerator model where capital does not adjust instantly). The unit cost of capital is derived as a dual from the equilibrium equation (supply of capital should be greater or equal to demand):

$$KAVC_t \geq K_t^* \tag{61}$$

Investment expenditures from firms are translated to demand for specific investment goods through a fixed factor coefficient investment matrix $tinvpv_{pr,br}$:

$$INV = \sum_{pr} \sum_{br} tinvpv_{pr,br} \cdot INVV_{br} \tag{62}$$

7.3.1 Trade

Final and intermediate consumers use a composite good (Y) that consists of domestically produced goods (XXD) and imports (IMP), following Armington (1969).

The buyer of the composite good seeks to minimize its total cost by choosing the optimum mix of XXD and IMP based on their relative prices and substitutability. The total expenditure on the composite good equals the expenditure in buying domestically produced goods and imported:

$$PY_i{\cdot}Y_i = PXD_i{\cdot}XXD_i + PIMP_i{\cdot}IMP_i \tag{63}$$

Imports and domestically produced goods are aggregated through a CET (constant elasticity of transformation) function:

$$Y_i = \left[\left(d_i^{xxd} \right)^{\frac{1}{sx}} \cdot (XXD_i)^{\frac{sx-1}{sx}} + \left(d_i^{imp} \right)^{\frac{1}{sx}} \cdot (IMP)^{\frac{sx-1}{sx}} \right]^{\frac{sx}{sx-1}} \tag{64}$$

where d_i^{xxd}, d_i^{imp} are the CET share parameters calibrated in the base year values, sx is the Armington elasticity of substitution and AC is the proportionality factor. The optimum demands for imports and domestically produced goods are:

$$XXD_i = Y_i \cdot AC_i^{sx-1} \cdot d_i^{xxd} \left[\frac{PY_i}{PXD_i} \right]^{\frac{1}{1-s}} \tag{65}$$

$$IMP_i = Y_i \cdot AC_i^{sx-1} \cdot d_i^{imp} \left[\frac{PY_i}{PIMP_i} \right]^{\frac{1}{1-s}} \tag{66}$$

In the next stage consumers decide on their optimum import demand by country:

$$IMPO_{i,j} = b_{i,j} \cdot IMP \cdot \left(\frac{PIMP_i}{PWXO_i} \right)^{si} \tag{67}$$

where $PWXO$ is the export price.

7.4 Elasticities

Two groups of parameters are distinguished in CGE models. The first group contains the parameters that are “initialised” via calibration as this is defined by Mansur and Whalley (1984) and the second group contains the parameters whose values are extracted from the relevant literature. The elasticity of substitution for each of the CES nesting levels, the income elasticities and the Armington elasticities used in the GEM-E3 model are presented in the following tables.

Table 19: Income elasticities

	σ_{fn}
Food beverages and tobacco	0.78
Clothing and footwear	0.6
Housing and water charges	1
Fuels and power	0.9
Household equipment and operation excl. heating and cooking appliances	0.4
Heating and cooking appliances	0.7
Medical care and health	0.74
Purchase of vehicles	0.4
Operation of personal transport equipment	1.2
Transport services	1.1
Communication	1.1
Recreational services	1.35
Miscellaneous goods and services	1.35

Source: E3M-Lab model parameters.

Table 20: Substitution elasticities

	$\sigma_{k,lem}$	$\sigma_{ele,lmo}$	$\sigma_{lav,ma,en}$	σ_{ma}	σ_{en}
Agriculture	0.3	0.2	0.5	0.2	0.6
Coal	0.15	0.1	0.1	0.1	0.1
Oil	0.15	0.1	0.1	0.1	0.1
Gas	0.15	0.1	0.1	0.1	0.1
Electricity	0.3	0.2	0.5	0.6	0.9
Ferrous and non ferrous Metals	0.4	0.2	0.5	0.5	0.9
Chemical industry	0.4	0.2	0.5	0.5	0.9
Rest of energy intensive industry	0.4	0.2	0.5	0.5	0.9
Electrical goods	0.4	0.2	0.5	0.3	0.6
Transport equipment	0.4	0.2	0.5	0.3	0.6
Rest of equipment manufacturing	0.4	0.2	0.5	0.3	0.6
Consumer goods industries	0.4	0.2	0.5	0.3	0.6
Construction	0.4	0.2	0.5	0.3	0.6
Telecommunication	0.4	0.2	0.5	0.3	0.6
Transport	0.4	0.2	0.5	0.3	0.6
Financial services	0.3	0.2	0.5	0.3	0.6
Market services	0.3	0.2	0.5	0.3	0.6
Non-market services	0.3	0.2	0.5	0.3	0.6

Source: E3M-Lab model parameters.

Table 21: Armington cities

	$\sigma_{d.m}$	σ_{m}
Agriculture	1.2	1.6
Coal	0.3	0.1
Oil	0.1	0.1
Gas	0.1	0.1
Electricity	0.3	0.3
Ferrous and non ferrous Metals	1.5	2.4
Chemical industry	1.5	2.4
Rest of energy intensive industry	1.5	2.4
Electrical goods	1.5	2.4
Transport equipment	1.5	2.4
Rest of equipment manufacturing	1.5	2.4
Consumer goods industries	1.7	2.8
Construction	0.6	1.6
Telecommunication	0.6	1.6
Transport	0.8	2.4
Financial services	0.6	1.6
Market services	0.6	1.6

Source: E3M-Lab model parameters.

8

Simulations

8.1 The business-as-usual scenario

In this scenario the EU27 undertakes a GHG mitigation policy based on the unilateral EU27 20/20 climate action. In particular, the EU has committed itself to reducing its GHG emissions by 20% (compared to 1990 levels) and to increasing the share of RES in final energy demand to 20% by 2020. The GHG target is split to a 21% reduction in the ETS sectors and a virtual 10% reduction in the non-ETS sectors. The GEM-E3 model simulated this target by auctioning the GHG permits to the ETS sectors and by imposing a carbon tax to the non-ETS sectors. Permit trade is allowed only between actors involved in the ETS. The government revenues from permit auctioning are then recycled into the economy through a lump-sum transfer to households (support of households income due to energy cost increase). GHG emission reductions through CDM projects are not considered. In addition, the EU27 undertakes energy efficiency measures that lead to an average of around 8% efficiency improvements.

Table 22: M20 EU27 macroeconomic aggregates

	billion $ 2004				Annual % changes		% change from M0
	2005	2010	2015	2020	05-10	10-20	2020
Gross Domestic Product	11, 441	11, 753	13, 111	14, 579	0.54	2.18	-0.20
Investment	2, 287	2, 176	2, 414	2, 685	-0.99	2.13	-0.03
Public Consumption	2, 655	2, 893	3, 222	3, 548	1.73	2.06	0.00
Private Consumption	6, 595	6, 651	7, 541	8, 440	0.17	2.41	0.04
Exports	4, 171	4, 361	4, 700	5, 120	0.89	1.62	-0.54
Imports	4, 268	4, 327	4, 766	5, 213	0.28	1.88	0.07
Employment (in m. persons)	213	219	230	236	0.51	0.75	-0.16
Permit Price (€/ tCO_2)			7	19			

M0 represents no explicit European emission policy
Source: own analysis based on GEM-E3 model.

8.2 Assumptions for the M30a scenario

The EU27 has committed itself to increasing its GHG mitigation effort to a 30% reduction (compared to 1990) if there is a comparable international GHG mitigation action. The GEM-E3 model has been used to evaluate the effects of the M30 policy in the environment of the business-as-usual equilibrium. The GHG emission reductions simulated in the M30a scenario follow the most recently announced pledges of both ANNEX I and non-ANNEX I countries. These are presented in Table 23 (the high pledges of ANNEX I are used in the scenario).

For each region participating in the GHG abatement effort all of its sectors are under a common target (-24% as compared to 2005 GHG emission levels) and participate to a single na-

Table 23: GHG emission reductions compared to 2005 based on the COP-15 pledges

	2020
EU27	-24%
United States of America	-17%
Japan	-25%
Canada	-17%
Oceania (Australia and New Zealand)	-12%
Russian Federation	25%
Brazil	23%
China	54%
India	81%
Rest of Annex I	51%
Rest of the World	28%

Source: GEM-E3 model parameters.

tional/regional market. In this scenario full auctioning applies to all regions and sectors. Government auctioned revenues are recycled back to the economy through lump-sum transfers in households. The same efficiency measures undertaken by the EU27 in the M20 scenario are introduced. No other region of the world undertakes energy efficiency measures.

8.3 Assumptions for alternative 30% scenarios

Next, we have performed a series of simulations introducing step-by-step the features that define the new equilibrium labelled as green growth.

The M30b scenario is based on the same assumptions as the M30a case but it doubles the energy efficiency measures undertaken by the EU27.

To simulate the M30c scenario the GEM-E3 model was extended so as to include learning-by-doing. This scenario includes the assumptions of M30a and the learning-by-doing feature is activated. It should be noted that learning-by-doing is currently incorporated only to power producing technologies. Since the GEM-E3 model is recursive dynamic and its agents are myopic (in their optimization process they assume that current prices remain constant throughout their planning period), a quasi adaptive expectations approach is already introduced in the formulation of firms' investment plans. Within this approach investors' (firms') future expectations regarding their output are exogenously specified. In view of the additional investments required to achieve the GHG emission reductions and RES deployment implied by the M30a scenario, the exogenously specified growth rate of agents' future expectations was modified. In particular, the parameter defining the expected growth rate of all production sectors (apart from coal, oil and gas) is increased by an additional percentage point.

The M30d scenario combines the assumptions of the M30b and M30c scenario.

The green growth scenario maintains the assumptions of the M30d scenario and complements them with regime change on the labor market. In GEM-E3, this means that the parameter representing the insider-outsider divide on the labor market is lowered, as the lower unemployment that comes with green growth lowers the barrier between insiders and outsiders. This is supported by the fact that the new jobs emerge mainly in the construction sector (including not only manual, but also clerical work), where on-the-job training delivers faster results than, say, in medical technology or financial services.

8.4 Results for M30a

The primary effects from imposing a GHG constraint into the model depend on two factors: i) the distance to the target (i.e. the amount of GHG emissions that is required to be reduced) and ii) the abatement options available to each region/country (i.e. substitutability between low and high GHG emitting technologies). The EU27 -30% GHG mitigation compared to 1990 levels is translated to a -11% in 2020 as compared to the same year of the reference case (which in our case is the M20 scenario). The secondary effects relate to the feedback of the rest of the economy to the changes occurring in the energy system. That is, changes in the relative prices of goods and services initiate a spiral of feedback effects among the different interconnected markets that ultimately lead to a restructuring of the overall economic system. The permit price that drives the GHG emission reduction is €50 t/CO_2e (€31 higher than the permit price in the M20 scenario). This equilibrium price incorporates both the primary and secondary effects of the policy intervention.

Adjustment to the emission constraint involves substitution away from commodities, the use of which (either in intermediate use or in final consumption) generates GHG emissions. This favours other production factors including labour, capital and mostly non-energy intermediate consumption. It also encourages consumption of non-energy goods and services, in the case of households. Since substitution cannot be perfect given the technical production possibilities and the preferences of the consumer, the agents would face higher overall costs. In particular, the permit price increases the user cost of energy driving firms and households to reduce their consumption of fuels and goods that are carbon intensive. Energy demand in firms and households is reduced by an average of 5% and 3.5% respectively at EU27 level in 2020 as compared to the reference case. The deployment of RES leads to a reduction of import demand for fossil fuels (3.7% at EU27 level in 2020 as compared to the reference case) freeing up resources to be used domestically for the production of the RES equipment. The substitution of imported energy by domestically produced energy services (e.g. RES) acts positively on domestic activity, but puts pressure on primary production factor resources. The full employment assumption of primary factors adopted by the GEM-E3 model implies that the additional demand for labour and capital will increase wages and the user cost of capital which will eventually increase the overall cost of production. Thus the combined effects are negative for activity and employment (see Table 24).

At firm level it is the energy sectors that play the most important role in the re-adjustment process. Coal production is substantially reduced due to the high increase in coal prices induced by the permit price. Oil demand is also affected especially in some EU member states where oil is used to a considerable extent for substitutable purposes (power generation and

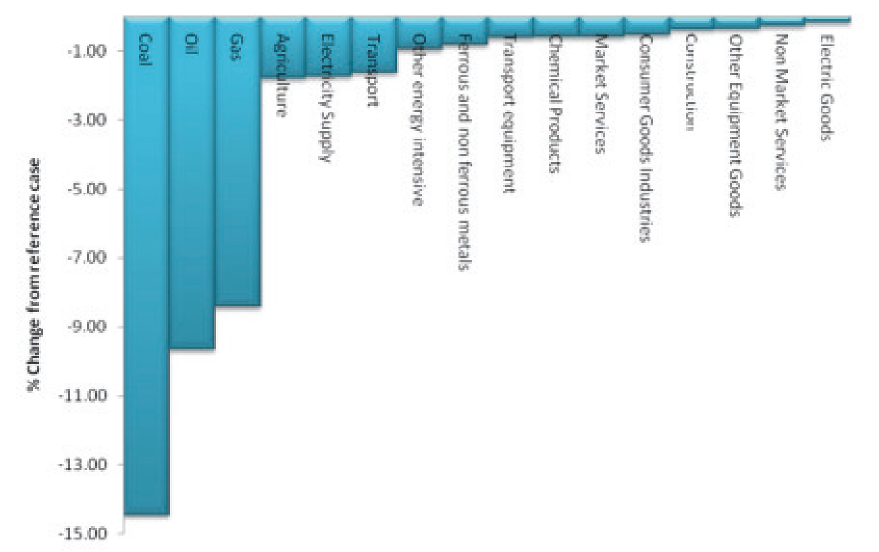
Table 24: Overview of M30 base case impact on key variables (EU27 % changes from reference case)

	2020
GDP	−0.60
Energy Consumption	−5.35
Imports of fuels	−3.71
Employment	−0.33
Real wage	0.97
Equivalent Variation (in b. €)	−19.94

Source: own analysis based on GEM-E3 model.

industry). Electricity use, to the extent that it is produced from coal and gas, also experiences substantial price increases and subsequent reductions in demand. Natural gas on the other hand being a substitute of other fossil fuels is affected less, implying an increase in its share as an energy source.

Figure 19: Changes at sectoral level (2020 – EU27)



Source: own analysis based on GEM-E3 model.

The negative impact on agricultural production mainly relates to the fact that agricultural activity is penalized both for its CO_2 and CH_4 emissions. Apart from the energy sectors and agriculture, it is the transport and energy intensive sectors that contribute most to the economic adjustment. The sharp reductions in the metals and the chemical industry are attributed both to the strong dependence of the metal industry on solid fuels and to the additional costs imposed to the chemical industry as a result of its HFC and N_2O emissions. Transport also presents a reduction in its production as compared to the reference case due to its heavy dependence on solid fuels. Production of transport equipment is linked to the activity of the transport sector hence producing a similar decrease, albeit to a lower extent, in its production compared to the reference case.

Equipment goods, construction and electrical goods show virtually zero change from the reference case. This is attributed to the importance of these sectors in manufacturing both the RES equipment and the equipment required for the non energy related GHG abatement technologies.

8.5 Results for alternative 30% pathways

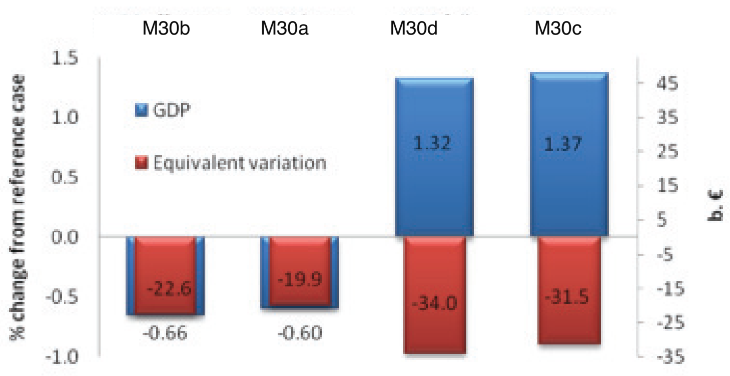
This subsection provides modifications of the M30a scenario that introduce stepwise the features defining the new growth path simulated in the green growth scenario. They relate to additional energy efficiency improvements (M30b), learning-by-doing and adjustment of investment expectations (M30c); with M30d including all characteristics of the above.

The energy saving programme (assumed in the M30b scenario) implies a demand side effect and an efficiency effect for the economy. The energy efficiency effect leads to a permanent improvement of energy productivity in its use in the production process and in its use in household consumption whereas the demand effects lead to an increase in the demand for goods required to construct the energy saving equipment during the policy implementation period. The effects from building the energy saving equipment are decomposed in a demand push effect for the whole economy and an increase in production costs. The demand-push effect increases domestic activity, employment and imports while the increase in production costs entails a loss of competitiveness for the economy. These effects are not permanent in the sense that after the period of intensive implementation of the policy the demand-push effects slow down, hence exerting a downward pressure on labour demand and ultimately on wage rates. On the other hand the effects from energy efficiency improvement are permanent leading to lower emissions and lower levels of energy consumption. So in the long run both, firms and households, will be able to free-up resources that were previously used for the consumption of energy products that are re-allocated to new investments (through increased savings) or to additional expenditure in other consumption categories. Consequently, the effect of the energy saving programme on GDP is negative (see Figure 20) in the short term (i.e. in 2020, as examined here) but could be positive in the long-term (i.e. once the energy saving expenditure stops and only the permanent energy efficiency gains are realized).

The M30c case implies additional investment as compared to the reference case and hence increased overall activity (see Figure 20). In this case GHG emissions increase and hence the price signal should be higher in order to achieve the GHG emission reduction target.

In the M30c scenario, households' savings increase in order to finance the increased demand for investments triggered by the higher expected growth rate. Increased savings of households act to the detriment of consumption and hence this scenario presents one of the highest welfare reductions (as these are measured through the equivalent variation which is a money metric utility measure). In the M30c scenario, the EU27 economy is found to be more competitive with respect to the other scenarios examined. This is attributed to two factors: i)

Figure 20: GDP and equivalent variation in M30 simulations

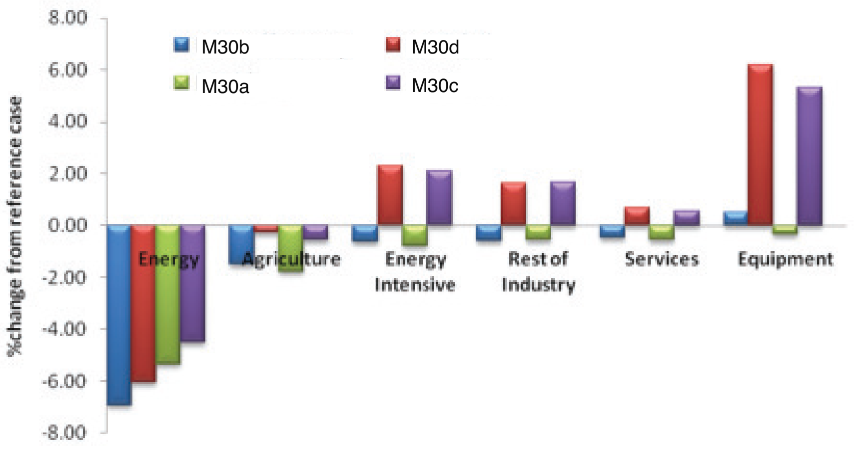


Source: own analysis based on GEM-E3 model.

the additional investment expenditures increase the capital stock of the economy and hence relieve the upward pressure in the user cost of capital and ii) the learning-by-doing effect reduces, relative to the other scenarios examined, the unit production cost of electricity.

From a sectoral point of view energy savings, by reducing unit demand for energy, also reduce the expenditure of the firm allocated to energy, but increase the expenditure in non energy commodities that are needed to implement the energy saving technology. This implies an increased demand for services and goods that are used for the construction of the energy saving equipment. Since part of this equipment is produced within the EU, sectors like electrical goods, other equipment goods and services of credit and insurance increase their output and employment (Figure 21). This effect is more pronounced in the M30d full case that implies increased activity not only to the firms producing the energy saving technology but also to firms that produce the RES equipment.

Figure 21: Production in M30



Source: own analysis based on GEM-E3 model.

9

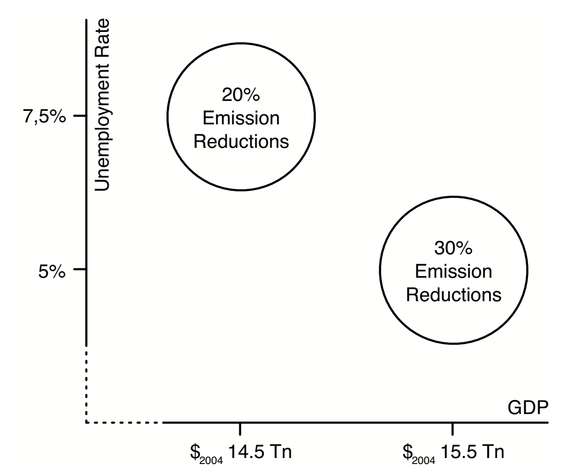
Growth, jobs, and emissions

9.1 Boosting the European economy

Before the financial crisis of 2007–08, GDP per capita was growing in Europe at a rate of slightly more than 2% per year. The crisis has reduced European GDP by about 4%, and there is no sign that this loss will be fully compensated anytime soon. It is likely that if Europe follows business as usual regional disparities in Europe will increase and average unemployment will stay high. In fact, decision-makers, investors, and the general public begin to expect such a future. This is a dangerous development: such expectations can turn into self-fulfilling prophecies.

However, post-crisis Europe can revitalize its economy by developing a credible vision of additional investment leading to higher growth and more jobs. The challenge of building a low-carbon economy can provide that vision. In line with OECD terminology (see www.oecd.org/greengrowth) we label the result as *green growth.* What will make the difference against business as usual is not simply investment in windfarms and the like. It is the shared understanding that developing the quality of life that comes with a sustainable future provides plenty of avenues for mutually reinforcing investments – in education, health, entertainment, housing, transport, and much more. In this perspective, raising the European climate target from 20% to 30% emission reduction can open the way towards higher growth and increased employment (Figure 22).

Figure 22: Two scenarios for Europe in 2020



Source: own analysis based on GEM-E3 simulations.

The financial crisis has reduced emissions, but in the wrong way. Now the target of reducing greenhouse gas emissions by 20% in 2020 as compared to 1990 is not a challenge any more.

It has become too weak to mobilize innovations and to stabilize political will. Sticking to that target is the equivalent of digging deeper while being stuck in a hole.

It is time for boldness. Clear policies, associated with a decisive move to a 30% target, can lead Europe towards a new growth path, one that is doubly beneficial for the climate and the EU economy. For this purpose, the climate target must not be pursued in isolation, but be embedded in a comprehensive range of measures, setting expectations for growth of the European economy at a more ambitious level. What matters is to explicitly declare an ambitious growth target in the aftermath of the financial crisis and to pursue this target on a variety of fronts – including incentives for additional investment, growth-oriented fiscal policy, public procurement, and of course climate policy.

The question is whether in the coming decade Europe will accept the challenge of increasing economic growth while reducing both unemployment and greenhouse gas emissions. New model results show that these three goals can actually reinforce one another. The simulations performed for the present study assume domestic reductions of 30% and no international climate agreement that would go beyond the modest pledges made in the Copenhagen Agreement of 2009. If more ambitious goals should be pursued in the future by major economies, the positive impacts for Europe would be larger. Under the given assumptions, over the coming decade raising the EU's climate target from 20% to 30% can foster the following outcomes (Table 25):

- increase the growth rate of the European economy by up 0.6% per year
- create up to 6 million additional jobs Europe-wide
- boost European investments from 18% to up to 22% of GDP in 2020
- increase European GDP in 2020 by $\$_{2004}$842 bn

Table 25: Macroeconomic features, EU27

	Green Growth	Business as Usual	Δ
GDP in 2020 (billion $\$_{2004}$)	15421	14579	5.77%
GDP growth-rate 2010–2020	2.8%	2.2%	0.6*pp*
Unemployment rate in 2020	5.3%	7.6%	−2.3*pp*
Number of unemployed (millions)	13.4	19.4	−30.9%
Investment in 2020 (share of GDP)	22.4%	18.4%	4.0*pp*
Investment in 2020 (billion $\$_{2004}$)	3457	2685	28.8%
Emissions (Mt of CO_2e)	3927	4414	−11.0%
Carbon Price (€/t CO_2)	32.19	19.47	65.3%

Δ*: Difference 20% vs. 30% either as percentage of 20% value or as difference in percentage points (pp).*
Source: own analysis based on GEM-E3 simulations.

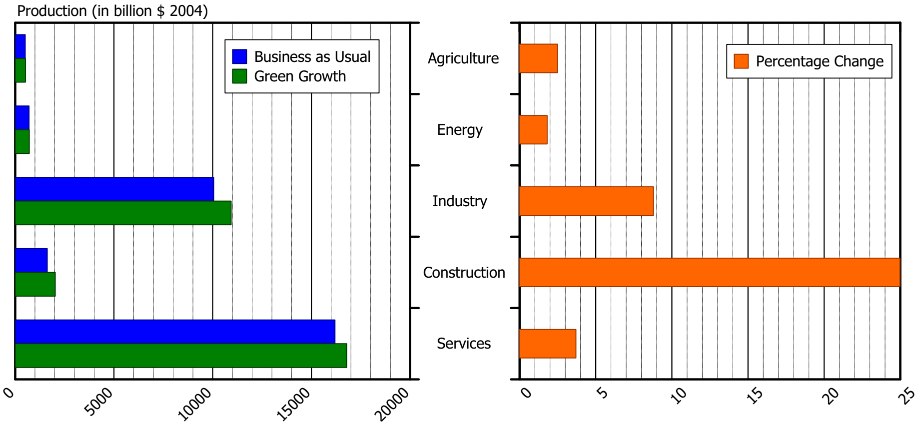
There are two reasons why this may seem too good to be true. First, it is often taken for granted that GDP can only be increased with increased emissions. There are, no doubt, situations where this is true, but in Europe in the years to come, serious emission reductions imply higher growth than business as usual. The reason is straightforward: such reductions require a renewal of the built environment, and the built environment is by far the largest component of the overall capital stock. Therefore, its renewal implies larger investment and therefore larger growth. To a lesser, but still significant extent, the same is true for investments in the energy efficiency of machinery and in renewable energy.

The second issue of relevance here is whether larger investment can indeed generate higher growth beyond the 2.2% that business as usual promises. The fact that before the financial crisis many European countries did indeed experience much higher growth suggests that this may well be possible. And there is ample evidence to the effect that investment induces productivity gains via learning-by-doing, especially in the case of new technologies like renewables or new building materials.

9.2 Sectoral dynamics

Along the new growth path, all broad economic sectors – agriculture, energy, industry, construction, and services – increase production (Figure 23). Even the energy sector gains, mainly because of the expansion of renewables. The largest procentual – although not absolute – increase happens in construction. The new growth path implies a major effort to retrofit buildings and enhance the built environment. This is advantageous in view of employment because people with very different vocational skills can operate in this sectors after a few months of on-the-job training (in construction, as in the industry, nowadays the majority of jobs is not centered around manual work - and there too, on-the-job training can be very effective).

Figure 23: Production by sector, EU27



Source: own analysis based on GEM-E3 simulations.

Emissions are reduced in all sectors except construction. The emissions reductions achieved by increased energy efficiency of buildings is much larger than the additional emissions from construction, however. Across the European economy, emissions are reduced by increasing energy efficiency and shifting from coal to renewables and gas. Energy efficiency is mainly, but not only, a matter of buildings. Over the next decade, renewables will be mainly wind, both on- and offshore. Carbon capture, photovoltaics and nuclear cannot make much of a difference over this time span. Nevertheless, they will be important to prepare for the longer term. The evolution of production costs and public acceptability will determine their future prospects.

The shift towards gas sometimes can raise concerns about energy security. European imports of natural gas, however, are reasonably diversified. The largest supplier, i.e. Russia, delivers just one third of total imports. Other major suppliers are Norway, Algeria, and Qatar. Due to the expansion of shale gas in the USA and the Chinese determination to limit dependency on energy imports, Europe is a vital customer for Russia. However, Eastern European countries need improved transport opportunities for gas imported into Western Europe, and in order to deal with the vagaries of fossil fuel markets storage facilities need to be improved across Europe.

9.3 Regional dynamics

Not only is the new growth path quite balanced with regard to sectors, it is also remarkably balanced between old and new member states, i.e. EU15 and EU12 countries (Tables 26 and 27).

Table 26: Macroeconomic features, EU15

	Green Growth	Business as Usual	Δ
GDP in 2020 (billion $\$_{2004}$)	14373	13594	5.7%
GDP growth-rate 2010–2020	2.7%	2.1%	0.6*pp*
Unemployment rate in 2020	5.1%	7.4%	−2.3*pp*
Investment in 2020 (share of GDP)	22.1%	18.1%	4.0*pp*
Investment in 2020 (billion $\$_{2004}$)	3178	2459	29.2%
Emissions (Mt of CO_2e)	3164	3581	−11.6%

Δ: Difference 20% vs. 30% either as percentage of 20% value or as difference in percentage points (pp).
Source: own analysis based on GEM-E3 simulations.

In both groups of countries, average growth rates are about 0.5% larger on the new growth path than for business as usual. This also means that the catch-up process of EU12 is maintained. The unemployment rate, which is somewhat higher in the EU12, decreases slightly more in this group of countries. Emissions, which are much larger in EU15, decrease more there. Overall, it is clear that none of the two groups of countries is at a disadvantage with the new growth path.

Table 27: Macroeconomic features, EU12

	Green Growth	Business as Usual	Δ
GDP in 2020 (billion $\$_{2004}$)	1048	986	6.3%
GDP growth-rate 2010–2020	3.8%	3.2%	0.6*pp*
Unemployment rate in 2020	6.1%	8.7%	−2.6*pp*
Investment in 2020 (share of GDP)	26.7%	22.9%	3.8*pp*
Investment in 2020 (billion $\$_{2004}$)	279	226	23.5%
Emissions (Mt of CO_2e)	763	833	−8.4%

Δ*: Difference 20% vs. 30% either as percentage of 20% value or as difference in percentage points (pp).*
Source: own analysis based on GEM-E3 simulations.

Even within the two groups, the new growth path is remarkably balanced. Table 28 gives a breakdown by countries: the new growth path corresponds pretty much to a tide that lifts all boats.

This holds for the EU12 as well (Table 29). The figures for emissions must not be misunderstood as normative assignments of emissions quota. They are important, though, because they show that economically reasonable emission reductions can be distributed among countries in ways that seem quite fair from a common sense point of view.

9.4 A virtuous circle

The basic mechanism creating the opportunity for a new growth path in Europe is the mobilization of a virtuous circle of additional investment, learning-by-doing and expectation formation. We discuss these three topics in turn.

9.4.1 Triggering investment

The starting point for a revitalization of the European economy is a substantial increase of investment. This is why an ambitious climate policy is actually a major opportunity for economic policy, too. Building wind turbines, implementing cogeneration of heat and electricity, insulating houses, modernizing the power grid, etc., all require substantial investment. If this green investment simply displaced investment in other sectors – health, education toolmaking, etc. – growth would not speed up and employment would only be re-allocated between sectors, without reducing the number of unemployed. However, in the coming years green investment can be part of a broader surge of investment.

Model results show that it is possible to increase the EU climate target to 30% while increasing the share of investment in GDP, which under business as usual would be 18%, by up to 4 percentage points. This is mainly, but not only, due to investment in the built environment, which makes up the largest part of the European capital stock.

Table 28: Macroeconomic features by country, EU15

		GDP in 2020 (billion $\$_{2004}$)	GDP growth rate	Unemploy-ment rate	Investment in 2020 (share of gdp)	Investment in 2020 (billion $\$_{2004}$)	Emission (Mt)
Austria	-20%	310	2.0%	4.7%	20.8%	64.7	86.3
	-30%	320	2.3%	3.6%	25.9%	82.7	78.5
	Δ	3.2%	0.3pp	-1.1pp	5.1pp	27.9%	-9.1%
Belgium	-20%	449	2.2%	7.8%	22.5%	101.1	111.0
	-30%	476	2.8%	5.3%	26.9%	127.7	105.0
	Δ	6.0%	0.6pp	-2.5pp	4.4pp	26.3%	-5.4%
Germany	-20%	2914	1.8%	8.5%	14.9%	433.2	880.1
	-30%	3103	2.4%	5.6%	18.6%	576.5	742.8
	Δ	6.5%	0.6pp	-2.9pp	3.7pp	33.1%	-15.6%
Denmark	-20%	239	1.6%	5.0%	18.2%	43.5	61.9
	-30%	245	1.9%	3.8%	21.7%	53.2	57.4
	Δ	2.5%	0.3pp	-1.2pp	3.5pp	22.1%	-7.4%
Spain	-20%	1314	3.0%	10.6%	24.1%	317.2	440.6
	-30%	1385	3.6%	7.0%	27.3%	378.4	387.6
	Δ	5.4%	0.6pp	-3.6pp	3.2pp	19.3%	-12.0%
Finland	-20%	215	2.0%	7.7%	19.2%	41.1	60.7
	-30%	219	2.2%	5.1%	24.0%	52.7	55.3
	Δ	1.9%	0.2pp	-2.6pp	4.8pp	28.2%	-9.0%
France	-20%	2206	2.0%	8.1%	18.9%	416.5	424.3
	-30%	2351	2.7%	5.4%	22.9%	537.4	383.5
	Δ	6.6%	0.7pp	-2.7pp	4.0pp	29.0%	-9.6%
United Kingdom	-20%	2377	2.3%	4.4%	15.3%	362.4	393.0
	-30%	2550	3.1%	3.5%	19.4%	495.1	347.0
	Δ	7.3%	0.8pp	-0.9pp	4.1pp	36.6%	-11.7%
Greece	-20%	270	2.8%	8.7%	25.1%	67.8	122.1
	-30%	283	3.3%	6.0%	27.0%	76.4	104.4
	Δ	4.8%	0.5pp	-2.7pp	1.9pp	12.8%	-14.5%
Ireland	-20%	218	3.2%	9.0%	8.8%	19.1	62.4
	-30%	224	3.5%	5.7%	12.1%	27.2	54.6
	Δ	2.8%	0.3pp	-3.3pp	3.3pp	42.6%	-12.6%
Italy	-20%	1820	1.8%	7.6%	20.4%	370.9	571.1
	-30%	1908	2.3%	5.0%	26.4%	504.2	512.5
	Δ	4.8%	0.5pp	-2.6pp	6.0pp	35.9%	-10.3%
Luxembourg	-20%	56	3.3%	3.4%	21.5%	12.0	16.5
	-30%	59	3.8%	3.1%	24.7%	14.5	15.6
	Δ	5.4%	0.5pp	-0.3pp	3.2pp	20.5%	-5.6%
Netherlands	-20%	603	1.7%	3.9%	17.8%	107.0	193.0
	-30%	627	2.1%	3.3%	19.5%	122.0	189.0
	Δ	4.0%	0.4pp	-0.6pp	1.7pp	13.8%	-2.1%
Portugal	-20%	178	2.0%	6.3%	24.5%	44.0	81.0
	-30%	184	2.3%	4.5%	30.1%	55.0	69.0
	Δ	3.4%	0.3pp	-1.8pp	5.6pp	27.2%	-14.5%
Sweden	-20%	425	2.3%	5.8%	13.8%	59.0	78.0
	-30%	439	2.6%	4.1%	17.0%	75.0	62.0
	Δ	3.3%	0.3pp	-1.7pp	3.2pp	27.4%	-20.1%

Δ: *Difference 20% vs. 30% either as percentage of 20% value or as difference in percentage points (pp).*
Source: own analysis based on GEM-E3 simulations.

Table 29: Macroeconomic features by country, EU12

		GDP in 2020 (billion $\$_{2004}$)	GDP growth rate	Unemploy-ment rate	Investment in 2020 (share of gdp)	Investment in 2020 (billion $\$_{2004}$)	Emission (Mt)
Bulgaria	-20%	41	3.1%	7.7%	20.8%	8.5	50.7
	-30%	41	3.2%	5.3%	24.4%	10.1	48.9
	Δ	0.0%	0.1pp	-2.4pp	3.6pp	18.8%	-3.5%
Cyprus	-20%	25	3.8%	5.1%	21.6%	5.3	7.8
	-30%	26	4.3%	4.0%	25.1%	6.5	7.1
	Δ	4.0%	0.5pp	-1.1pp	3.5pp	21.2%	-9.8%
Czech Republic	-20%	144	3.0%	6.0%	22.0%	31.6	113.3
	-30%	151	3.6%	4.3%	26.2%	39.6	106.3
	Δ	4.9%	0.6pp	-1.7pp	4.2pp	25.2%	-6.1%
Estonia	-20%	12	3.2%	7.5%	19.7%	2.4	18.0
	-30%	13	3.5%	5.1%	25.1%	3.2	15.9
	Δ	8.3%	0.3pp	-2.4pp	5.4pp	31.3%	-11.6%
Lithuania	-20%	32	3.6%	8.0%	19.9%	6.4	12.8
	-30%	34	4.2%	5.7%	21.5%	7.4	12.1
	Δ	6.3%	0.6pp	-2.3pp	1.6pp	14.4%	-5.0%
Latvia	-20%	19	3.0%	7.7%	21.6%	4.2	9.4
	-30%	20	3.5%	5.4%	26.5%	5.4	7.6
	Δ	5.3%	0.5pp	-2.3pp	4.9pp	28.6%	-18.8%
Malta	-20%	8	2.6%	6.0%	20.2%	1.6	2.4
	-30%	8	3.1%	4.3%	24.5%	2.0	2.4
	Δ	0.0%	0.5pp	-1.7pp	4.3pp	26.9%	0.4%
Slovakia	-20%	81	4.3%	12.5%	21.4%	17.3	46.2
	-30%	85	4.8%	8.6%	25.1%	21.5	42.7
	Δ	4.9%	0.5pp	-3.9pp	3.7pp	23.9%	-7.6%
Slovenia	-20%	51	3.0%	4.7%	24.9%	12.7	21.9
	-30%	54	3.7%	3.7%	27.5%	15.0	19.4
	Δ	5.9%	0.7pp	-1pp	2.6pp	18.0%	-11.4%
Romania	-20%	123	3.7%	5.1%	36.4%	44.8	117.8
	-30%	137	4.8%	3.9%	40.3%	55.2	112.1
	Δ	11.4%	1.1pp	-1.2pp	3.9pp	23.1%	-4.8%
Poland	-20%	328	3.0%	12.5%	20.3%	66.4	364.2
	-30%	351	3.7%	8.5%	23.9%	83.8	328.7
	Δ	7.0%	0.7pp	-4pp	3.6pp	26.2%	-9.7%
Hungary	-20%	122	2.7%	4.9%	20.2%	24.6	68.7
	-30%	126	3.0%	3.7%	23.7%	29.9	59.8
	Δ	3.3%	0.3pp	-1.2pp	3.5pp	21.3%	-12.8%

Δ: *Difference 20% vs. 30% either as percentage of 20% value or as difference in percentage points (pp).*
Source: own analysis based on GEM-E3 simulations.

To realise the win-win opportunity that comes with the 30% reduction target requires consistent policies and measures that reframe expectations in a broader framework of low-carbon growth. Mainstreaming climate concerns into the next decade of institutional reforms can decisively help the EU to enter a path of low-carbon growth in line with its broader aspirations of sustainable development (EU Sustainable Development Strategy: Commission of European Communities (CEC) 2005; European Commission (EC) 2010d).

No single measure can deliver the type of reductions that are needed to meet the 30% target by 2020, but a combined approach is required. At present, however, there is a bewildering multitude of climate policies and measures in place. In order to get on new growth path, it will be essential to greatly increase the coherence of, and synergies between those measures. There may well be quite a bit of red tape to be eliminated as well.

The problem, then, is not a lack of measures, but rather the lack of an overarching thrust of those measures. This needs to be provided at the European level. However, here again the variety of policies and measures leaves room for improvement.

In order to turn this profusion of policies and measures into an effective thrust towards a new growth path, two steps will be essential. First, to declare explicitly that entering this growth path is indeed the goal of the EU. Moving from the meanwhile redundant target of 20% greenhouse gas emissions reduction towards a schedule aiming first at 30% and ultimately at a near-zero emissions economy, should be an integral component of this goal setting. Simultaneously, a target of increasing European economic growth by about 0.5% and decreasing the unemployment rate in Europe by at least 2% should be stated as forcefully as the ECB target of an inflation rate slightly below 2%.

Second, the EU needs to walk the talk, i.e. to implement measures that do establish the thrust towards the new growth path. They include both macro- and micro-economic measures (see section 10.2.4).

9.4.2 Learning-by-doing

If the EU announces and implements a new growth strategy including an ambitious target for emissions reduction, it can trigger additional investments that significantly increase the share of gross investment in GDP. This additional investment induces learning-by-doing across the economy as a whole, and at an even higher rate where it comes to new technologies like advanced construction materials, renewable energy and more.

From Wright's classical study of factors affecting the costs of airplanes (Wright 1936) to current work on technological progress in information technology (Koh and Magee 2006), a huge literature documents the importance of learning-by-doing. Three elements are essential here. First, even for familiar products with a long technological history like shoes, chairs, or windows, learning-by-doing is an on-going process leading to increased labor productivity in their production. Second, for new technologies that succeed in entering a competitive market, learning rates are much higher than for well-established technologies. And third, there is no way of telling in advance whether a new technology that looks plausible at first sight will actually succeed in the market place, nor is there a way of telling how long it will take for a "new" technology to become a "familiar" one.

What can be confidently expected, then, is that an increase in European investment will accelerate learning-by-doing and therefore increase labor productivity and decrease unit production costs. This will happen across the whole economy, but at higher speed in sectors using new technologies that have begun to show their competitiveness. Such technologies include the use of wind energy, as well as advanced medical technology, new construction materials, and information technology.

With new technologies, however, there is a danger of overconfidence: it is easy to claim that amazing cost reductions will make expensive new production processes competitive in a few decades, but it is nearly impossible to find empirical evidence for such a claim as soon as one talks about a particular technology. In the present study, therefore, we have only assumed learning rates that hold even for well-established technologies. This means that our results may well be too conservative, which we consider a virtue in the present context.

An even greater virtue, however, is to break out of the straightjacket of mind that takes the modest rate of productivity increase displayed by the European economy in the recent past as the upper limit of what that economy is capable of. If such were the case, increased investments would only lead to higher production costs and therefore to lower returns or higher inflation or both. In reality, a new growth path is possible because of a virtuous cycle that moves from higher investment to higher learning-by-doing, from there to improved expectations, and from there again to higher investment.

Clearly, there are limits to the extent to which additional investment can trigger learning-by-doing, and this in turn limits the amount of emission reductions that can be achieved in a given time span by a win-win strategy. A reduction of 30% in 2020 compared to 1990 levels is certainly feasible along a higher growth path than business as usual.

9.4.3 Expectation management

Additional investment induces learning-by-doing, which enables the economy to grow faster than it could have done otherwise. The faster growth in turn leads to more positive expectations for the future, which leads to further investment. This is the virtuous cycle leading to the new growth path.

However, investors are no fools: they try to correct their expectation whenever there may be a reason to do so – after all, their fortunes are at stake. This leads to the danger of volatile expectations, a major challenge for monetary policy. Indeed, monetary policy has important lessons to offer for a policy aiming at a new growth path. The first lesson is that the expectations of investors must indeed be consciously managed. If this had not been done in 2007-2008, the world would have experienced a global economic breakdown that would have dwarfed even the global crisis of 1929.

A next lesson is that expectation management starts with explicitly stating goals, loud and clear. In the case of the ECB, the main goal is an inflation rate slightly below 2%. To be effective, the goal declaration must be credible. An inflation rate of 0% would not be credible, because experience has shown that seriously pursuing such a goal would throw the economy in a serious depression. Nor would a rate of 6% or more be credible, because again experience has shown that an inflation at that rate would pose a continuous danger of turning into a runaway inflation and into major social unrest. If the EU would announce a growth target of 5% for the coming years, this would not be credible, despite the fact that many countries, including European ones, rather easily achieve growth rates of 5% and more. But for Europe as a whole, such a growth target would simply be too far away from the experience of the past decades. At the same time, if the EU should stick to the 20% emissions reduction target as an expressions of its will to assume global responsibility, perhaps even to claim leadership, it would loose credibility, too: after the financial crisis, this target simply does not express a will to tackle global environmental problems.

The problem of credibility is also essential to asses the possible effects of conceivable intermediate targets. The key problem is not to find some magic number, but to show that the EU is determined to get beyond business as usual. Otherwise the expectations of investors will stay focused on this perspective and neglect the possibility of a new growth path. As a result, no additional investment would occur, and the investment needed to achieve a given target would crowd out other, economically more promising investments. There would then indeed be an additional cost to the economy as a whole rather than a win-win strategy. The growth rate would not be slightly higher than in business as usual, but indeed slightly lower. Of course there is no sharp threshold at which the expectations of investors would mechanically switch towards the new growth path. Much depends on how the EU will communicate its target for 2020, especially how that target will be embedded in a broader view of the growth path and the emissions trajectory the EU wants to realize.

Credibility, however, is not only a matter of announcing targets, but also of implementing them. Central banks have learned over decades that only by consistently pursuing their announced targets through a long series of decisions, can they establish a solid credibility. The same is true with a new growth path. Sticking to the target of increasing growth and investment while reducing unemployment and emissions will be essential. Public procurement, reviewing the common agricultural policy, building complex European infrastructures, research and development, etc., these are all areas where the credibility of the new growth path can be established.

The last lesson from monetary policy to be considered here concerns the global context in which European targets must be met. A credible inflation target is one that does not depend on what the U.S., China or global markets do. The appropriate way to pursue the target will vary greatly depending on global circumstances, but not the target itself. The same holds for the new growth path. The economic opportunities of a European 30% scenario are available independently of an international post-2012 climate agreement. The simulations performed for the present study assume no international climate agreement. As a reference frame, we have taken the modest pledges made in the Copenhagen Agreement of 2009. If more ambitious goals should be pursued in the future by major economies, the positive impacts for Europe would be even larger.

By declaring its will to achieve a new growth path and then by increasing growth while reducing emissions and unemployment, Europe can find a new and influential role in the global arena of the 21th century. It should not be forgotten that after the global crisis of 1929, a surge of investment in Europe as elsewhere was initiated by the perspective of military armament. By showing that in the decade up to 2020 the vision of sustainable development can be turned into high economic growth with decreasing greenhouse gas emissions, Europe can offer a perspective for organizing the expectations of investors worldwide. This may end up being the most significant contribution of Europe to global emissions reductions.

9.5 The role of the carbon price

For this transition, a moderate increase in the carbon price is necessary, because in a market economy price signals are major drivers of investment. However, the effect of carbon prices on long-term investment like the one needed to enhance the energy efficiency of buildings or to decarbonise power production is much too slow for investment to achieve a 30% reduction by 2020. Therefore, the shifts in carbon price that can be achieved by the European emissions trading system must be combined with micro-economic incentives like partial support for R&D aiming at green growth. The support must be partial in order to avoid white elephants being sold by shrewd lobbies to public authorities, but it is essential in order to break deeply engrained patterns of business as usual in European technological development.

The temptation of trying to pick winners in technological evolution is one public authorities must stubbornly refuse. But this does not mean that one should ignore robust facts that do matter. The prospect of electric planes flying across European skies anytime soon is as low as the one of nuclear fusion reducing European emissions by 2020. Over the relatively short time frame of a decade, the two most promising paths to reduce emissions further can be identified as cogeneration and cheaper wind energy. Micro-economic incentives should not be restricted to these, but there are sound reasons for a major European effort in these two areas.

By combining price with non-price signals in a setting of green growth, it is then possible to achieve the 30% reduction at a moderate carbon price. Moreover, it is possible that this micro-economic cost will be more than offset by the macro-economic benefits that come with the transition to green growth. For the individual agents, this means that small increases in energy prices will not be a problem because they come with larger increases in income. Communicating the link between the two is a major ingredient of a successful climate policy.

It is not credible to communicate that link in the form of highly specific numerical information like the one provided by a computer simulation. Such simulations are needed to check whether some imagined future is consistent with quantitative and structural knowledge that we may have about the economy we are talking about. But once such consistency has been established, what matters is a sense of direction combined with mechanisms for regular monitoring of what works and what does not. The question then is whether in the coming decade Europe will accept the challenge of increasing economic growth while reducing both unemployment and greenhouse gas emissions. The key result of the present study is that these three goals can actually reinforce each other.

10

Measures

The EU 30% reduction of GHG emissions by 2020 can be understood as a single environmental policy goal relatively detached from other policies, or more broadly, as a structural transformative target to move the current economic regime to another better-off dynamic equilibrium. Our results provide evidence that the latter framing is a much more robust way of understanding the current climate challenge. If a careful mix of policies and measures are taken, meeting this target could significantly act as a system's attractor to boost a large amount of new investments, improve EU competitiveness, and create jobs for up to 6 million unemployed. Mainstreaming climate concerns into the next decade of institutional reforms can decisively help the EU to enter into a pathway of green economic growth and social welfare in line with its broader aspirations of sustainable development (EU Sustainable Development Strategy: Commission of European Communities (CEC) 2005; European Commission (EC) 2010d).

No single measure can deliver the type of reductions that are needed to meet the 30% target by 2020, but a combined approach is required. In this regard, traditional regulation approaches focusing, e.g., on strengthening standards have to be applied jointly with other instruments such as carbon taxes or tightening the cap-and-trade system while at the same time supporting technological and organisational innovation.

10.1 Policies and measures within member states

The European Environmental Agency (2010) currently cites a total of 860 policies and measures that EU countries (EU15) have officially reported to the UNFCCC as part of their effort to reduce GHG emissions. Out of these, 558 have been implemented, 204 planned, 68 adopted, and 30 have expired. They are also classified under different categories – with some measures taking more than one category. A simple quantitative analysis of this data base yields the picture shown in Table 30 of the main focus of climate policy making within the original EU15 members.

The main thrust of climate related measures tends to be economic, followed by those of regulatory type.

Table 30: Main focus of climate policy making

Type of measure	Number of citations
Economic	371
Regulatory	342
Information	182
Fiscal	119
Voluntary	80
Planning	76
Education	49
Research	39

Source: European Environmental Agency (2010).

10.2 Policies and measures at EU level

Our main focus is on policies at EU level. In this regard, we first review measures which are already in place within the European Union or which have been proposed by the EC. Secondly, we select some additional ones which we consider to be of special relevance to support the transition to a high employment de-carbonised EU economy in the coming years.

10.2.1 The 20% target and the EU 2009 Climate and Energy Package

In March 2009, the Council of the EU approved the ‘Climate and Energy package’ in an attempt to link a number of measures related to the reduction of GHG emissions, the promotion of renewable energy, and the improvement of energy efficiency. This followed some of the measures that had been promoted in the EU 2007–2102 Energy Efficiency Action Plan (Commission of European Communities (CEC) 2006). The overall aim of the new package was to achieve a 20% reduction of GHG emissions, with a 20% share in renewable energy by 2020. The package included the following pieces of legislation:

- The adoption of the EU Directive for the Promotion of the Use of Energy from Renewable Sources (European Commission (EC) 2009b). It explicitly sets the goal of achieving 20% of EU final consumption of energy from renewable sources as well as 10% of the EU energy consumption of the transport sector from renewable sources. In order to provide investors with the necessary certainty and to promote technological development, the Directive also established, for the first time, mandatory national targets for the overall share of energy from renewable sources in the gross final consumption of energy. With regard to biofuels and bioliquids, the Directive also established a number of sustainability criteria. These are produced to integrate biodiversity concerns, the protection of rare, threatened or endangered species and ecosystems. They further ensure that the effective contribution to the reduction of GHG emissions is met. The Directive will be transposed into national laws in 2011.
- The adoption of the new EU Directive to improve and extend the greenhouse gas emission allowance trading scheme (ETS, European Commission (EC) 2009b). After 2013, GHG emission permits will not be given for free but will be auctioned by member states. Sectors included in the ETS will have to start purchasing 20% of their emissions at auctions in 2013, and this percentage will increase gradually to 70% in 2020 and up to 100% in 2027. In this regard, all power producers are required to buy their emissions allowances in auctions as to avoid windfall profits. The directive includes a solidarity mechanism for less affluent EU countries in that they will receive 12% more allowances than the actual EU share in GHG emissions and thus will obtain greater revenues from these allowances. This legislative act states that each EU state will determine how these revenues are used, although at least half of them should be used to abate climate change either in the EU or abroad and to compensate for the potential social and distributional effects of the transition towards a low-carbon economy.

- The Decision to reduce GHG emissions to meet the EU commitments up to 2020 (the 'efforts-sharing decision', European Commission (EC) 2009a). This decision establishes binding emission targets within the EU for sectors which are not covered by the ETS. This includes activities such as housing, transport and agriculture. The goal for these sectors is to reduce 10% of the 2005 emissions by 2020. In the same guise, principles of equity and solidarity have been introduced within the EU, taking into account that countries with lower GDP but greater prospects of growth may increase their emissions by 20%. In contrast countries with high GDP may cut their emissions by 20%. Several flexibility mechanisms have been introduced, including the recourse to CDMs and emissions cuts trading between EU countries and transferring reduction excesses to future years.

- A Regulation to set emission performance standards for new passenger cars (European Commission (EC) 2009f). It sets the first legally-binding standards for CO_2 emissions for new passenger cars that will have to be applied as of 2012.

- The revision of the Directive on environmental quality standards for fuels and biofuels (European Commission (EC) 2009d). It establishes for the fist time a target to reduce GHG from biofuels by 2020 by 6%. Among other ways to achieve this, it allows petrol to have a higher content of biofuels, e.g., up to 10% of ethanol.

- A revised Directive on Carbon Capture and Storage (European Commission (EC) 2009e). The goal is to make possible the deployment of this technology in case a decision is taken to use it as part of the EU mitigation policy. Thus, this directive establishes the conditions for the assessment, authorisation and closure of storage sites.

Hence, this package was in accordance with but extended the Second European Climate Change programme of 2005. Originally, this second programme focused in strengthening the ETS system by including aviation by 2012 and proposed to make possible the implementation of the CCS technology by developing an adequate regulatory framework. The present legislative developments require higher efforts from the ETS sectors while introducing a greater contribution from the non-ETS sectors. In fact, this is likely to become a trend in the coming years, as shown by the recent approval of the Directive on the Energy Performance of Buildings (European Commission (EC) 2010c). The aim of this new Directive (which sets a common framework for calculating energy performance in buildings, the minimum energy performance requirements for new and existing buildings, as well as the general procedures for certification, inspection, and control) is that, starting in 2020, all new residential buildings produce as much energy as they consume.

Finally, Information and Communication Technologies (ICT) are increasingly being acknowledged to play an essential role in moving towards a low-carbon economy in the EU, through their role in improving energy efficiency. In this regard two EC Communications and one recommendation were produced between 2008 and 2009 (Commission of European Communities (CEC) 2008; Commission of European Communities (CEC) 2009a; Commission of European Communities (CEC) 2009b), and four working groups were created within the 'ICT for Energy Efficiency Forum' (ICT4EE) with industry to deal with these issues. The overall goal is to identify joint solutions with the building and construction sectors to improve environmental and energy performance of new and existing buildings, and to develop new simulation tools and applications in these and other sectors. The ICT4EE also works with international standardisation organisations outside the EU (Japan).

10.2.2 Towards the 30% target – Existing and proposed measures by the EC

The following options have already been cited by the European Commission Staff as a way to meet the 30% reduction target by 2020 (European Commission (EC) 2010b; European Commission (EC) 2010a):

- Strengthening the ETS according to the EC, reducing auctioning rights by 15% during the period 2013–2020 should be sufficient to meet the 30% target, and this would also increase the auctioning revenue by around a third. This should be complemented by a benchmarking policy which financially rewards those fast movers who invest in top performing technology. The Commission also mentions the possibility of including imports into the ETS, although such proposals should be compatible with WTO requirements and may be limited to a number of standardised commodities such as steel or cement.

- Technology regulation: to encourage energy and resource efficiency, which can be made possible by product standards, or measures contained in the Ecodesign Directive, limiting CO_2 emissions from vehicles, implementing the Digital Agenda, and promoting the development and implementation of smart grids and smart meters (e.g. in line with SET-PLAN, see below).

- Carbon taxes: to be applied only on non-ETS sectors, such as for fuels and products to reflect the CO_2 component or/and increase transport efficiency. The Commission mentions that revenue from taxes could be used to create local green jobs and allow for greener public procurement.

- Mainstreaming climate concerns in EU integration funds and policies**,** and in particular, to reorient *EU cohesion and structural funds* to develop renewable energy and low-carbon infrastructures; and to integrate these policies with other policies, including market integration, transport and Common Agricultural Policy (CAP).

- Moving beyond current CDM system: by substituting part of the current demand for CDM with new sectoral credits with larger potential for GHG emission reductions, like in the power sector in advanced developing economies.

- Other measures: reduction of maritime emissions and other policies oriented to avoiding the loss of tropical forests.

10.2.3 Technological options

The Strategic Energy Technology Plan (SET-PLAN, Commission of European Communities (CEC) 2007) was created by the FP7 and implemented on the 26th of June 2008 to advise the transition towards clean technology in Europe. It specifically mentions the following top key EU technology challenges for the next 10 years to meet the 2020 GHG targets:

- Make second generation biofuels competitive alternatives to fossil fuels, while respecting the sustainability of their production.
- Enable commercial use of technologies for CO_2 capture, transport and storage through demonstration at industrial scale, including whole system efficiency and advanced research.
- Double the power generation capacity of the largest wind turbines, with off-shore wind as the lead application.
- Demonstrate commercial readiness of large-scale Photovoltaic (PV) and Concentrated Solar Power.
- Enable a single, smart European electricity grid able to accommodate the massive integration of renewable and decentralised energy sources.
- Bring to mass market more efficient energy conversion and end-use devices and systems, in buildings, transport and industry, such as poly-generation and fuel cells.
- Maintain competitiveness in fission technologies, together with long-term waste management solutions.

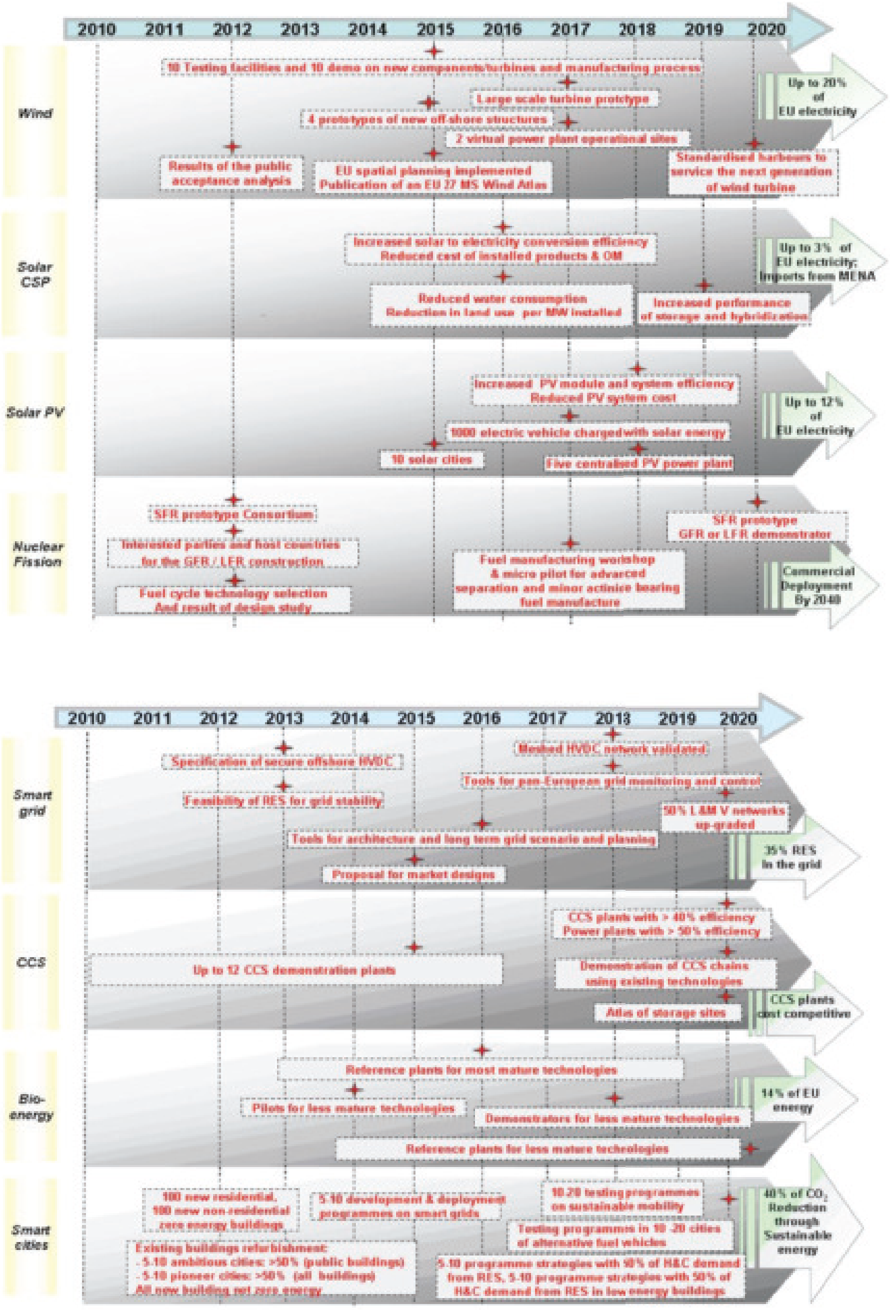
The SET-Plan has also designed a road map for its implementation which is summarised in figure 24.

10.2.4 Additional measures

In addition, the present study considers that a well-designed and comprehensive climate policy ought to consider the need for implementing the following measures.

- Macro economic measures:
  - Using part of the ETS auctioning revenue to support mitigation efforts in Eastern European countries.
  - Using resources from the structural funds to support mitigation efforts in Eastern European countries.

Figure 24: A technology roadmap for the investment and development of low carbon technologies



Source: Commission of European Communities (CEC) (2009c).

- Incentivising entrepreneurial investment by tax reliefs balanced with marginal tax increases on capital incomes used for other purposes that are not so invested.

  - Building in green growth expectations in public procurement and other relevant policies.
  - Adding the explicit management of growth expectations based on low-carbon and green investments to the public policy toolkit, as essential element of that growth itself.

- Micro economic measures:
  - Enhancing building codes to foster investment in energy efficiency.
  - Enhancing standards for energy efficiency in transport.
  - Using part of the ETS auctioning revenue to foster energy efficiency and renewable energies
  - Developing innovative feed-in tariffs to foster renewable energies,
  - Implementing regional learning networks of enterprises (as used successfully in parts of Germany).
  - Supporting the training in new professions related to renewable energy, non-nuclear, and low carbon sectors, not only for the deployment of technologies but also for the development of new services and communication strategies.
  - Raising awareness of the cost benefits in terms of energy savings to consumers through targeted education campaigns.

The above set of policies will require a regulatory reform in tune with the Renewable Energy Directive (RE-D) in a way that:

- Removes many institutional market barriers that impede energy consumers to produce their own energy and control their own energy savings (e.g., connecting smart meters and to the smart grid).
- Discourages current subsidies to non-renewable energies and carbon-intensive technologies and processes (such as coal) and redirects such funds to subsidize renewable low-carbon sources of energy.
- Avoids regressive effects of the implementation of low-carbon, energy efficiency measures.
- Contributes to building positive investment expectations by ensuring acceptable levels of return for investments of low carbon technologies over a medium period of time (as, e.g., the feed-in laws in Spain).
- Develops a whole wave of innovation in financial instruments to support the deployment of large low-carbon infrastructures, such as the *climate bonds*[15].

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[15] See http://climate.org/climatelab/Climate_Bonds;
http://www.sustainablefinancialmarkets.net/wp-content/uploads/2009/12/climate_bonds_4pager_2dec091.pdf

This framework requires the full implementation of the Climate and Energy Package, the Directive on Energy Performance in Buildings (European Commission (EC) 2010c) and, wherever applicable, requires to tighten the mandatory targets together with policies that boost climate Research, Development and Innovation (R & D & I) through standardisation and certification actions in line with the SET-PLAN.

The new extended package of measures should also promote the standardisation of smart grid infrastructures and smart household appliances to promote faster and higher penetration of electricity renewable energy. In particular, it should stimulate the competition and participation of small and medium producers into the grid to reduce costs of net energy consumers to become net suppliers. Finally, and at member state level, the harmonisation of the national methodologies used for the reporting and quantification of the effects of the different climate policies and measures, both in terms of expected GHG emission reductions and economic costs, should be encouraged.

- Other integrated approaches; the example of Agri-Food systems:

Considering the role of Agri-Food systems (AFS) provides an instructive example for how climate policy is interlinked with other policy areas. This requires taking into account the whole chain involved in the production, distribution, and consumption of food and the disposal of food waste. In particular, an increased demand for environmentally friendly or ‘sustainable’ food may contribute to changes in the way AFS operate so that GHG emissions could be reduced. Even more important are the shifts in lifestyles and overall culture that come with changes in food-related habits, symbols and emotions. Relevant policy measures in this area include:

1. *Production*: e.g. using less intensive agricultural practices so as to help the restoration of the top soil and increase the GHG capture potential of the farmed soil; improving the efficiency of the agricultural production and reducing the intensity of cattle raising; reducing the consumption of fertilisers and chemicals. The CAP policy is of central relevance in this regard, as an integrated climate policy which considers AFS would entail increasing the share of the agri-environmental measures of the CAP and/or redirecting some of the CAP funding mechanisms to mainstream climate concerns (Commission of European Communities (CEC) 2010).
2. *Distribution*: changes in the scale and modes of transport of food, e.g. reducing the food miles of certain foods, changing the way food is distributed (e.g. by road) or reducing the unnecessary trade of certain food products within the EU.
3. *Consumption*: e.g. by promoting changes in dietary content of meat and dairy products (largely responsible for methane emissions) and reducing the amount of wasted food. Reduce the amount of unnecessarily processed and packed food.
4. *Disposal and waste*: reducing the amount of packaging and waste (largely deriving from convenient and processed food) and developing systems to reduce the total emissions produced from the treatment of food and drinks waste.

Some estimations for the case of the UK account that the food system as a whole contributes around 19% of the country's GHG emissions. In this line, WRAP (2009); WRAP (2010) in the UK developed a 'quick win' scenario which considers two types of measures that could be easily achievable by the UK households to reduce GHG emissions by 2020:

1. To reduce by half the edible food waste by 2020.
2. To reduce by a quarter the meat and dairy consumption by 2020.

According to WRAP (cited in New Economics Foundation 2010), in the UK, a total of 20 Mt of GHG emissions result from the edible food which is thrown away every year, which is equivalent to all CO_2 emitted by a quarter of the cars on the UK roads. Around 30 Mt of household waste is produced yearly in the UK, of which 4.9 Mt is packaging and 8.3 Mt is food waste. In their view:

> If over the next 20 years households in the UK didn't throw away edible food, a total of nearly 500 Mt of GHG emissions would be avoided. (. . .) Additionally, dietary changes that reduce the consumption of the most carbon intensive food products deliver a substantial saving, mainly because of reduced methane emissions from livestock. Changing diets to reduce meat consumption can save 846 Mt and ensuring that edible food is not treated as waste, a GHG emission reduction of about 456 Mt is possible by 2050. (WRAP 2009 p. 3)

Furthermore, a 50% reduction in household edible food waste by 2020 would deliver a saving of 27 Mt of GHG emissions by 2020, a total of 232 Mt cumulatively by 2050. Increasing the efficiency of AFS can also reduce costs and increase producers' profits. Taking the UK as a reference, WRAP estimates that saving in GDP can be of the order of 0.14% and 0.18% respectively, and therefore, implementing such additional measures would not entail any additional costs. They also consider that despite meat and dairy products only account for less than a quarter of the weekly average food intake in the UK, they produce nearly 60% of the food related GHG emissions. Provided that in the UK people consume an excess of calories comparing with what is recommended by the UK Health department, there is an obvious potential to reduce such excess of GHG intense food products. Paying attention to links between the AFS and climate change can be an opportunity to gain support for climate policy from the strong and basically sound intuition of many people that caring about nature and caring about health are two sides of the same coin.

11

The Role of the New Member States

The New Member States (NMS) of the EU profit fully from the increased growth and employment effects associated with a green growth strategy. The effect is underpinned by the relatively lower cost of implementing certain measures such as boosting energy efficiency in buildings and transportation, as well as carbon efficiency in electricity generation. Existing market failures are overcome by retaining already decided measures such as the dedication of a share of the revenue of the auction of ETS permits to the NMS, as well as focused additional measures like further leveraging the structural adjustment fund in the next planning period.

The New Member States are still laden with lowhanging fruit, in terms of potential efficiency improvements and renewable energy increases. However, for historic reasons concerns of energy security have ranked above the decarbonisation of the energy system.

Below we look at the vital statistics of the NMS energy systems, the role of energy security and adjustment payments. We have added case studies on Poland and Hungary, each illustrating different aspects of the change dynamics.

11.1 Eastern power and efficiency

Energy intensity and associated CO_2 emissions vary between regions in Europe, both in absolute and per capita. Table 31 below places the Eastern European energy system in the perspective of the EU27 averages, with typical examples from each of the three regions displayed. The emissions per unit GDP represent the efficiency of the economy and emissions per capita are a measure of equity throughout the EU. It is clear from the statistics that the efficiency gaps between most Eastern European countries and the EU27 average are substantial. This is due to a combination of inefficiency in buildings and industry, with a heavy reliance on coal in electricity generation.

Table 31: Eastern European energy system in the perspective of the EU27 averages

	TPES/Population (toe/capita)	TPES/GDP (PPP) (toe/k$ 2000)	CO_2/Population (t CO_2/capita)	CO_2/GDP (kg CO_2/k$ 2000)
EU27	3.55	0.14	7.92	0.32
France	4.15	0.15	5.81	0.21
Germany	4.03	0.14	9.71	0.34
Italy	3.00	0.11	7.38	0.37
Spain	3.21	0.13	7.68	0.32
Bulgaria	2.65	0.28	6.57	0.70
Czech rep.	4.43	0.22	11.8	0.58
Poland	2.55	0.18	7.99	0.57
Romania	1.81	0.19	4.27	0.46
Hungary	2.66	0.16	5.36	0.33

Source: International Energy Agency (IEA) 2007a.

In terms of reduction targets, it is worth noting that the start year of the EU CO_2 statistics (1990) is just after the dramatic drop in energy consumption in 1989, due to the collapse of the Soviet system and its satellites. In fact Poland, for example, uses 1988 as the base year in its reports on Kyoto progress to the UNFCCC. Note that the base year under the Climate Change Convention is 1990 except for Bulgaria (1988), Hungary (average of 1985 to 1987), Poland (1988), Romania (1989) and Slovenia (1986), as defined by decisions 9/CP.2 and 11/CP.4. Total primary energy consumption has remained relatively flat, implying that the increased consumption from economic growth has been entirely offset by a decrease in energy intensity. The challenge in the next decade is essentially to further reduce energy intensity, while accommodating growth.

11.2 Energy security

With the important exception of coal, Eastern Europe is heavily dependent on preliminaty energy imports from Russia for its needs. This is particularly strong for natural gas, with the exception of Romania that produces a substantial but rapidly dwindling amount. Several countries have coal reserves, but Poland has by far the largest production, with substantial reserves, although with an R/P ratio of only 58. This lack of diversity in supply would be an issue for any country from a perspective of energy security, but in the case of Eastern Europe this is further exacerbated by historic chafes as well as legacy contractual terms. The latter cause repeated flare-ups and supply shutdowns as Russia attempts to renegotiate the terms more in line with the commercial reality of the energy markets. In 2006 this happened in Ukraine due to a dispute between Naftohaz Ukrainy and Gazprom and in June 2010 in Belarus. Because the same pipelines supply Western Europe, the knock-on effect of these contractual disputes is continent-wide.

A notable development potential, radically reducing the dependency on Russia, is the recent focus on shale gas deposits in Poland. Over the past two years, the Polish Environment Ministry has issued around 60 licenses for shale gas exploration in Poland. American estimates show that shale gas reserves in Poland amount to a minimum of 1.5 trillion m^3. Poland's top geologist Henryk Jezierski believes, however, that it will take up to five years to find out how big the reserves are. It will then take between 10 and 15 years to begin extracting the gas. Shale gas is methane locked up in shale rock formations with low porosity and low permeability, making it very difficult to extract. The quantities are vast and are estimated to far exceed the total traditional gas reserves. Shale gas has caused a veritable revolution in North America, turning the assumption that NA would become dependent on large amounts of imported gas through LNG (liquefied natural gas) - like oil - on its head and causing the price of gas to drop from $11/MMBTU to $4/MMBTU (British Thermal Unit). Extracting shale gas is done by fracturing the rock underground with immense amounts of water added with chemicals; it is expensive and the environmental impact of injection and potential release of methane into the atmosphere (Howarth 2010) is as yet unclear. The impact on emissions from power generation would be substantial since a typical coal power plant emits about 0.9 kg CO_2/kWh-el, while an NGCC (Natural Gas Combined-Cycle) power plant emits about 0.4 kg CO_2/kWh-el. The risks need independent study, and both shale gas producers and environmental regulators need to take them seriously. Nevertheless, given the very substantial impact of shale gas on US energy supply and security (adding 40% to the reserve base at a stroke – or 60 years of supply; Moniz, Jacoby and Meggs 2010), the large scale acquisition of land by Exxon and Chevron in Poland in 2010 is an indication of a possible similar supply revolution. At a conference on European shale gas in June 2010 in Brussels, Ewa Zalevska, director of the Geology and Geological Concessions Department at the Polish Environment Ministry, admitted that Warsaw was harbouring major ambitions to develop shale gas, the switch towards which she described as "the 21st Century's gold rush".

11.3 Structural adjustment and green growth

Although in principle decarbonisation should be relatively easier in the NMS, in practice market inefficiencies throw up substantial hurdles, as advocated by the states themselves. The GEM-E3 results appear to indicate that the overall increased investment will allow the NMS to achieve the targeted M30 reductions without any additional support. However, in our view this does not do justice to the structural issues in those economies. Additional support can come from two sources – first, a further targeting of the existing structural adjustment funds towards the M30 goal, and secondly, a disproportionate allocation of the ETS auction revenues to support non-ETS adjustments.

Decarbonising the energy mix in Eastern Europe is not at present one of the objectives of the four existing Structural Funds; it could be made to fit under one of the existing or a new objective could be added, although that would likely not come into force until the next planning period 2013–2018. The total budget for the period 2007–2013 is €347 bn, split between the three objectives of Convergence (€283 bn), Regional Competitiveness and Employment (€55 bn), and European Territorial Cooperation (€9 bn).

Justifying building efficiency programmes in terms of employment and development is more credible than providing capital for retrofitting the power infrastructure.

Indeed between 2007 and 2013, the total amount of Structural and Cohesion Funds allocated to environmental programmes has doubled since the previous period to around €100 bn – 30% of the total. Half of this investment will be devoted to direct infrastructure investments related to water and waste treatment, renewal of contaminated sites, pollution reduction, and support for nature protection and risk prevention. The other half will go to indirect investments with an environmental impact on areas such as transport and energy systems, eco-innovation, environmental management for businesses, urban and rural regeneration, and eco-tourism. For example, over €9 bn is earmarked to support energy efficiency and renewable energies.

11.4 Case study – Poland

Poland has weathered the financial crisis very well. Like South Korea, it has let its currency slide, while shunning the deficit-swelling policies of Britain and America. Ironically perhaps because of still having to enter the Euro within the Growth and Stability Pact criteria, Poland faces the crisis in a stronger position than many. Poland was the only member of the EU with economic growth in 2009. Cities such as Czestochowa (population 250k) exemplify the bottom-up efforts that are occurring in various places in Poland. With financing from the EIB, the city opened a combined coal-biomass plant helping to reduce CO_2 emissions by 24% over 2003. An energy efficiency plan for buildings is complemented with small hydro, solar, CHP and wind plants.

The Polish economy has a unique set of challenges and opportunities in climate mitigation. High coal usage resulting in a GDP emissions intensity more than twice the EU average (0.76 t CO_2e/ $ 1,000 PPP GDP) (McKinsey 2010).

Carbon dioxide emissions from Poland's use of fossil fuels and cement production climbed at a remarkably steady rate of 3.9% per year from 1800 until 1980, when they dropped abruptly (11.7%), recovering to a lower rate of 1.4% per year. While the absolute emissions of Poland are 5th in the EU (2005) and the per capita emissions middle of the pack (10.3 tCO_2e per capita), Poland ranks at the top for emissions intensity at 0.76 tCO_2e/k$ PPP GDP (McKinsey 2010). The latter figure is twice the level of Western European countries.

So, clearly the challenge of Poland is to reduce its emissions intensity at a faster rate than the development of the economy. In fact, Poland was the country that achieved the best results within EU12, in controlling its energy intensity. There is no doubt that this has been a result of several factors. First and probably most important was the momentum towards privatisation in Poland in the face of various difficulties. Additionally, new firms have been successful in responding to the increased energy prices and managed to improve significantly their efficiency leaving behind public sector traditions. Finally, the Polish primary energy fuel exhibited gradual change; coal became less important while oil, natural gas, CHP and renewable energy sources moved up the agenda (Konstantinos 2009).

More than half of the total abatement potential is in the power and building sectors, with the building sector having negative abatement costs of €18/t CO_2e (McKinsey 2010). Although ultimately a high return activity, the practical challenges of energy efficiency in buildings are not insignificant, but the challenges are shared amongst many countries in Europe enabling learning both in technology and in policy implementation. In the power sector, the issue is to replace the ageing coal fleet with lower carbon alternatives. The current options are new coal with CCS, nuclear, wind and gas potentially with CCS. In practice, a mix of solutions is likely, as a more diversified power system is more resilient, including potentially a high capacity DC interconnection with the European power system for additional security of supply and load balancing for the intermittency of renewables. Coal with CCS is likely an expensive option (McKinsey 2010), but potentially necessary for retrofits such as being done at Belchatow. Gas is a realistic option but requires a diversity of sources, ranging from LNG and Russian import to the potentially large Polish shale reserves. The LCOE of gas ranges from 30 to 110 €/MWh, strongly depending on the cost of the fuel (at $5-15/mmBTU). Nuclear has substantial cost and planning uncertainty with a 2020 LCOE ranging from 25–170 €/MWh (IEA/OECD 2010), mainly due to the escalating capital cost (Cooper 2009); the Zarnowiec plant is not expected on line before 2020 at the earliest. The cost of wind power is expected to fall by 2020 to an LCOE of 20–140 €/MWh, driven by the assumptions on cost reduction from volume construction and the degree of efficiency (IEA/OECD 2010). In practice, a mix of gas and wind seems to be the power solution with the best risk/cost profile. For gas the challenge will be maintaining supply diversity and for wind an appropriate interconnection to the European grid to manage intermittency. Cogeneration, although widely applied in Poland, still has substantial upside to reach European best practice levels of 35–45% of power.

In 2003, the council of Ministers adopted the target of a 40% reduction from 1988 levels by 2020, from 570 to 342 Mt CO_2e. As in all 27 member states, Poland is required to contribute to a 21% emission reduction applying to all industrial sectors covered by the ETS. In sectors outside the ETS, Poland is allocated an increase in nonETS emissions by 14%. Finally, Poland is to double the renewable share of its energy from 7.2% (in 2005) to 15%.

Poland is progressing towards these goals, with energy efficiency improvements well above the European average. With a significant amount of AAU surplus, equivalent to 500 million tons of CO_2 for the period of 2008 to 2012, Poland has made a first C25 mln emissions trading contract with Spain in 2009. Poland is one of nine EU countries that have announced that they will meet their renewable target of 15% by 2020, or possibly slightly exceed it. Nevertheless continued progress is challenging.

In the context of an increased EU27 commitment to 30% CO_2e reduction by 2020, upside opportunities exist for Poland. With an increased investment level, both in Poland and in the rest of the EU, higher expectations and learning by doing can lead to a better outcome than the current path. This Green Growth perspective includes a 27% increase in levels of investment by 2020, leading to an increase in GDP by up to 7%, the creation of as many as 500,000 jobs in the economy (see Table 32) and economy wide positive effects (see Figure 25). Similar actions and policies across the EU27 are a prerequisite for this outcome.

Table 32: Macroeconomic features, Poland

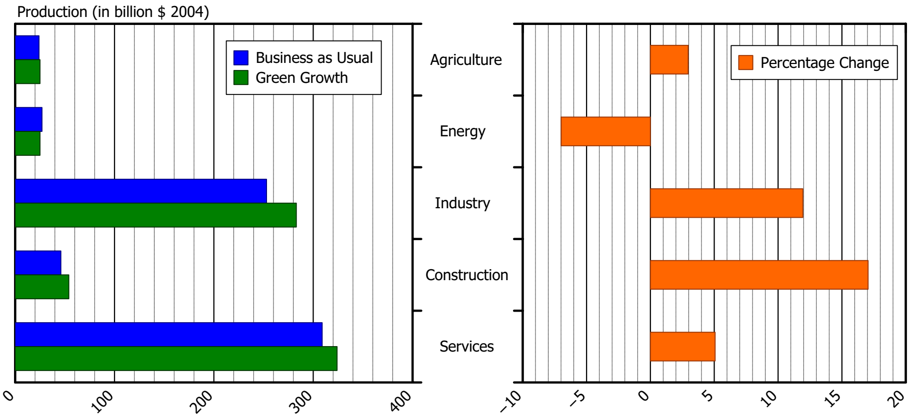
	Green Growth	Business as Usual	Δ
GDP in 2020 (billion $\$_{2004}$)	351	328	7.0%
GDP growth-rate 2010–2020	3.7%	3.0%	0.7*pp*
Unemployment rate in 2020	8.5%	12.5%	−3.9*pp*
Investment in 2020 (share of GDP)	23.9%	20.3%	3.6*pp*
Investment in 2020 (billion $\$_{2004}$)	84	66	27.3%
Emissions (Mt of CO_2e)	329	364	−9.6%

Δ: *Difference 20% vs. 30% either as percentage of 20% value or as difference in percentage points (pp).*
Source: own analysis based on GEM-E3 simulations.

11.5 Case study – Hungary

Despite declining budget deficits over the past two years (from over 9% of GDP in 2006 to 3.3% in 2008) imposed by the austerity measures in late 2006, the global financial crisis in

Figure 25: Compare results Green Growth vs. business as usual Poland



Source: GEM-E3 results.

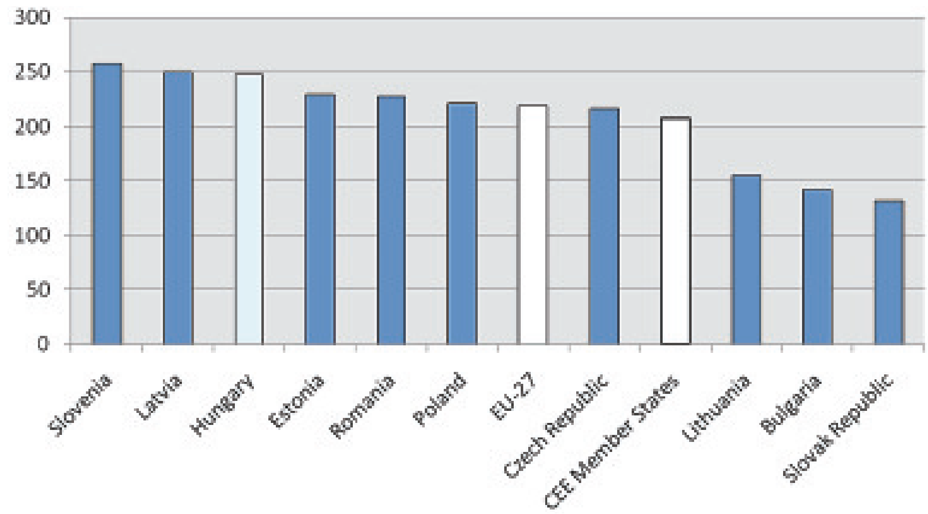
late 2008 led Hungary to seek and receive an IMF-financial assistance package worth over $25 bn. The global economic downturn, declining exports, low domestic consumption and fixed asset accumulation resulted in an economic contraction of 6.3% in 2009 (Hungarian GDP of €100 mn in 2009). In spite of the many challenges that accompany the global economic crisis, Hungary remains an attractive market for investment: the private sector accounts for more than 80% of GDP, and foreign ownership of and investment in Hungarian firms is widespread, with cumulative foreign direct investment totaling more than $200 bn since 1989 (OECD 2010).

By ratifying the Kyoto Protocol, Hungary committed to reducing its GHG emissions by 6%. The total amount of GHG emissions declined rapidly from 1990, due to the collapse of the heavy industry. As in 2008 the emissions were 34% lower than in the base year (average of 1985-87), Hungary, unlike other Member States will have no problem to meet its commitments. However, Hungary imports 80% of its natural gas, 99% of crude oil, 100% of nuclear fuel and 61% of raw materials from Russia, flowing along a single transmission route. Therefore, energy dependency and security issues have been a primary concern of the government, especially since the supply interruptions of January 2006 (OECD/IEA 2007).

Electricity prices have been rising steadily since 1996. Household electricity prices have increased by over 140% over a decade and are currently slightly below the European averages. In 2006, prices for industrial users reached the EU25 average and since then continued to increase. Between 2000 and 2007, an average Hungarian household spent 10% of its net income on energy bills and, as an average for the period 2005–2007, around 1.5 million people declared to be unable to afford keeping their homes adequately warm. Particularly affected population segments are the elderly, single-person households, households living in dwellings supplied by district heating and the poor rural population including ethnic minorities (HCSO 2009).

The largest GHG reduction potential in Hungary is the housing sector: buildings contribute approximately half of energy-related CO_2 emissions, which is partially caused by the inefficiency of the building stock. Currently, Hungary displays one of the lowest energy efficiencies among CEE Member States (See Figure 26). Among former socialist EU Member States, only Latvia and Slovenia are less energy-efficient in residential heating. This sector has also been shown to have the highest cost-effective climate change mitigation potentials in Hungary. In addition, Hungary has the second lowest employment and activity rate, making it a target laboratory for the cost effectiveness of building energy efficiency measures.

Figure 26: Households' specific energy consumption (kWh/m^{2}a) scaled to EU average climate. Hungary vs. CEE Member States. Average 2000–2007 — 3CSEP2010



Source: Central European University (2010).

The National Energy Efficiency Action Plan set in 2008 aims to improve energy efficiency by 1% annually between 2008 and 2016. The main tasks are refurbishments of public buildings, turning new building operations to climate friendly, passive houses, energy-saving systems, insulation of schools and hospitals, and cogeneration.

Several scenarios can be considered (Central European University 2010), leading to between 43,000 and 130,000 jobs created from building energy efficiency in 2020, with 100,000 dwellings to 250,000 dwellings per year. The cost at an average of €250/m^2 is a fraction of the cost in Germany at €700/m^2. The programme creates between 36,000 and 90,000 jobs by 2020. The total required investment is between €1.4 bn and €3.5 bn, effectively a relatively efficient 37 FTE per €1 mn invested (benchmark 10–30 FTE per €1 mn). The CO_2 reduction is between 8 and 12 Mt/year. The programme is ultimately profitable, but requires upfront capital as the pay-back is relatively long. Potential sources of funds are the Hungarian energy subsidies (mostly gas), annually of €800 mn, and €400 mn from the EU.

The Energy Policy Concept, adopted by the Hungarian Parliament in 2008, has set the aim of increasing the share of renewables to 13% (186.4 PJ) of the total energy consumption by 2020, from 5.4% (55 PJ) in 2009, in order to comply with the EU RES Directive. The target is broken down by sector: 79.7 PJ (9470 GWh) in electricity production, 87.1 PJ in heat production and 19.6 PJ from biofuels within fuel consumption (European Commission 2007; OECD/IEA 2007). It takes into account the need to reconstruct the subsidization system, to restructure the feed-in tariff for green electricity, which exist since 2004. Presently, the government supports electricity-aimed renewables most of all, and especially the largest projects. Nevertheless, subsidizing smaller, heating-aimed projects is also important, like the modernization and the disconnection of the heating systems of schools from the natural gas network. The development should be set off by less considerable projects and with little amounts in order to incrementally reach a more efficient, more diversified energy supply.

The largest technically achievable potential is in biomass through the development of decentralized small-scale biomass power plants. This can be combined with use of cogeneration, which is also promising when heating is based on fossil fuels. Hungary also has a very good potential in the use of geothermal energy. Wind energy has an energy production cap of 710 MW due to a poor GRID system (current at 190 MW) (Kovacs 2009). Solar power has a very big potential, but the subsidization system does not meet with the investment prices. Hydropower is not efficient enough due to geographical reasons.

As all 27 EU Member States, Hungary is required to contribute to a 21% emission reduction applying to all industrial sectors covered by the ETS. In Hungary, the ETS covers installations responsible for 40% of emissions. The Hungarian ETS and infrastructure is quite advanced. While for the moment Hungary has no problem in meeting its emissions commitments, the power generating sector and some other industries such as petrochemicals and oil will still face significant challenges when the 3rd phase of the ETS system is implemented in 2013 because the base year for future reductions is 2005. Currently, the allocation of allowances is for free. Full auctioning of the allowances starting in 2013 will almost double the cost of electricity produced from coal and will increase the cost of electricity produced from gas by 50% (Smith 2010).

In the context of an increased EU27 commitment to 30% CO_2e reduction by 2020, upside opportunities exist for Hungary. With an increased investment level, both in Hungary and in the rest of the EU, higher expectations and learning by doing can lead to a better outcome than the current path.

In addition to lowering its import of natural gas, by connecting the energy policy to economic development and tackling the institutional problems in the energy sector, Hungary could lower its level of unemployment (10.3%, compared to an EU average of 8.9% in 2009) (Central European University 2010).

A 30% reduction policy could lead to a GDP increase up to $126 bn in 2020 (a 3.3% increase compared to $122 bn, see Table 33). The average annual growth rate would increase by 0.3% with respect to a 20% reduction policy.

Private consumption would be reduced by \$3 bn and investment would increase by \$5 bn, where private investment represents 80% of this increase.

The increase of growth would result in a positive effect on the labour market. A 30% reduction policy has the potential to reduce the unemployment rate to 3.7%. Compared with a 20% reduction scenario (4.9%) the employment would increase by 100,000 jobs. The remaining unemployment corresponds to 30% of today's unemployment rate (around 11%). Further economy-wide positive effects on production are represented in Figure (27).

In a 30% scenario, the economy wide energy use (energy per GDP) decreases by 8% with respect to a 20% scenario and achieves 74% of today's level. The highest change is expected for the ETS sector (-10%) and households (-12%, Energy per households income).

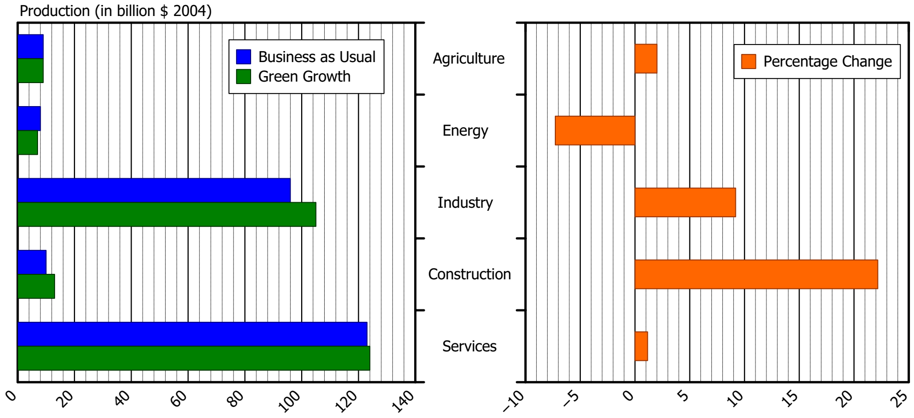
Less use of energy and the transformation in the power production will lead to an economy wide reduction in GHG emission to 60 Mt CO_2e. Compared with a 20% scenario the reduction is 9 Mt CO_2e.

Table 33: Macroeconomic features, Hungary

	Green Growth	Business as Usual	Δ
GDP in 2020 (billion $\$_{2004}$)	126	122	3.3%
GDP growth-rate 2010–2020	3.0%	2.7%	0.3*pp*
Unemployment rate in 2020	3.7%	4.9%	−1.2*pp*
Investment in 2020 (share of GDP)	23.7%	20.2%	3.5*pp*
Investment in 2020 (billion $\$_{2004}$)	30	25	20.0%
Emissions (Mt of CO_2e)	60	69	−13.0%

Δ: Difference 20% vs. 30% either as percentage of 20% value or as difference in percentage points (pp).
Source: own analysis based on GEM-E3 simulations.

Figure 27: Compare results Green Growth vs. business as usual Hungary



Source: GEM-E3 results.

12

Green Growth and energy intensive industries

12.1 Emission of energy intensive industries

Energy intensive industries cover the energy sector and the industrial sectors. In the energy sector (mainly electricity and heat), the end product is homogeneous, and the technologies are relatively uniform. In contrast, the industrial sector is characterized by a diversity of activities, processes, and technologies. The main energy intensive industries are chemicals, cement, steel, and aluminium, food and tobacco, pulp and paper, and machinery. Given the lack of uniformity in the industry sector, there are a large number of diverse actors operating in a multitude of regulatory contexts.

There is no standard definition of the 'energy intensive industries'. As an example, in the UK, the energy-intensive industries are precisely defined as the industries characterized by: (i) energy intensity of 3% or more (i.e. energy costs must be 3% or more of the production value for the sector); (ii) import penetration ratio higher than 50% (ratio calculated for the sector as a whole to determine its exposure to international competition); (iii) energy intensity of 10% or more for industries that do not meet the international competitiveness criteria. At the European level, the energy intensive sectors are defined as the sectors which are facing international competition and could be substantially disadvantaged in case a carbon constraint is imposed unilaterally on EU industries.

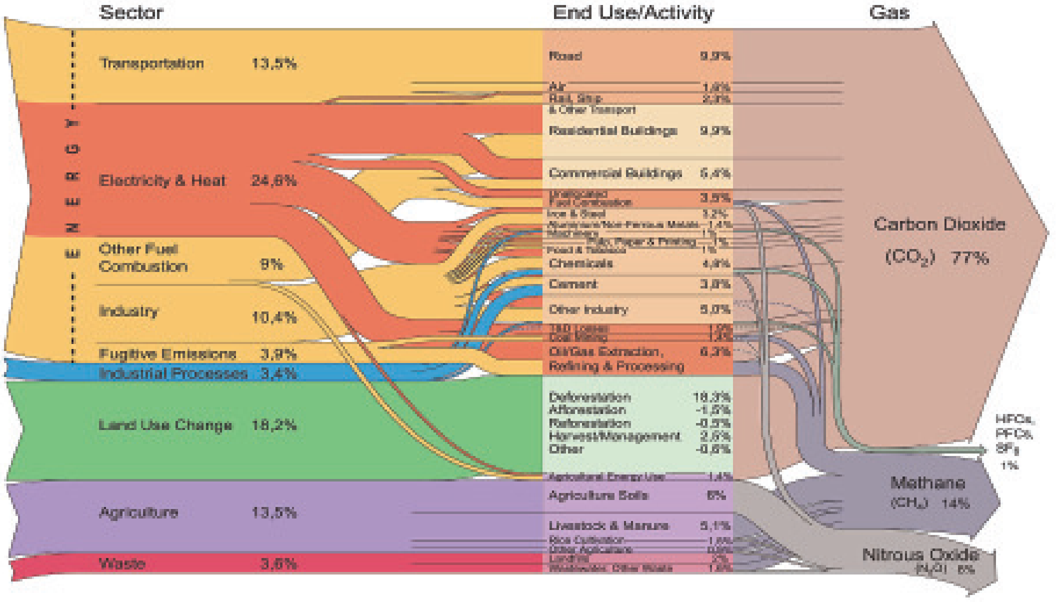
The EC Directive 2009/29/EC states:

> In this context, the Commission should identify which energy-intensive industry sectors or subsectors are likely to be subject to carbon leakage. It should base its analysis on the assessment of the inability of industries to pass on the cost of required allowances in product prices without significant loss of market share to installations outside the Community, which do not take comparable action to reduce their emissions. Energy-intensive industries, which are determined to be exposed to a significant risk of carbon leakage could receive a higher amount of free allocation or an effective carbon equalization system could be introduced with a view to putting installations from the Community which are at significant risk of carbon leakage and those from third countries on a comparable footing. (European Commission (EC) 2009c)

Generally, the energy intensive industries cover ETS (energy production, steel and iron, cement) and non-ETS sectors (chemicals, aluminium, copper and stainless steel, chlorine and silicon).

Regarding the amount of GHG emissions for which the energy intensive industries are responsible, different studies present different figures. According to (International Energy Agency (IEA) 2007b), aluminium, cement, iron and steel industries accounted for more than 10% of global GHG emissions in 2007 and were growing rapidly. According to Baron and Genasci (2007), more than 30% of the world's energy consumption and 36% of GHG emissions are attributable to manufacturing industries among which chemical, petrochemicals, iron and steel, cement, paper and pulp; other minerals and metals account for more than two-thirds of this amount. According to (WRI/CAIT 2007), based on 2000 data and calculations on CO_2e, industry and industrial processes sector are responsible for 13.8% while the energy industries account for 34% of the world GHG emissions (see Figure 28). The most energy-intensive industries account as follows: iron and steel (3.2%), aluminium and non-ferrous metals (1.4%), pulp, paper and printing (1%), chemicals (4.8%), cement (3.8%) and other industries (5%).

Figure 28: World GHG emission by sector



*All data is for 2000. All calculations are based on CO_2e, using 100-year global warming potentials from (*Intergovernmental Panel on Climate Change 2010*), based on the total global estimate of 41,755 MtCO_2e. Land use change includes both emissions and absorptions. Dotted lines represent flows of less then 0.1% of total GHG emissions*

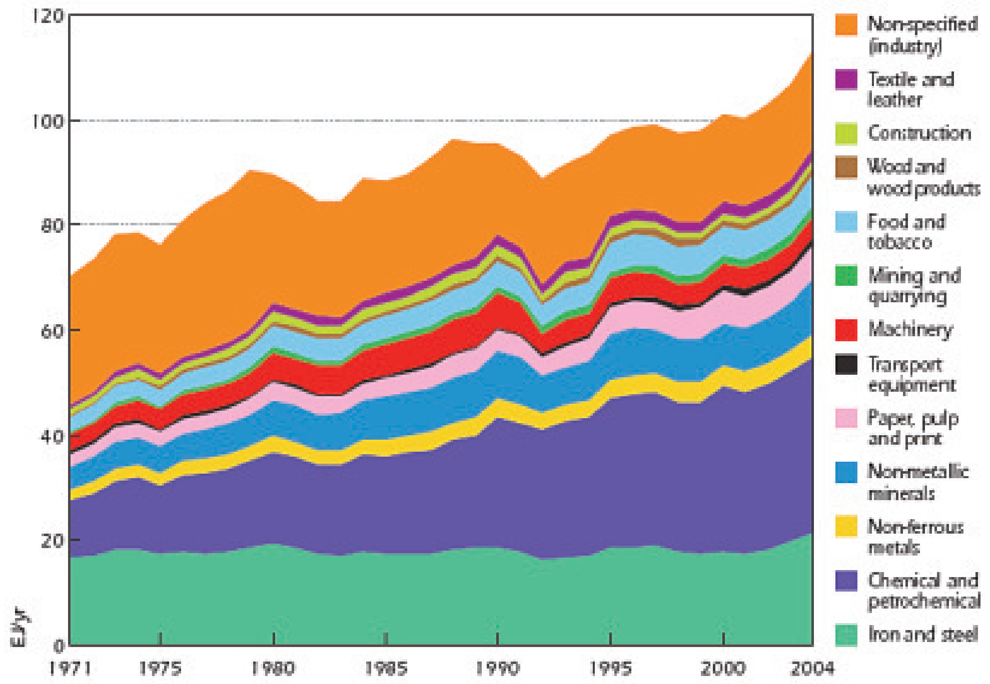
Source: World Resources Institute, Climate Analysis Indicator Tool (CAIT), Navigating the Numbers: Greenhouse Gas Data and International Climate Policy, December 2005; Intergovernmental Panel on Climate Change, 1996 (data for 2000).

While these figures and calculations are different, there is however consensus on the importance of these emissions and their reduction. The energy intensive industries face the challenges of energy price increases, factoring in the cost of carbon emissions, the need to invest in low carbon technologies and reskilling for many employees, that should transform production processes and supply chains in the shift from a high to a low carbon economy.

Overall, the industry's use of energy has grown by 61% between 1971 and 2004 (see Figure 29). However, in terms of emissions, between 1990 and 2002 the industry has declined as a relative share of many countries' national emissions totals since 1990, as evidenced by the relatively modest growth rates, some of which are negative. Industry emissions have declined since 1990 in Mexico (-26 %), Russia (-22 %), Australia (-18 %), EU25 (-15 %), and the U.S.

(-10 %). Growth has been significant in India (+49%), China (+21%), Brazil (+61%), and South Korea (+77%), but slower than in other non-industrial sectors.

Figure 29: Industrial final energy use



The discontinuity around 1990 is caused by developments in Eastern Europe and the FSU that resulted in a rapid decline of industrial production
Source: International Energy Agency (IEA) 2006.

It is also important to note that the growth rate of the industry's use of energy varies significantly between sub-sectors. For example, chemicals and petrochemicals, which are the heaviest industrial energy users, doubled their energy and feedstock demand between 1971 and 2004, whereas energy consumption for iron and steel has been relatively stable. Also, much of the growth in industrial energy demand has occured in emerging economies. China alone accounts for about 80% of the growth in the last 25 years. Today, China is the world's largest producer of iron and steel, ammonia and cement.

Energy efficiency has improved substantially in all the energy intensive manufacturing industries over the last 25 years in every world region. This is not surprising. It reflects the adoption of new technology in enterprises where energy is a major cost component. Generally, new manufacturing plants are more efficient than old ones. There also is a trend towards larger plants, which is usually positive for energy efficiency.

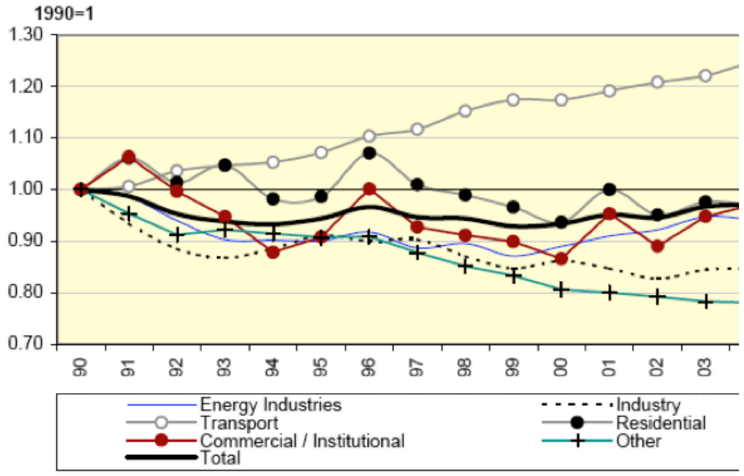
Broadly, it is the Asian OECD countries (Japan and Korea) that have the highest levels of manufacturing industry energy efficiency, followed by Europe and North America. This reflects differences in natural resource endowments, national circumstances, energy prices, average age of plants, industrial processes as well as energy and environmental policy measures.

The energy and CO_2 intensities of emerging and transition economies show a mixed picture. Where production has expanded, the industry may be using a new plant with the latest technology. For example, the most efficient aluminium smelters are in Africa and some of the most efficient cement kilns are in India. However, in some industries and regions where production levels have stalled, manufacturers have failed to upgrade to the most efficient technology. For example, older equipment remains dominant in parts of the Russian Federation and Ukraine. The widespread use of coal in China reduces its energy efficiency (International Energy Agency (IEA) 2008b).

12.2 Importance of the energy intensive industries in Europe

In Europe, the CO_2 emissions of the industry (data for 2007) accounted for 22% of the total European emissions while the energy industries accounted for 38.2%. The share of the industry emissions in Europe has declined since 1990 by approx. 15% (see Figure 30).

Figure 30: CO_2 emissions by sector: EU27, excluding LULUCF



Source: European Environment Agency (EEA) (2010a).

The emissions of the industry are distributed as follows: industrial processes (7%), iron and steel (2.7%), aluminium and non-ferrous metals (0.3%), pulp, paper and printing (0.7%), food, beverages and tobacco (1%), chemicals (2,3%), cement and other industries (9%).

Around 50% of the EU's total CO_2 emissions (and about 40% of its overall greenhouse gas emissions) are covered by the ETS which targets two main groups of industrial actors: power producers (responsible for around 60% of the ETS emissions) and energy-intensive industries: cement, oil refining, chemicals, pulp and paper, steel. In Phase I of the ETS, from 2005 to 2007, the system covered CO_2 emissions from high-emitting installations in the power and heat generation industry and in selected energy-intensive industrial sectors: combustion plants, oil refineries, coke ovens, iron and steel plants and factories making cement, glass, lime, bricks, ceramics, pulp and paper. In Phase II, from 2008 to 2012, emissions of nitrous oxide of the production of nitric acid are also included. In addition, from the 1st of January 2008 the geographical coverage of the EU ETS has been extended beyond the 27 EU Member States to include Iceland, Liechtenstein and Norway.

Energy intensive sectors include also non-ETS sectors such as copper and stainless steel, aluminium, chlorine and silicon.

From 2013 it is proposed that the scope of the ETS be further extended to cover also CO_2 emissions from the petrochemicals, ammonia and aluminium sectors; nitrous oxide emissions from the production of nitric, adipic and glyoxylic acid; and perfluorocarbon emissions from aluminium production.

Both phases I and II of the ETS having shown the high financial value of emission allowances, the national allocation plans were negotiated by European governments under high lobbying pressures from the energy intensive sectors (Anger, Bohringer and Oberndorfer 2008). The main lobby organization is the European Alliance of Energy Intensive Industries which includes CEFIC (European Chemical Industry Council), CEMBUREAU (The European Cement Association), CEPI (Confederation of European Paper Industries), CERAME-UNIE (Liaison Office of the European Ceramic Industry), CPIV (Standing Committee of the European Glass Industries), EULA (European Lime Industry), EURO ALLIAGES (Comité de Liaison des Industries de Ferro-Alliages), EURO CHLOR (Chlor-alkali industry), EUROFER (European Confederation of Iron and Steel Industries), EUROMETAUX (European Association of Metals), EXCA (European Expanded Clay Association), IFIEC EUROPE (International Federation of Industrial Energy Consumers).

It is worth noting that the European industry output has fallen from a peak in 2007 to the 1998 level in 2008 due to the financial crisis. The crisis has affected all sectors, though not evenly. The biggest falls in output have occurred in motor vehicles, metal machinery, electrical equipment and textiles; other sectors such as pharmaceuticals and food have remained relatively stable. For example, the motor vehicles sector went from an average annual growth of 2.6% over 2001-2007 to -5.5% in 2008. Over the same period, the intra EU exports growth rate went from 6.6% to -8.4%. In addition, the outside-EU exports of several sectors have also contracted sharply since 2008 (European Comission Staff 2009).

12.3 Sectoral overview

Table 34 represents the main characteristics of the market structure and economic significance of the energy-intensive industry.

Table 34: Energy-intensive industry market structure and economic significance

	Chemicals, Rubber & Plastics	Iron & Steel	Cement	Aluminium & other non-ferrous metals
Share of EU CO_2 emissions (%)	2.3	2.7	4.6	0.3
Turnover in EU (M€)	537,000	150,000	14,000	139,000
Value added (M€)	241,000	31,085	11,876	17,500
Share of industrial value added (%)	14	1.8	0,6	1.1
EU production (Mt/y in 2005)	436	187	239	8
Share of world production (%)	29	15	11	33
Share of production internationally traded (%)	70	32	6	75
Sector concentration level	Low (80,000 companies)	High (Top 5 for 60% of production)	High (Top 5 for 60% of production)	Very high (Top 3 for 80% of production)
Uniformity of products & processes	Low (+70,000 products)	High	High	High
Employment in EU (thousands of jobs)	3,560	550	56	334
Share of EU industrial employment (%)	10	1.6	1.4	1
Main EU producers	Germany, France, Italy, UK	Germany, Italy, France, Spain, UK	Spain, Italy, Germany, France	Germany, France, Spain, UK

Source: data from multiple sources: mainly Eurostat (2010), CEFIC, CEMBUREAU, EUROFER and EUROMETAUX compiled by the authors.

Chemicals The chemicals industry is a science-based, high technology, very capital intensive and complex industry consisting of five main sub-sectors: Petrochemicals, Inorganics, Polymers, Specialty & Fine Chemicals and Consumer Chemicals. It directly affects the competitiveness of its downstream user industries.

With a turnover of €537 bn (CEFIC), the EU is a leading chemicals producing region in the world (29% of world production). Its output includes more than 70,000 products: fertilizers and biocides, paints and coatings, soaps and detergents, perfumes and cosmetics, explosives, plastics, rubber products etc.

The EU basic chemical production is dominated by a few countries. Germany is on top, followed by France, UK, the Netherlands, Belgium and Ireland. In terms of turnover, the petrochemical industry is the most important subsector. The petrochemical industry produces chemicals using natural hydrocarbons (e.g. fossil fuels) as major raw materials. By cracking the hydrocarbons and transforming them, a wide number of plastics are being produced. With the Middle East expanding in production capacity and Asia being the biggest growing demander of petrochemicals, the EU industry nowadays finds itself in a transformation towards high-end products to remain competitive.

The EU has an important trade surplus in chemicals (€35.3 bn in 2007). It has a surplus with every main trading region. However, the EU's chemicals trade balance evolution shows that the trade performance is deteriorating with certain countries in certain sub-sectors, and especially with India and China with whom the EU currently has a trade deficit for chemicals in general.

Between 1995 and 2007 the global market for chemicals grew by 40%, but the share of the EU chemicals industry fell by 4 percentage points from 33.7% to 29.7%. The US (-3.8 %) and Japan (-7.5 %) also lost considerable market share during the same period, while China's market share rose from 4.3% to 15%.

There are substantial differences between sub-sectors. The EU has recently increased its trade surplus in specialty chemicals with most of its main trading partners, except for advanced chemical producing countries such as US and Japan. The same applies to consumer chemicals and polymers. By contrast, EU trade performance in basic organics (including petrochemicals, fermentation products) is deteriorating. Fertilizers and oleo-chemicals are the sub-sectors where the EU's trade position is weakest.

Poland is the main chemicals producer from the new Member States, accounting for almost 2% of total EU chemicals sales. The chemicals industry in the new Member States is still small in comparison to the old Member States. Moreover, basic chemicals dominate it, with older and less efficient installations in most cases.

The sub-sectors of the chemicals industry that are active in the fields of energy or energy saving (solar panels, insulation, carbon capture) and water purification have very high growth potential. Electronic chemicals and pharmaceuticals have very good growth prospects too.

Feedstock costs (mostly oil, but with renewables taking on an increasing role) and energy costs are major cost drivers for the chemicals industry, especially for the petrochemicals sub-sector. In the past 15 years, EU industry has also achieved remarkable progress in energy efficiency. By 2006, production in the EU15 chemicals industry had risen by 67% since 1990, while total energy consumption has decreased and CO_2 emissions went down by 32%.

Iron and steel Iron and steel is a very energy- and capital-intensive industry. It is one of the main inputs for many industries producing investment goods (mechanical engineering, transport, construction, etc.).

To produce steel, the EU imports raw materials (coal and iron ore), but steel is also recyclable (about 60% of steel in the EU is produced from iron ore and 40% is produced from steel scrap).

With a turnover of approximately €150 bn and a production of 198Mt, the EU27 accounted for 15% of world steel production in 2008 (European Comission Staff 2009) (19% according to IISI). The industry employs around 440,000 people. The EU is the world's second biggest steel producer after China (34% share of world production).

In the last five years, the global steel industry landscape changed, with the rapid emergence of new players on the world market, like Brazil, Russia, India, and China. The global crude steel production has increased by 34%, driven by strong demand in China. In 2006 alone, China's and India's steel production grew by 19 and 13% respectively, adding some 73Mt to global output. Since 2003, Asia has accounted for 82% of the global output growth. China has moved from the first importer of steel in 2003 to the first exporter in 2006 (WSA). Prices reached peak levels before mid-2008 and started to decline in the second half of the year as a consequence of the economic crisis.

The EU steel market is mature and highly competitive as well as technology intensive and highly innovative. Only 30% of the steel products on the market today existed ten years ago.

While iron and semi-finished steel products are considered as homogeneous products, finished steel products differ in their quality level and their use. The sector's production routes are also quite diverse. On the production side, we distinguish the more energy-intensive basic oxygen furnace (BOF) from the electric-arc furnace (EAF), entirely based on recycled steel products (scrap).

The steel industry is a moderately concentrated industry. In 2005, the top 10 producers represented 26.4% of the total world production and the next largest ten accounted for an additional 8%. Furthermore, in some countries steel is dominated by a small number of large producers, for example in Australia and Korea. In others, such as China, it is characterized by a large number of small producers with rather low levels of energy efficiency, although a number of very large efficient plants have emerged in recent years. There are 800 to 900 steel-makers in China, the first 200 of which account for 95% of total capacity. Countries such as Brazil, Mexico, Russia and Ukraine specialized in semi-finished slab production.

32% of the annual production of steel is internationally traded. Global steel trade grew from 100Mt to more than 300Mt between 1975 and 2006. The share of trade in finished steel has been constantly increasing, from 23% of total world production in 1975 to over 42% in 2004 (Baron and Genasci 2007). This development is driven by cost differentials across regions, but has been going on before any CO_2 cost started appearing on companies' accounts as claimed by the EUROFER.

In the EU, the top five companies make 59% of all steel produced. By comparison, ten years ago, the top five companies produced only 37% of total EU output. The share of the new Member States in the total EU27 output is approximately 16%.

Europe, as Japan and the United States, faces higher production costs for bulk steelmaking than other regions, which could eventually drive companies to relocate their upstream production to countries such as Brazil where there is easy access to raw materials and where long-term electricity contracts can be concluded with state-owned generators. Identifying the role of any CO_2 cost in this expected trend will prove difficult (Reinaud 2005). The delocalization started in the 1970s, due to the development of cheaper iron ore and coal production in developing countries, and to low overseas transport cost.

The steel industry is a major industrial emitter of CO_2 in the EU and is subject to the ETS. In assessing the impact of the ETS on the sector's competitiveness, it is necessary to distinguish between the two different processes of steel making: BOF in integrated mills producing from iron ore, and EAF producing from steel scrap. The integrated route emits five times more CO_2 per ton of steel than the EAF route. Most of the emissions in EAF are indirect emissions resulting from electricity consumption. In BOF only 10% of the emissions are indirect (International Energy Agency (IEA) 2008b).

The EU steel market is the most open in the world, and from 2004 all tariffs were fully abolished following the ‘zero for zero’ agreement for steel under the Uruguay Round. As a consequence of the high level of prices in 2006 and 2007, the EU market became and still remains an attractive market for steel-producing third countries. Consequently, the EU moved from the position of net exporter to one of net importer, with 5.3Mt of net imports in 2006, 14.8Mt in 2007 and 5.3Mt in 2008. Therefore the main external challenges are trade distorting measures applied by third countries. The difficulty of access to third markets is due to tariff and non-tariff barriers, and protectionist legislation (for example, export duties for scrap from Russia and Ukraine, and for coke from China). Most recently, anti-dumping investigations have been launched for tubes, galvanized sheets and stainless steel flat products (European Comission Staff 2010).

Cement The cement industry produces a relatively homogenous product, based on a limited set of processes. It is capital intensive with the cost of laying down a cement production plant equivalent to around 3 years’ turnover. Demand for cement is cyclical, depending entirely on building and civil engineering requirements. The production process is a highly energy intensive one, with energy costs generally considered to be between 30% and 40% of total costs. Kilns which produce clinker, the intermediate product in cement manufacture, represent a very high, long term investment which makes it difficult to respond to short term fluctuations in demand or comply with new legislation affecting energy or emissions.

The global production of cement (2,284Mt/y in 2005) is dominated by China (46.6%), Europe being the second largest producer. The large producer countries in Europe are Spain (2.1%), Italy (1.7%), Germany (1.4%), and France (0.9%).

The EU cement sector is made up of 149 companies but is highly concentrated, the five largest companies holding about 60% of the EU market share. Most of the companies are vertically integrated upstream as they quarry their own raw material and process it up to the final product, as well as downstream into concrete. There is no over-capacity in the cement sector in Europe.

International trade in the cement sector is low (6%). Where European cement producers have identified demand for cement in non-EU countries, they have generally invested in manufacturing sites in those countries. This happened in the 1970s and then again in the mid 1980s, when production facilities were acquired in North America. These moves were followed by acquisitions in Latin America in the late 1980s, followed by a third wave of acquisitions from 1989 in central and eastern European markets. As such, EU companies now own almost 60% of US production capacity, and have significant production facilities in the rest of the world. As an illustration, in 2007, only 3% of the EU production was exported outside the EU whilst non-EU27 imports supplied 7% of consumption (mainly from China, Thailand, and the Philippines).

Production technologies have high environmental performance, as the industry has reached a level of performance, which in many cases cannot be improved upon with current technologies, and therefore further major improvements at the production stage are unlikely in the short term.

The cement industry is one of the big industrial CO_2 emitters worldwide and contributes 5% to total emissions. The sector has every incentive to reduce energy consumption. Besides CO_2 emissions, the cement industry's main emissions are NO_x, SO_2 and dust. Dust abatement has been widely applied for many years and SO_2 is a plant specific issue, but the abatement of NO_x is a relatively new issue for the industry. Some plants have installed general primary measures to improve clinker quality, thus reducing energy consumption and emissions to air.

The industry can also increase the use of wastes as alternative raw materials and fuels and further develop new products for energy-efficient

Aluminium & other non-ferrous metals The non-ferrous metals industries are characterized by high capital intensity and low flexibility due to high establishment and closure costs, high energy intensity (as much as 37% in the case of primary aluminium) and medium/low labour intensity. The sector is highly dependent on demand from its main consumer sectors, such as construction, mechanical engineering, aviation or the automotive sector. The most influential factors in the investment decisions of metal producers are access to raw materials and energy at competitive prices, plus proximity to end-users.

The EU non-ferrous metals industry accounts for one fifth of the world's refined metal production and at least one third of the world's output of semi-manufactured products.

The non-ferrous metals sector accounts for 2% of the EU industry revenue (€139.04 bn), 1.37% of EU manufacturing value added (€23.4 bn) and 1.0% of employment (334,700 people: 217,700 employed by the 3,590 enterprises in the basic precious and non-ferrous metals manufacturing sector and 117,000 employed by the 4,056 enterprises in the casting sector for light metals and other non ferrous metals, European Comission Staff 2009).

The largest producer country in Europe is Germany, which leads the field in primary aluminium and copper, lead, and cadmium production. France, Spain and the UK are also big producers of aluminium. Other copper producing countries apart from Germany are Poland, Belgium and Spain. Italy is a big producer of aluminium and copper. The biggest producer of zinc is Spain, followed by Finland and Germany. For nickel the biggest producer is Finland, followed by the UK and Greece, and Belgium for tin.

Europe is the biggest consumer of non-ferrous metals worldwide and has a large non-ferrous metals refining capacity for processing ores and concentrates, as well as for melting recycled metals (scrap). The EU has become the main net importer of refined non-ferrous metals in the world, and its dependence on imported metals has grown in recent decades. In 2006 the EU27 had a trade deficit of €25.9 bn in basic precious metals and other non-ferrous metals. The main exporters of basic precious and non-ferrous metals to the EU were Russia (14.8%), Chile (12.4%) and Norway (10.4%).

In the whole area of manufacturing of basic precious and non-ferrous metals in the EU27, aluminium represented the largest activity, with €9.1 bn of value added in 2006, ahead of copper and zinc. The production volume of the non-ferrous metal industries has been growing slightly during the past 10 years (1998-2007) but, overall, the EU is losing its share on the world market, and its dependence on imported raw material for metal production and metals is growing rapidly.

Aluminium is heavily traded, reflecting the fact that capacity investment is driven by electricity costs, but also that, as a material with rather high value per ton, transport costs weigh little in the final price. As a result, proximity to markets is not the overriding factor that it is for materials like cement.

The global growth of aluminium output has been driven by China, with a reported growth of 42% between 2004 and 2006. In 2007, China accounted for 40% of the global production, Russia ranking second, with 12% (International Aluminium Institute (IAI)).

The EU aluminium sector is the most integrated, being dominated by three multinational companies. The technologies used being mature, there is no expectation of a breakthrough technology to reduce energy consumption and CO_2 emissions in the next 2-3 decades.

The aluminium industry sees large opportunities in the further use of aluminium and aluminium alloys in the automotive industry. For the copper sector, 65% of its annual European demand is currently used in the generation, distribution and use of electricity. This area has the biggest potential for the promotion of renewable energy use by wind turbines and in vehicle technology.

Aluminium's electricity intensity is by far the highest, raising concern about the sector's indirect CO_2 emissions whenever power is generated from fossil fuels. The aluminium industry has been actively pursuing new forms of power contracts in order to access electricity supply at prices below spot prices (Reinaud 2008).

12.4 Carbon leakages

Chemicals The European Chemical Industry Council (CEFIC), the umbrella organization for the national chemical federations and chemical companies in Europe, stresses that emissions trading or taxes constrain their competitiveness and their ability to grow as the European chemicals companies act on a global market and there are high risks of carbon leakage. However, evidence of outsourcing and off-shoring is difficult to find in the chemicals industry. Its vertically integrated nature and very high capital intensity make the outsourcing and off-shoring of parts of the production process difficult. As a result, short-term relocation of production facilities is not a common phenomenon. As more and more user industries are emerging in Asia, the chemicals industry is increasingly installing production capacities in this region.

Moreover, studies such as (de Bruyn et al. 2010) show evidence that the costs of the freely obtained allowances under the ETS by the chemicals industry have been passed through in the product prices. This is most convincing for polyethylene and polyvinylchloride, suggesting a 100% cost-pass-through for these products. For the more CO_2 intensive production of polystyrene, the costs are only passed through for about 1/3.

Iron and steel The European Confederation of Iron and Steel Industries (EUROFER) claims there is no scope for the iron and steel sector to cover the cost of auctioned emission rights under the ETS.

However, studies assessing the competitiveness impact and the environmental effectiveness of the ETS in the iron and steel industry (on competitiveness of production and profitability) show evidence that EU iron and steel industries were able to pass through the costs of the European Union Allowances into the product prices, up to 100% (Demailly and Quirion 2008). As these allowances were obtained at no cost, these studies suggest that the iron and steel sector has made substantial windfall profits during Phase I and II of the ETS.

In addition, some evidence of carbon leakage seems to be found within the iron and steel sector where the most polluting production processes seem to have been passed through to Russia and Ukraine. This was rational from a cost perspective as EU manufacturers were facing shortage in capacities, but it may have been adding to the windfall profits that were being made in the iron and steel sector, resulting in the over-allocation in the iron and steel sector (de Bruyn et al. 2010).

Cement Investments in the EU cement industry have fallen away much, but this is not obviously correlated with the EU environmental regulation, ETS and REACH. The local nature of the cement sector enables producers to pass cost increases on to consumers, thereby offsetting in part or totally the cost effect of the carbon constraint. However, the EU cement industry is in competition, especially around the periphery of the EU, with other countries, which do not conform to European quality standards, energy use, environmental monitoring or working conditions.

Cement producers point to striking differences in levels of allowance allocation under the ETS for plants that share similar efficiency characteristics (Vanderborght 2006) but available data fail to confirm this.

Moreover, as for the iron and steel sector, it seems that the cement producers have made windfall profits under the ETS. For example, Lafarge, in its 2009 annual report (Lafarge 2009, page 58) states that the company made €142 mn from the sale of carbon credits in 2009 and that in 2010 the freely allocated permits will also “exceed our needs” (Lafarge 2009, page F29).

Aluminium & other non-ferrous metals Under the revised ETS, the non-ferrous metals sector will from 2013 be covered by the ETS. However, the aluminium industry is working with the European Commission to remain outside the ETS, on the basis of the diffusion of best practice and the use of best available technologies for greenfield projects. If successful, it would be a first example of so-called global agreement combining a quantitative target (based on emissions intensity) and technology elements (the adoption of best available technology for new projects).

The IEA/OECD study on the impact of the ETS on the aluminium industry (Reinaud 2008) shows that the European primary aluminium on average has not suffered from carbon leakage during Phase I of the ETS. This seems to be a consequence of the prevalence of long-term electricity contracts and of a high cycle for demand of aluminium, which should alleviate concomitant increases in cost, including those related to CO_2.

However, as some EU based smelters have suffered from increases in electricity prices following the end of their long term contracts, it is yet unclear how quickly such a phenomenon will develop and lead to an additional increase in aluminium imports, from what would have happened in the absence of the ETS. The region is obviously less attractive for new capacity than regions that guarantee lower energy costs.

The carbon constraint is, nonetheless, only one element in this European picture, as higher electricity prices prevailed before the introduction of the ETS (with the exception of China and India).

12.5 Over-estimation of adaptation cost to regulation

There is a growing awareness that complying with environmental regulations is often much less expensive than claimed by businesses. The number of retrospective studies on the cost of environmental regulations is growing, and many early estimates of the cost of complying with particular regulations can now be compared with actual costs (Hodges 1997; Ackerman 2006).

It is not clear to what extent businesses overstate their expected costs for strategic reasons, or to what extent they fail to anticipate process and product technology changes when making early estimates. It is clear, however, that input substitution, innovation, and the flexibility of capital have allowed actual costs to be consistently much lower than early predictions. The pattern of overestimating the cost of complying with specific regulations is striking. Studies show that environmental regulations are not as restrictive or burdensome as businesses often claim, and they suggest that analyses of regulations, such as cost-benefit analyses, should be conducted with care. In particular, any analysis of environmental policy decisions should be conducted with the understanding that ex-ante estimates are often several orders of magnitude too high. Table 35 shows as an example given by Hodges (1997) the overestimation of the cost of control as a ratio between ex-post and ex-ante cost estimations for the compliance with new regulation for a number of pollutants.

12.6 Sectoral impacts on employment

Changes in international competitiveness caused by EU climate policies can lead to a loss of jobs in energy-intensive sectors or to carbon leakages through relocation of jobs to non-EU countries with relatively lower environmental standards. However, from the study of the four energy intensive industries above, it seems that the most important aspect in terms of employment is the skilled European labor force.

The EU chemicals (including rubber and plastics) industries employ a workforce of above 3 million (data for 2007; European Comission Staff 2009). The employment in the sector has

Table 35: Overestimation of the cost of compliance with new regulation

	McKinsey ($10/tCO$_2$)			Reinaud/IEA ($10/tCO$_2$)		
Industry	Cost increase (%)	Net of free allowances (%)	Net of allowances and cost pass-through[*] (%)	Cost increase (%)	Net of free allowances (%)	Demand reduction[†] (%)
BOF Steel	6.2	1.0	0.6 (6%)	5.89	0.63	0.79 (-1.56)
EAF Steel	1.0	0.9	0.2 (66%)	1.65	0.63	0.36 (-1.56)
Cement	13.1	1.4	-0.6 – 1.4 (0% – 15%)	14.47	1.77	0.29 (-0.27)
Primary Aluminum	4.1	4.1	4.1 (0%)	2.7[‡]	2.7[‡]	2.09[‡] (-0.86)
Secondary Aluminium	0.2	0.2	0.2 (0%)			
Newsprint				3.62	0.95	1.44 (-1.88)
Chemical Pulp	0.4	0.2	0.0 (50%)			
Paper from Chemical Pulp	0.8	0.4	0.3 – 0.4 (0% – 20%)			
Chemical Pulp/Paper	0.9	0.4	0.2 – 0.4 (0% – 20%)			
Mechanical Pulp/Paper	2.0	1.5	1.1 – 1.5 (0% – 20%)			
Thermo-Mechanical Pulp/Paper	2.7	2.2	1.7 – 2.2 (0% – 20%)			
Recovered Pulp/Paper	1.2	0.7	0.4 – 0.7 (0% – 20%)			
Average Process Petroleum Refining	7.4	0.9	-4.5 – -0.9 (25% – 75%)			

[*] *Note: Estimated industry-level cost pass-through rates from the McKinsey study are shown in parentheses.* [†] *Expected % reduction in demand assuming full pass-through of net costs (including free allocation). Assumed demand elasticites are shown in parentheses.* [‡] *Denotes figures for aggregate aluminum industry (primary and secondary)*

Source: Hodges (1997).

fallen by 2.1% p.a. over the last decade. Operating chemical plants and processes requires a highly skilled and educated workforce. Chemical companies in Europe start having problems in finding new, skilled and well-trained employees.

The EU iron and steel industries employ 550,000 people (data for 2007; European Comission Staff 2009). Skills of the European labor force are among the current competitive advantages of this sector in relation to its competitors. There is a need to develop new competencies and continuous training, particularly in the areas of new engineering fields and managerial skills. There will also be a demographic problem in the future, as many people working in the steel sector will be retiring in the next ten years. The same applies to the situation in science and technical universities related to the sector, which may affect the innovation capacity of the EU iron and steel industries.

The EU cement industry is a low labor intensity industry, which employs 56,000 people. The employment in the sector has decreased steadily in recent years. Health and safety at work is the main concern for workers, the average life expectancy of a cement worker being about 62 years.

The EU aluminium and other non-ferrous metals industries employ 334,000 people. The employment remained stable till 2006, whereas productivity increased (data for 2007; European Comission Staff 2009). While one of the industry's major strengths is a skilled and available workforce, it is nevertheless faced with a problem of an ageing workforce and the need to attract new skilled employees.

As a conclusion, the EU should focus on maintaining a skilled European labor force and use climate policies as an opportunity to transform and/or upskill certain jobs and to create many new jobs, such as additional insulation fitters for retrofitting homes or jobs for producing renewables.

12.7 Conclusions

Energy intensive industries face different degrees of competition pressure according to their presence on the international market. Some commodities are mainly traded on a regional scale due to difficulties in shipping them. This implies a low sensitivity to competitive pressure from other actors in the same sector. The more industries operate in the global rather than regional market, and the more their products are traded at the international level, the more they are exposed to competition.

Although these industries have made considerable contributions to energy and resource efficiency, they still hold significant potentials towards higher resource productivity (Schonsleben et al. 2010).

As we have shown in the analysis of four of the energy intensive industries above, fear of carbon leakage should not be exaggerated. Arguments against tightening the environmental stringency of the ETS are not justified on grounds of the loss of competitiveness. Regardless of which sector actually did pass through the costs, the conclusion of this research is that substantial windfall profits have been made by energy intensive companies that obtained allowances for free, but calculated their market value in the prices of the products (Demailly and Quirion 2008).

This conclusion is also in line with the report published by the OECD in August 2009 (OECD 2009) arguing that industry must play its part in the reduction of emissions and that "exempting energy intensive industries from carbon pricing, for example, could raise the cost – by 50% in 2050 – of stabilizing concentrations at 550 ppm CO_2e." The OECD's Secretary-General Angel Gurría made clear in a recent speech (OECD 2010) that this was still the OECD's opinion. He said that "one of the main obstacles to make progress in addressing these and other crucial climate challenges relates to concerns around the possible impact of policy commitments on competitiveness" and that the ETS's ambitions "have been somewhat undermined by competitiveness concerns".

In this context it is remarkable that the green growth strategy, that the OECD strongly endorses, has been first formulated as an official policy in South Korea, a country well-known for its energy intensive industries.

In Europe, the pressure from energy intensive industries afraid by a transition to green growth remains high. In a letter addressed to EU Climate Action Commissioner and signed by EURELECTRIC President and Vice-President, the European Electricity Industry expressed "strong concerns over some of the issues surrounding a move from the EU to a - 30% GHG reduction by 2020" stating that "given the current economic situation and the fiscal constraints likely to flow from it, this would pose an unacceptable additional burden on all electricity customers" (EURELECTRIC 2010).

In a communication in May 2010, the European Alliance of Energy Intensive Industries states:

> It is unacceptable to suggest manipulating carbon markets by withholding allowances from the market in order to reach environmental objectives in isolation from the rest of the world. This would further destabilize industrial operators' prospects under the EU emissions trading system: cancelling allowances in order to reach even more ambitious targets restricts EU companies' ability to purchase emission rights, and causes increases of direct costs and electricity prices, further endangering industries' ability to operate in Europe. Such policies run against the EU Lisbon Agenda and the EU 2020 Strategy. Moreover, industry still awaits the regulatory proposal for compensation for the CO_2 costs in electricity prices; these indirect cost impacts must also be integrated when assessing the risk of carbon leakage. (EAEII 2010).

However, when it comes to green growth, not all news from industries is tainted in such black colour. The Joint Business Declaration of the Climate Group[16] is favorable to M30:

> Business welcomes the strong public endorsement given to the 30% greenhouse gas reduction target by Denmark, France, Germany and the UK. Moving to a 30% emissions reduction target is a win–win for Europe. As well as the numerous economic and social benefits of cutting greenhouse gas emissions, it will spur innovation and investment thus creating millions of new jobs in a low carbon economy, with the global low carbon goods and services sector estimated to be worth over €3.4 tn and growing rapidly. (Climate Group 2010).

We should note that none of the intensive energy industries' companies joined the declaration.

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[16] Businesses which have explicitly supported this Declaration: Acciona, Alstom, Asda, Atkins, Barilla, BNP Paribas, BSkyB, Capgemini, Centrica, Climate Change Capital, Crédit Agricole, DHV Group, Elopak, Eneco, F&C Asset Management, GE Energy, Johnson Controls Inc, Kingfisher, Google, Marks and Spencer, Nike, Philips Lighting, SKAI Group of Companies, Sony Europe, Standard Life, Swiss Re, Tryg, Thames Water and Vodafone.

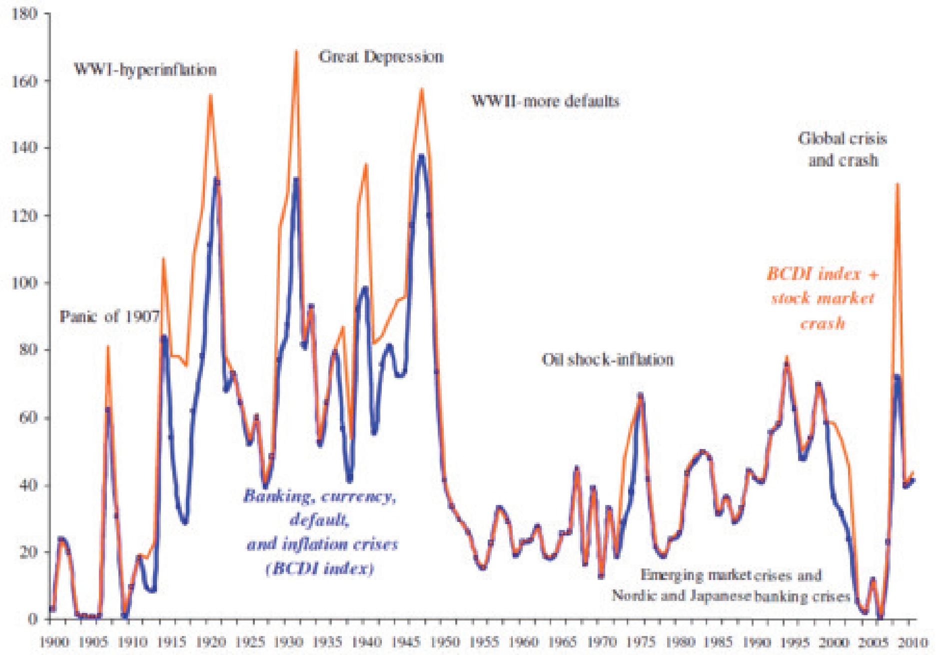
13

Historical context

The final section of this report offers a sketch of the historical context in which a green growth strategy can be seen as an opportunity for Europe to meet the twin challenges of climate change and poor economic prospects from business as usual.

According to Reinhart and Reinhart (2010), large destabilising economic events such as the last financial crisis produce consequences that usually span over a decade after they materialise. Based on the analysis of 15 severe post-war economic crises worldwide since the Great Depression, they find a general pattern of fall in GDP growth, increase in unemployment rates, and a drop in house prices during the decades after the crises, illustrated in Figure 31. Unemployment affects most severely the more advanced economies. In 10 of these 15 events, unemployment never returned to the pre-crisis level in the decade after the crisis. An additional limitation of the EU to cope with global crises, and a source of economic instability itself, comes from the relative lack of integration between fiscal and monetary policies, an issue that is increasingly being tackled by recent political developments.

Figure 31: Varieties of crises: World aggregate, 1900-June 2010, composite index

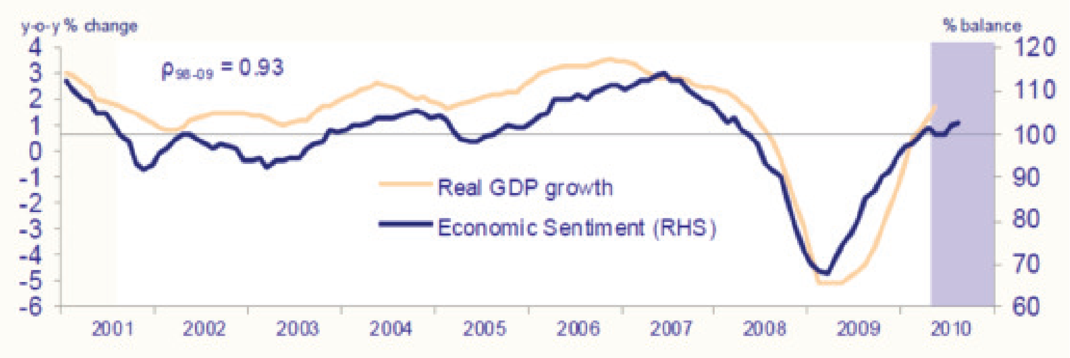


*The banking, currency, default (domestic and external) and inflation (**BCDI**) index takes values between 0 and 5 (for any country in any given year) depending on the varieties of crises taking place. This index is calculated annually for the 66 countries in the sample for 1800-2010:6, and weighted by the country's share in world income*
Source: Reinhart and Reinhart (2010).

Reinhart and Reinhart (2010) argue that such a situation partly reflects a correction of expectations, which move from a situation of lending euphoria before the crisis to the collapse of financial intermediation. In these situations, they see it necessary to provide the appropriate financial stimulus both to supply and demand (not only the latter) to avoid that the changed expectations develop into a (crisis-amplifying) self-fulfilling prophecy.

However, it is possible that in the last economic crisis the correction of expectations has occurred earlier than in other episodes, as shown in Figure 32, which portrays the evolution of the Economic Sentiment Indicator in the EU during the last decade.

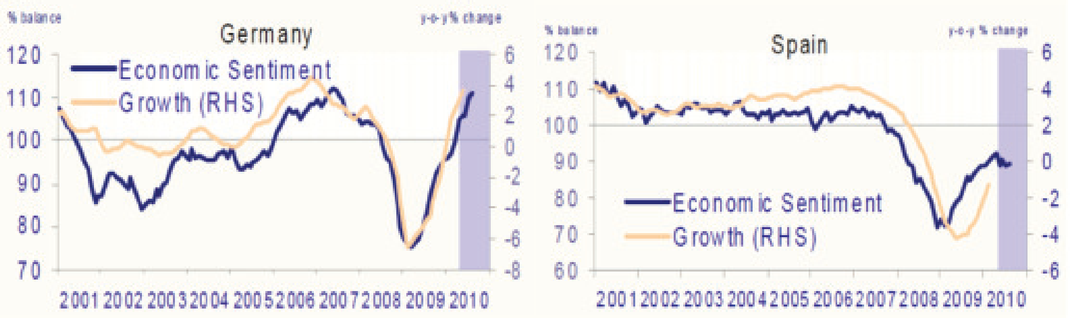
Figure 32: Economic sentiment indicator and GDP evolution in the EU



Source: European Commission (EC) - Economic and Financial Affairs (2010b).

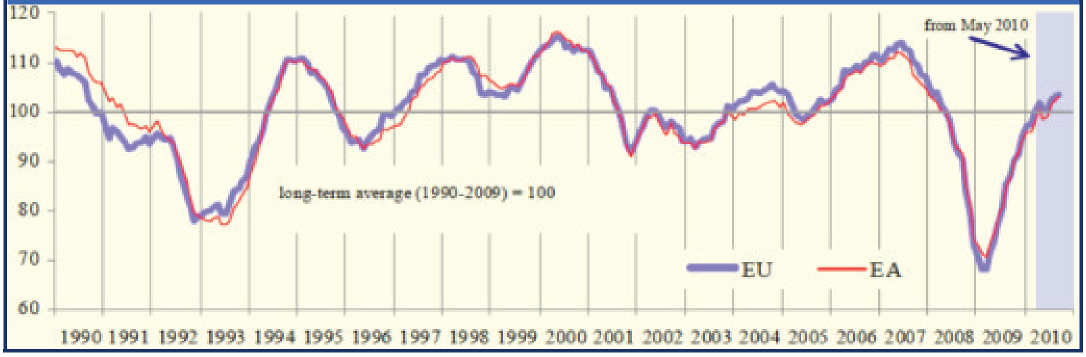
Within the EU there are strong regional differences, both for the Economic Sentiment Indicator and for GDP growth, as the comparison between these data for Germany and Spain shows (Figure 33). These differences also reflect different patterns of economic structure and employment rates.

Figure 33: Economic sentiment indicator and GDP evolution in Germany & Spain



Source: European Commission (EC) - Economic and Financial Affairs (2010b).

Figure 34: Longer time perspective of the economic sentiment indicator

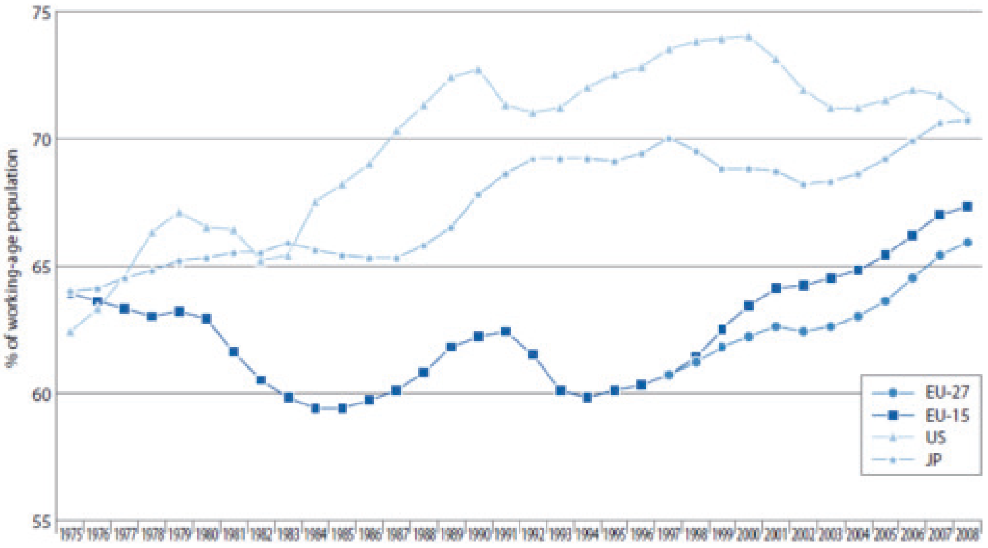


Source: European Commission (EC) - Economic and Financial Affairs (2010a).

A longer time perspective of the evolution of the economic sentiment indicator shows how economic expectations are subject to a cyclical behaviour in the EU and in the Euro Area (EA), see Figure 34.

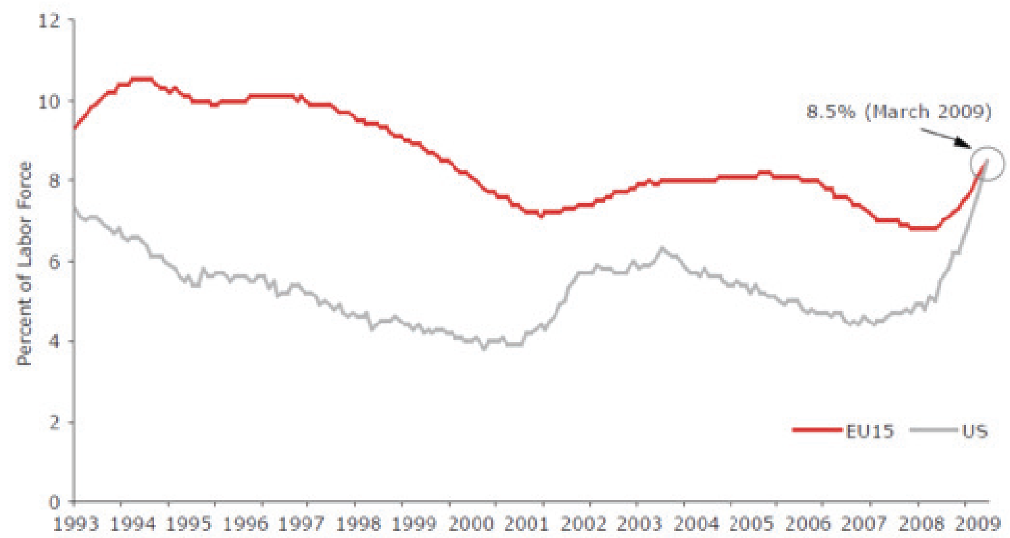
Economic globalisation may also be producing a certain convergence in the evolution of key macroeconomic indicators in some of the major economies, as reflected in Figure 35 and Figure 36.

Figure 35: Employment rates in the EU, USA and Japan, 1975-2008



Source: Eurostat (2009).

Figure 36: Unemployment rate in the US and EU15, 1993-2009



Source: Schmitt, Rho and Fremstad (2009).

Regarding climate, the double effect of the economic crisis and the implementation of the climate policies package resulted in EU levels of GHG which were lower than a decade ago (Table 36, Figures 37 and 38).

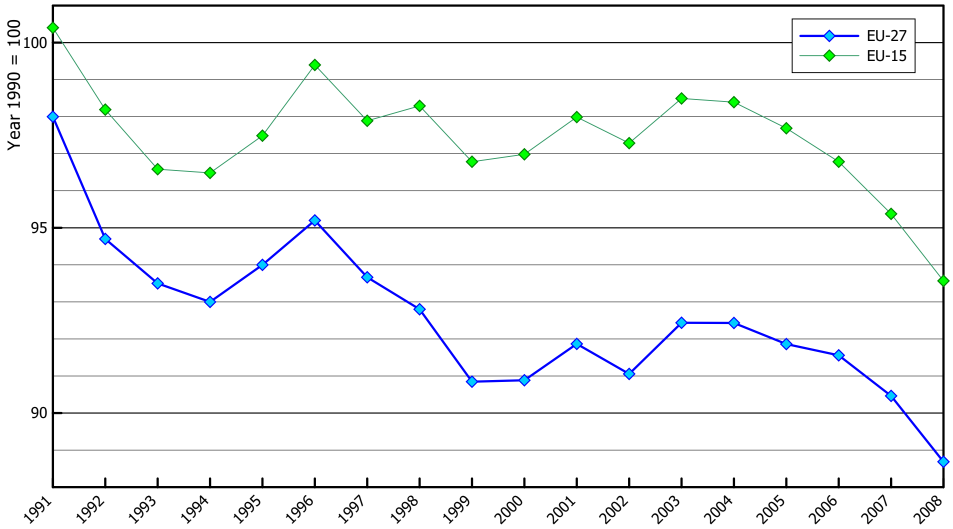
Table 36: GHG emissions (in thousend tons CO$_2$e-equivalent) in Europe

	1998	1999	2000	2001	2002	2003
EU27 countries	5.169.055	5.060.167	5.062.303	5.116.970	5.071.816	5.148.740
Mt & Index	(92,9)	(90,9)	(90,9)	(91,9)	(91,1)	(92,5)
EU15 countries	4.171.400	4.106.413	4.114.482	4.158.862	4.130.878	4.178.162
Mt & Index	(98,3)	(96,7)	(96,9)	(98)	(97,3)	(98,4)
	2004	2005	2006	2007	2008	
EU27 countries	5.148.450	5.116.735	5.099.814	5.038.775	4.939.738	
Mt & Index	(92,5)	(91,9)	(91,6)	(90,5)	(88,7)	
EU15 countries	4.174.104	4.144.796	4.108.170	4.046.189	3.970.473	
Mt& Index	(98,3)	(97,6)	(96,8)	(95,3)	(93,5)	

Source: Eurostat (2010) [ENV_AIR_IND].

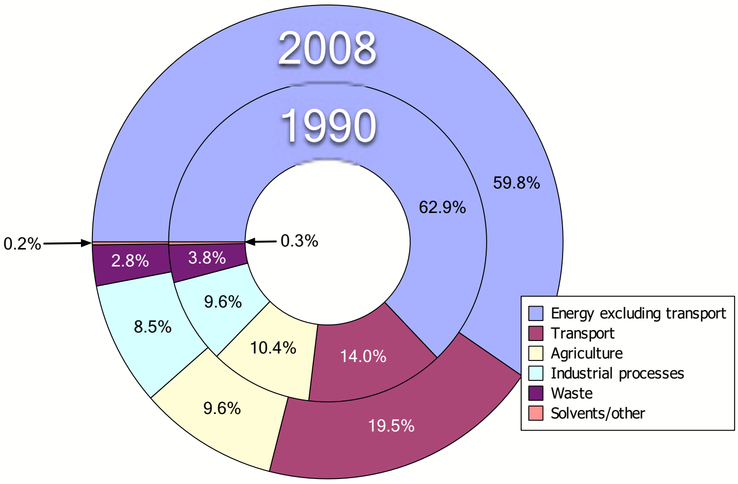
In the EU27, total GHG emissions without Land Use, Land Use Change and Forestry (LULUCF) decreased by 11.5% between 1990 and 2008 (627 Mt of CO$_2$e). The reduction of emissions was larger in the EU27 (11.3%) than in the EU15 (6.5%). The most substantial reductions by EU27 states during this period were accounted for in public electricity and heat production, energy use in manufacturing industries and households, as well as agriculture.

Figure 37: Greenhouse gas emissions, EU27, 1990-2008



Source: Eurostat (2010) [ENV_AIR_IND].

Figure 38: Greenhouse gas emissions by source sector, EU27



Based on data in Mt CO_2 equivalent
Source: Eurostat (2010) [ENV_AIR_IND].

Within the EU27, there were also marked differences in the evolution of GHG emissions, as shown by two important contributors to GHG emissions such as Spain and Poland which account for about 8% of the total EU27 GHG emissions. These countries constitute the fifth and sixth largest emitters in the EU27; Spain increased its emissions by 42% between 1990 and 2008, Poland decreased its GHG emissions by 12.7%. The main reasons for the increase in Spain were emissions coming from transport, electricity and heat production as well as from manufacturing industries. In Poland, the main sources of reduction, similar to other New Member States, were the decline of energy inefficient heavy industries and the restructuring of the economies in the eighties and nineties. A sharp decrease in EU emissions in the period of 2007-2008 came from Germany (19 Mt) and Spain (17 Mt) achieved in the first place by the reduction of electricity by conventional power plants and, in the case of Spain, by a decline in the use of coal for power generation. An additional difference during this last period of 2007-2008 was that emissions from road transport slightly decreased in the EU15 (by 2.9%) while transport emissions increased in the New Member States (European Environment Agency (EEA) 2010a).

In this respect, it is worth mentioning that while the crisis has somewhat reduced the importance given by European public to the urgency of climate change compared to the crisis, more than six out of ten Europeans (62%) think that fighting climate change can have a positive impact on the European economy, and this view has increased from previous records in this regard (Eurobarometer 2009).

13.1 The international context. Stimuli, venture capital and private equity for green growth investments.

Many of the expectations placed in the Copenhagen summit in December 2009 were not met, and its effects can be interpreted in several ways. On the one hand, it made evident some of the weaknesses and limitations of current international climate politics and architecture that failed to deliver efficient responses for limiting global GHG emissions in time to avoid catastrophic outcomes. Thus, a need to reform and strengthen the current climate regime was seen. On the other hand, it also made it clear that alternative approaches to dealing with climate change are required, and, in particular, approaches that involve an increasing participation of private investors as part of a new global trend towards green growth.

The Copenhagen Accord was reached by a group of 29 Heads of State and Governments. It reinforced the EU commitment to contribute to the objective of limiting global warming below 2^{o}C above the preindustrial levels (and considering the long-term goal of a 1.5^{o}C rise). In contrast to the EU aspirations, the Accord was not a legally binding agreement (as stated by European Commission (EC) 2010d), although this is the ultimate EU policy purpose. The EU reiterated its conditional offer to move toward a 30% reduction of GHG emissions by 2020 compared to the 1990 levels, provided that other developed countries reach similar commitments and that developing countries contribute accordingly taking into account their responsibilities and their respective capabilities. At present, 138 countries, including the EU27 are likely to or have engaged with the Accord thus representing the 86.76% of the global emissions[17]. However, even at the higher level of the pledges, estimated for the developed countries to be at 17.8%, projected reductions fall short of the 25-40% (or more) reductions that are required to meet the 2^{o} target – a goal which is further complicated if developed

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[17] Data from World Resource Institute, cited in:
http://www.usclimatenetwork.org/policy/copenhagen-accord-commitments

countries bank their unused emissions or Assigned Amount Units for the next commitment period after Kyoto. Despite this complex political and environmental context, it is hoped that a legally binding agreement will emerge in the South African negotiations of COP17 in 2011.

To a large extent, the success of such a binding agreement will depend on the possibility of demonstrating the suitability of implementing innovative policy mechanisms to support the financing of both mitigation and adaptation policies, and, in particular, the investment and support for international transfer of low carbon technologies at a large scale. In this regard, the Institutional Investors Group on Climate Change (IIGCC), which comprises some of the largest pension funds in the EU and the US (representing $15,000 bn in assets), recently issued a statement alerting of the need of taking immediate action to prevent the risk of global economic disruptions worse than those caused by the recent financial crisis. While investment in low-carbon technologies is increasing especially in Asia, and is expected to be globally a bit more than $200 bn in 2010, it is still far below the estimated $500 bn annually that are necessary in order to limit temperature rise above the 2^oC level. Among the measures which are called for by the IIGCC are the development of a climate finance architecture which facilitates the role for private investments, the expansion and deepening of the international carbon market, the support of energy efficiency and carbon markets in developing countries, and several domestic policy measures that include the phasing out of fossil-fuel subsidies as agreed by the G-20 leaders in 2009[18].

Thus, the rapid growth in the development of more energy and carbon efficient technologies can be framed as part of a broader international strategy to gain market competitiveness by boosting new forms of green growth. In this respect, stimuli to support green growth investments are playing an increasingly important role worldwide. In this new international context, and according to the United Nations, the amount of green growth stimuli commitments have increased as never before, and governments in 2009 began to spend an estimated $187.6 bn in such commitments (United Nations Environment Programme (UNEP) and New Energy Finance 2010, data from Bloomberg NEF), a process that will last for some years to have it fully materialised. However in the EU, and compared with the rest of other nations, these commitments are still rather low (Figure 39 and Figure 40).

Of particular relevance is the case of the Asia-Oceania region, as in 2009, China surpassed the US as the country with the highest investment in clean energy, and Brazil came second in venture capital and private equity investment just after the US:

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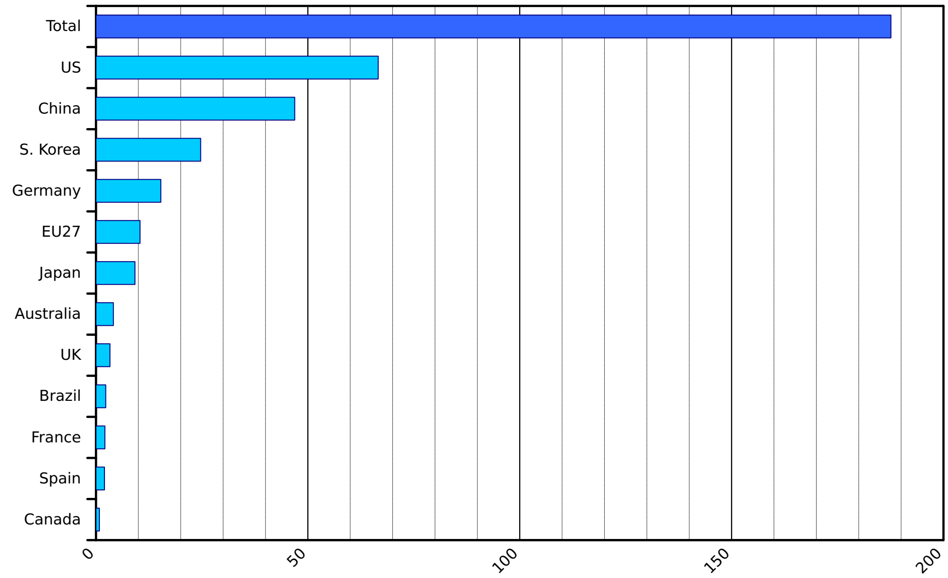
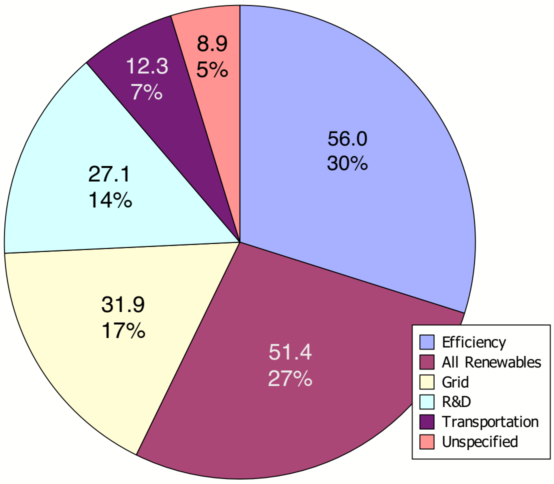
[18] The IICCC underlines the urgent need to move towards low-carbon and resource-efficient economies and the role of policies in creating an atmosphere that builds confidence in these sectors: According to the Chairman of IIGCC "experiences from a number of countries around the world show how structured policies can bolster investor confidence, help ramp up renewable energy investments, bring technologies down the cost curve and thereby eventually strengthen their competitiveness"; http://www.iigcc.org/__data/assets/pdf_file/0016/15154/2010-Global-Investor-Statement-Press-Release.pdf; retrieved on the 18^{th} Nov 2010.

Figure 39: Green growth stimuli commitments, selected nations, in $ bn



Source: United Nations Environment Programme (UNEP) and New Energy Finance (2010).

Figure 40: Global green growth stimuli, by sectors



Source: United Nations Environment Programme (UNEP) and New Energy Finance (2010).

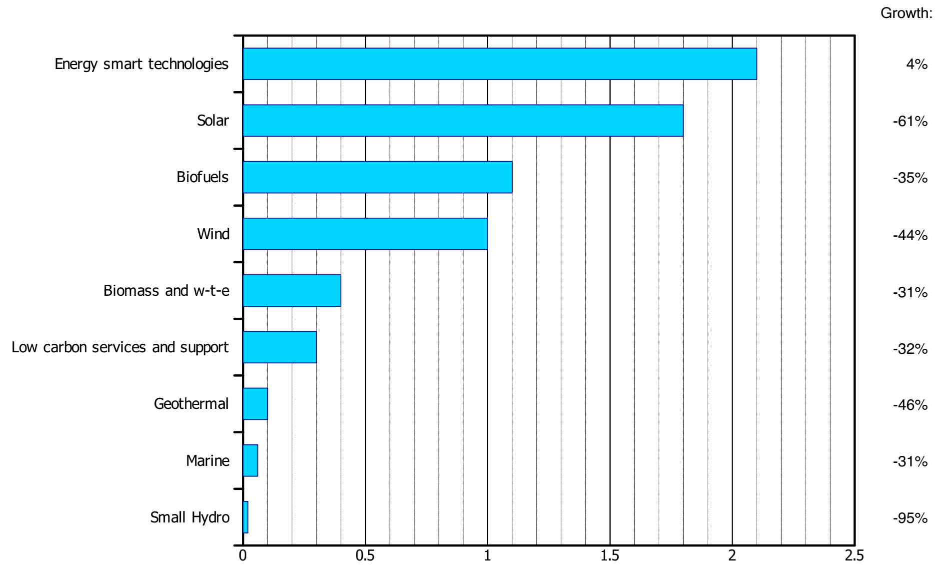
the main reason for Asia-Oceania's investment growth was China, where an expansionary economic policy spurred bank lending and government measures encouraged the development of large renewable energy projects, such as wind "mega-bases". There was official backing for the building of wind and solar generating capacity as a way of bolstering the domestic manufacturing industry, as well as adding to energy security and

> the availability of power (United Nations Environment Programme (UNEP) and New Energy Finance 2010, p. 19).

The crisis negatively affected the recent growing trends in venture capital (VC) and private equity (PE) in clean technologies. At the same time it distributed some of these funds differently between the various green growth sectors. In 2009

> energy-smart technologies for the first time attracted more VC/PE investment than any other sector. This reflects a focus on energy efficiency by governments disbursing stimulus money, and also a surge in support for electric vehicles (United Nations Environment Programme (UNEP) and New Energy Finance 2010, p. 27).

Figure 41: Venture capital /private equity, by sector worldwide, in $ bn 2004-2009



Source: United Nations Environment Programme (UNEP) and New Energy Finance (2010).

Nevertheless, and if we look at the international context, the amount of subsidies given to green growth are far behind compared to those received by fossils fuels. According to the latest report from the International Energy Agency, in 2009 fossils fuels received a total of $312 bn (International Energy Agency (IEA) 2010a), although some estimations increase this figure to $550 bn in 2010 (Global Studies Initiatives, cf, in United Nations Environment Programme (UNEP) and New Energy Finance 2010). The vast majority of these subsidies was used in non-OECD countries and is concentrated in strong oil and gas producers, so it is unlikely that those subsidies will move easily to renewable energy investments. Against this backdrop, Europe has the opportunity to redefine its comparative advantages in the global economy by taking full advantage of a green growth strategy, including a redefinition of climate policy targets that fits this strategy.

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