Stockholm Environment Institute

Europe's Share of the Climate Challenge

Domestic Actions and International Obligations to Protect the Planet

Charles Heaps, Peter Erickson, Sivan Kartha, Eric Kemp-Benedict

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20
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CONTENTS

LIST OF TABLES AND FIGURES

ABBREVIATIONS

CAES	Compressed Air Energy Storage
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CH_4	Methane
CSP	Concentrating Solar Power
DSM	Demand Side Management
EEA	European Environment Agency
EC	European Commission
EU	European Union
FoEE	Friends of the Earth Europe
PJ	Petajoules
GDP	Gross Domestic Product
GDRs	Greenhouse Development Rights
GHG	Greenhouse Gas
GW	Gigawatt
GWP	Global Warming Potential
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LEAP	Long range Energy Alternatives Planning System
LULUCF	Land Use, Land Use Change and Forestry
MDGs	Millennium Development Goals
MENA	Middle East and North Africa
$MtCO_2e$	Million Metric Tonnes CO_2 equivalent
MSW	Municipal Solid Waste
MW	Megawatt
NAI	Non-Annex 1 Countries
N_2O	Nitrous Oxide
NGCC	Natural Gas Combined Cycle
NPV	Net Present Value
PPP	Purchasing Power Parity
PV	Solar Photovoltaic
RCI	Responsibility and Capacity Index
SEI	Stockholm Environment Institute
TWh	Terawatt-hours
UNFCCC	United Nations Framework Convention on Climate Change

CONVERSION FACTORS

ENERGY

1 GJ = 1E9 J
1 PJ = 1E15J = 1E6 GJ
1 GWh = 3.6E3 GJ
1 TWh = 3.6E6 GJ
1 TOE = 41.868 GJ (TOE=Tonne of Oil Equivalent)

CARBON/CO_2

1 tCe = 3.667 tCO_2e = 44/12 tCO_2e

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"A 2° response, or even a 3° one, requires more political effort – much more – than is currently being applied in any of the major economies. It requires a mobilisation of effort that normally is only achieved in wartime."

John Ashton
Special Representative for Climate Change, United Kingdom
10 March 2009

1 EXECUTIVE SUMMARY

Even while science is unambiguously telling us that even 2°C of warming would be highly dangerous for our planet, many people are rapidly losing all confidence that we will be able to prevent this level of warming, or even far more. But a climate catastrophe can be averted. Doing so demands political leadership and courageous policy initiatives, both of which go well beyond politics as usual.

This report examines how Europe can show such leadership: firstly, by undertaking **domestic actions** to rapidly reduce emissions of greenhouse gases (GHGs), and secondly, by fulfilling its **international obligations** to help other countries address the twin crises of climate change and development.

Firstly, we analyse how Europe can embark on a transition to a low GHG future – enabling it to achieve large emission reductions on a rapid timescale. We present a detailed sector-by-sector mitigation scenario for all 27 EU countries that can achieve GHG emissions reductions of 40 per cent in 2020 and 90 per cent in 2050 relative to 1990 levels. This scenario achieves these cuts by a combination of radical improvements in energy efficiency, the accelerated retirement of fossil fuels and a dramatic shift toward various types of renewable energy, including wind, solar, wave, geothermal and biomass-based combined heat and power (CHP).

Secondly, we assess Europe's international obligations for assisting the world's developing nations make a transition to a low-GHG future. By considering the climate crisis in the context of the no-less-severe development crisis facing the world's poor, we use the Greenhouse Development Rights framework (Baer *et al.*, 2008) as a basis for assessing fair contributions to a global climate effort. We estimate Europe's fair share to be between €150 billion and €450 billion in 2020 depending on the assumed average cost of mitigation, which translates into approximately 1.1 per cent and 3.3 per cent of the EU's projected 2020 GDP of €13.6tn, respectively.

At the request of Friends of the Earth Europe, this analysis is designed to explore whether the specified levels of emissions reductions can be met without resorting to certain potentially significant mitigation options. In particular, we assume no new nuclear power, the phase out of existing nuclear power facilities, no carbon capture and storage (CCS) for fossil-based electricity generation and no biofuels (often referred to as agrofuels), whether produced within the EU or imported. Even without these mitigation options, Europe is still able to fully meet its 2020 target of 40 per cent solely through domestic options, *i.e.*, with no international offsets[1].

In addition to the scenario's technical measures we also examine the role of sufficiency and equity in helping promote the needed transition to a low carbon future. This is reflected in lower levels of GDP representing a future that is less materialistic than our normal "business as usual" assumptions about the future, albeit one that is still far richer than today. In fact in our mitigation scenario, GDP grows by a factor of "only" 1.6 between 2008 and 2050 versus the 1.8 times growth seen in the baseline scenario. Increased levels of equity among EU countries are also assumed, on the basis that achieving an EU-wide mobilisation to address the climate crisis and achieving a consensus on how to share the burden of the task will require greater solidarity between nations.

Our mitigation scenario presents a detailed bottom-up assessment of the technologies and key policy options that can be enacted in each of the major GHG

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[1] Beyond 2030, there is still no use of offsets, but the scenario does include some solar-based electricity from the Middle East or North Africa.

emitting sectors of the economy: buildings, industry (energy and process emissions), transport, electric generation, combined heat and power, solid waste, land use, and agriculture. We take a deliberately conservative approach by only including options that are either already commercially available, or that are in development now and are expected to become commercialised in the coming 20–30 years. We exclude potentially major pathways such as hydrogen fuel cells and second generation biofuels, which appear to be many years away from large-scale market penetration, while we have included options such as electric vehicles as key components of the scenario only in the last period of the study 2020–2050.

We have also followed the maxim put forward by David MacKay (MacKay, 2009) that a key attribute of any energy plan is that "it must add up". Specifically, we have focused on whether sufficient renewable energy sources are available to meet the requirements of the scenario, whilst taking a conservative approach with respect to renewables by considering only their currently estimated economic potential.

Our mitigation scenario shows that EU-wide GHG reductions of 40 per cent in 2020 and 90 per cent in 2050 are indeed possible. However, our scenario should not be viewed as the only pathway. It represents only an initial exploration or a technical existence proof for testing whether the type of deep cuts that science tells us are needed could be achieved. It is not overly concerned with the short-run political plausibility of options in the context of the current insufficient political will and lack of ambition. Instead it is intended to explore what might be possible under the assumption of a **major mobilisation** to meet the climate challenge.

We estimate the cumulative incremental cost of the mitigation scenario for households, services and transport, electric generation and avoided fuel purchases to be about €2 trillion for the 2010–2020 period. This cost is equivalent to about two per cent of Europe's GDP over the same period, although there is significant uncertainty in our estimate. Other, more extensive economic studies that considered similarly ambitious reduction targets and technologies have found costs to be in the range of one per cent to three per cent across a longer time period. Put another way, this cost would be the equivalent of temporarily holding GDP constant for about one year before resuming normal growth: a small cost when viewed in the context of the seriousness of the climate crisis.

2 INTRODUCTION: THE CLIMATE CHALLENGE

Our earth today is about 0.75°C warmer than it was in the 19th century, at the dawn of the industrial age. The earth's warming is accelerating, and without an unprecedented effort to curb our greenhouse gas (GHG) emissions, scientists project that the earth's temperature could have risen by 5°C by the end of the 21st century, and possibly more. Although a few degrees of warming might not sound very threatening, it would in fact be sufficient to completely transform the surface of the earth. After all, only 4 to 7°C of warming distinguishes the inhospitable depths of an ice age from the hospitable climate in which human civilisation emerged and has flourished (IPCC, 2007).

It is not surprising, then, that a warming of 2°C over preindustrial temperature levels has been adopted by many governments, institutions, and civil society organisations as a level of climate change that must be avoided. Recently, countries convened at the "Major Economies Forum" – including the United States, the European Union, Japan, Russia, China, India, Indonesia, South Africa, and Brazil among others – issued a joint statement recognising the scientific grounds for keeping warming below 2°C. Yet, as is clearly articulated in the IPCC's Fourth Assessment Report (IPCC, 2007) and reinforced by a steady stream of subsequent studies, even 2°C would be a highly dangerous level of warming. There is, to take only one example, a significant if not well-quantified risk that a warming of even less than 2°C could trigger the irreversible melting of large portions of the Greenland and West Antarctic Ice Sheets. With a manifest warming of only 0.75°C, we are already seeing effects – such as the precipitous receding of the Arctic sea ice and the release of greenhouse gases from melting permafrost – that are not only dangerous in themselves but also the beginnings of positive feedbacks that, we now know, will further accelerate the warming. Significantly, the fact that these feedbacks are already in motion is strong evidence that the overall sensitivity of the climate system is quite high, and that stabilisation concentrations that even recently were considered to be manageably safe – 450 ppm CO_2 equivalent for example – are in fact quite dangerous. Consequently, some are now calling for keeping warming *well below* 2°C, and two key blocs of countries in the international climate negotiations – the Alliance of Small Island States and the Least Developed Countries, which together represent nearly 800 million people in 80 countries – have demanded that nations limit warming to "as far below 1.5°C as possible."

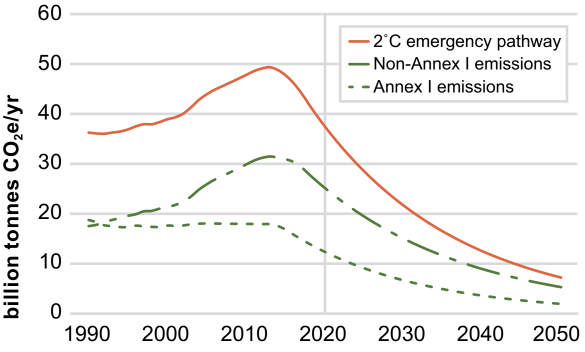

Figure 1: The South's dilemma

The red line shows a global pathway that would preserve a reasonable likelihood of keeping warming below 2°C. It is truly an emergency pathway, reflecting global action sufficiently ambitious to cause global GHG emissions to peak by 2015 and fall to 80 per cent below 1990 levels in 2050. The dotted green line shows Annex 1 emissions declining to 40 per cent below 1990 levels by 2020, and eventually to near-zero levels. The dot-dashed green line shows, by subtraction, the severely limited emissions space that would remain for the developing countries.

The challenge involved in keeping global warming below 1.5°C – or even 2°C – is monumental, and our generation will be judged by whether or not we rose to the challenge.

It is no surprise that developing countries are keenly motivated to minimise global warming. They are, after all, especially vulnerable to the impacts of climate change, and will suffer its damages disproportionately. However, the sharp emission limits that are implied by a stringent climate protection goal put developing countries in an extraordinarily difficult position.

A simple thought experiment illustrates the deep structure of the climate problem, and the true scale of the challenge facing developing countries. Figure 1 shows an assessment of the size of the remaining global carbon budget, defined by a pathway ambitious enough to be considered a 2°C pathway (the red solid line). We also show (the green dotted line) the portion of that budget that developed[2] countries would consume even

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[2] Within the UNFCCC negotiations, the developed countries are referred to as "Annex 1" countries, and the developing countries as "non-Annex 1" countries. The Annex 1 countries comprise roughly one-fifth of the

if they undertake rather ambitious efforts to virtually eliminate their emissions by 2050 (in line with the scenario for Europe we describe in Sections 3 and 4). Doing so reveals, by simple subtraction, the alarmingly small size of the carbon budget (the green dot-dashed line) that would remain for the rest of the world (*i.e.* the developing world).

A few more details only make the picture starker. First, the efforts implied by this 2°C pathway are heroic indeed. It reflects, in fact, an *emergency* response, in which global emissions peak before 2015 and decline to 80 per cent below 1990 levels by 2050, such that CO_2 concentrations can peak below 420 ppm and then start to fall toward 350 ppm.[3] Still, even such an ambitious global mobilisation would hardly mean that we were "safe." We would still suffer considerable climate impacts and risks, would probably fail to keep warming below 1.5°C, and would be subject to an approximately 15–30 per cent chance of exceeding 2°C. [4] This trajectory is one that the IPCC would refer[5] to as being "likely", but not "very likely" to keep warming below 2°C.

Second, the Annex 1 emission path shown here is significantly more aggressive than even the most ambitious of current EU and US proposals. It has emissions declining at more than five per cent annually from 2012 onwards, reaching a level 40 per cent below 1990 levels by 2020, and ultimately dropping to near-zero levels after 2050. In contrast, the aggregate level of ambition represented by the various proposals put forward by Annex 1 countries falls far short of this. For example, the UNFCCC Secretariat (2009) has estimated that reduction pledges by Annex 1 countries sum to a patently inadequate 17–24 per cent reduction below 1990 levels by 2020.[6]

Third, despite the apparent stringency of the Annex 1 pathway shown, the atmospheric space remaining for developing countries would be radically constrained. In fact, developing country emissions would have to peak only a few years later than those in the North – before 2020 – and then to nearly halve over each of the subsequent decades. And all this would have to take place while most of the South's citizens were still struggling out of poverty and desperately seeking a meaningful improvement in their living standards. And, if Annex 1 reductions are any less ambitious than those shown here, it will of course imply the need for even more radical reductions in the South.

It is this third point that makes the climate challenge truly daunting. It is now clear that carbon-based development is no longer an option, either in the North or the South. Yet the only proven routes to development involve expanding access to energy services, and, consequently, a seemingly inevitable increase in fossil fuel use and thus carbon emissions. From the standpoint of the South, this seems to pit development squarely against climate protection. It is for this reason that developing countries remain unambiguous in their insistence that, as important as it is to deal with climate change, a solution cannot come at the expense of their development.

But a climate solution does not have to come at the expense of their development. Clean energy alternatives exist – but currently only as "alternatives" that have not been broadly pursued or proven as a viable basis for achieving development. The North has not led the world in deploying these alternatives, and indeed continues to take steps (such as building coal fired power plants and energy-intensive transport infrastructure) that further entrench conventional GHG-intensive development paths.

That poverty – rather than climate change – is foremost in the minds of southern negotiators should thus surprise no one. The development crisis has shown itself to be not merely a challenge but an intractable crisis, badly in need of an expansion of resources and political attention. To make matters worse, the impacts

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world's population and three-quarters of the world's income.

[3] Recent research indicates that once CO_2 concentrations peak they are likely to remain stable in the atmosphere for a very long time in the absence of measures to actively accelerate withdrawals of CO_2 from the atmosphere, and only decline extremely slowly, with a result that they will not return to 350 ppm except on millennia time scales (Solomon *et al.*, 2009, Eby *et al.*, 2009).

[4] For details, see Baer and Mastrandrea (2006), and for more recent analyses with consistent results, see Meinshausen *et al.*, (2009).

[5] The precise language used by the IPCC to refer to probabilistic statements is given in (IPCC WGI, 2007; Box TS.1, p. 23).

[6] This is the estimate as of August 2009, three months before the milestone Copenhagen Conference of Parties to the UNFCCC. A second technical analysis (AOSIS, 2009) estimates the combined Annex 1 pledge to be 10–16 per cent.

of climate change are now directly affecting the world's poor, not as some abstract future threat, but as a tangible force undermining food security, water security, and livelihoods. And now, the South's negotiators have to face the very real possibility that the imperatives of climate stabilisation will deprive their countries of access to the cheap fossil energy sources that made development possible for the wealthy countries. Both China and India have long counted on their vast coal reserves to fuel their long-awaited growth. With even the minimal Millennium Development Goals being treated as second-order priorities, and little demonstrated interest in meeting them on the part of the North, the South has little reason to assume that the North would not willingly allow the exigencies of the climate crisis to eclipse the poverty crisis.

Figure 1 plainly illustrates the immutable facts of the linked climate and development crises; it is the developing world's trajectory in particular that is bracing, if not shocking. The industrialised world trajectory would require a major effort, but industrialised countries do have the technology, financial resources, and institutional infrastructure to launch themselves into the necessary transition, if they choose to do so. The developing country trajectory reflects the real challenge. Looking at the sharp and imminent downward turn in the developing country trajectory, a developing country climate negotiator could easily feel trapped by the implacable limits of the climate system, and indeed angered by the possibility that, once again, development will be sacrificed, if not to the worsening impacts of climate change, then to the need to keep within the world's nearly exhausted carbon budget.

The implications for the EU, and the rest of the industrialised world, are clear. First, these countries must ensure that the developing world has access to the necessary financial and technological resources to undertake a full-fledged climate mobilisation. Without the necessary resources, the developing world's mitigation efforts will be much more modest, and much less than what is necessary to address the climate crisis. Its main focus will be the much more immediate and pressing crisis of poverty.

Second, the EU and the rest of the industrialised world must make a sufficiently large portion of the remaining carbon budget available to the developing world. As can be seen from Figure 1, the world's carbon budget is very sharply limited, and even if the industrialised world's emissions drop to 40 per cent below 1990 levels by 2020, and then to almost 90 per cent below 1990 levels by 2050, this would consume roughly one-third of the remaining carbon budget.[7] This severely limits the budget available to the developing world, which will need to have passed its emissions peak well before 2020 and started a rapid decline. If the industrialised world's emissions were curbed much less ambitiously[8], leaving an even smaller remaining budget for the developing world, it would call into question the feasibility of development for the world's poor.

However, even while the science is telling us, quite unambiguously, how profoundly our world will be affected by another degree or two of warming, many people are losing all confidence that we will be able to prevent such a warming, or even a far greater one. This loss of confidence is driven not by doubt about our collective scientific and technological abilities; nor by any convincing arguments that it would be prohibitively costly to leave our self-destructive path, compared to the cost of inaction[9]; rather, it is driven by

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[7] As recently presented in *Nature* by Meinshausen *et al.* (2009), to preserve a reasonable chance of keeping warming below 2°C requires limiting global carbon dioxide emissions to less than 1000 $GtCO_2$ over the first half of the 21st century, for both land-based and fossil fuel-based carbon dioxide emissions. If heroic efforts were taken to bring deforestation and land degradation to a halt within one decade, then emissions from land could be limited to approximately 60 $GtCO_2$. This leaves approximately 940 $GtCO_2$ for emissions from the use of fossil fuel, of which we have already emitted approximately 280 $GtCO_2$ in just one decade since 21st century began. The remainder (660 $GtCO_2$) is barely one-third of the total fossil CO_2 budget (less than 2000 $GtCO_2$) that we will have used over the entire two century era of fossil fuel dominance.

[8] Annex 1 reductions of 40 per cent by 2020 and 95 per cent by 2050 would consume about 210 $GtCO_2$ of the remaining 660 $GtCO_2$ fossil carbon budget. This level of reductions is at the stringent end of the ranges presented in the IPCC 4th Assessment Report for Annex 1 (25–40 per cent by 2020 and 80–95 per cent by 2050, relative to 1990 levels) for emission scenarios consistent with stabilization at 450 ppm CO_2e (IPCC WG III, 2007; Box 13.7, p. 776). If Annex 1 countries were less ambitious, and their reductions reached only the lower end of these ranges (20 per cent by 2020 and 80 per cent by 2050), they would occupy a significantly greater fraction of the available budget: roughly 305 $GtCO_2$ (between 2010 and 2050), leaving 355 $GtCO_2$ for non-Annex 1 countries to emit.

[9] Such arguments are amply dispelled by comprehensive analyses such as those presented in the IPCC's 4th

the widespread assumption that our societies are not up to the political challenge of saving our climate.

This deflating sentiment must be proven wrong. A climate catastrophe can be averted, but doing so demands political leadership and courageous policy initiatives, both of which go well beyond politics-as-usual.

This report examines what Europe will need to do to show such leadership: firstly, it will need to undertake **domestic actions** to rapidly reduce emissions of greenhouse gases (GHGs), and secondly, it will need to fulfil its **international obligations** to help other countries address the twin crises of climate change and development.

The remainder of this report examines the how Europe can meet these two challenges:

- In Sections 3 through 5, we examine how, by undertaking aggressive emission reductions in the near term, Europe can embark on a transition to a low GHG future. We present a sector-by-sector, bottom-up analysis of a mitigation scenario that would allow Europe to achieve a 40 per cent reduction in GHG emissions by 2020 and approximately 90 per cent reductions by 2050.

- In Section 6, we examine Europe's obligation to help launch a *global* transformation to a climate-consistent development path. By considering the climate crisis in the context of the no-less-severe development crisis facing the world's majority, we offer a frame through which to understand fair expectations of the highly developed nations of the world in enabling the developing world to adapt to climate change and transition to a low-GHG future.

Assessment Report (IPCC, 2007), the *Economics of Climate Change* report (Stern, 2006), and the recent "Economics of 350" (Ackerman *et al.*, 2009).

3 DOMESTIC ACTIONS: A MITIGATION SCENARIO FOR EUROPE

Sections 3 and 4 of this study explore and clarify the characteristics of a deep reduction scenario for Europe, through a detailed mitigation analysis for reaching 40 per cent domestic GHG emission reductions below 1990 levels by 2020, with deeper reductions approaching 90 per cent by 2050.

We do this by analysing how Europe's energy sector might evolve between now and 2050 under two very different scenarios: a **baseline** scenario that assumes the continuation of current policies and a corresponding modest rise in GHG emissions, and a **mitigation** scenario that examines the feasibility of making deep cuts in GHG emissions. Taking such a long term perspective is difficult because of the huge uncertainties about how technologies, policies, costs and Europe's social structure will change between now and 2050. Nonetheless, such a perspective is essential due to the long lifetimes and capital intensive nature of energy systems, and because the problem addressed is inherently long-term: namely dramatically reducing GHG emissions.

The overall EU27-wide GHG emissions trajectories in the two scenarios are shown in Figure 2, expressed as the total carbon dioxide equivalent emissions of the major greenhouse gases (CO_2, CH_4, and N_2O).

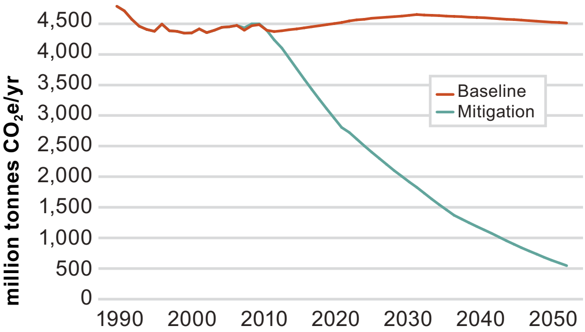

Figure 2: EU27 GHG emissions in the two scenarios [10] [11]
Includes both energy sector and non-energy sector emissions of CO_2, CH_4 and N_2O. Does not include high GWP gases (HFCs, PFCs, SF_6)

Our **baseline** scenario examines how Europe's energy system might evolve if current policies continue largely unchanged. In the baseline, GHG emissions grow only slightly through 2050 as significant economic growth is balanced by improvements in energy efficiency and a gradual transition away from coal: the most carbon intensive fuel. Our baseline is built upon detailed historical energy statistics for each EU27 country published by the International Energy Agency (IEA), which have been extrapolated into the future based on a variety of information sources: historical trends, a variety of national level studies, and the European Commission's own baseline energy projections to 2030 (EC, 2008). Information from these sources has been further augmented and adjusted, for example to reflect the impact of the recent global economic crisis and to include projections for GHG emissions from international air travel and non-energy sector GHG sources and sinks (industrial processes,

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[10] Our 1990 energy sector-only emissions of CO_2 are estimated as 4075 $MtCO_2$. This can be compared to a value of 4040 $MtCO_2$ reported by the IEA (IEA WEO, 2008) and 4083 $MtCO_2$ reported by the EEA (EEA, 2009). The minor differences in estimates appear to be due primarily to the simplified set of fuels and emission factors required in our analysis. Total net GHG emissions (after factoring in LULUCF sinks) reported by EEA in 1990 are 5230 $MtCO_2e$ (5563 $MtCO_2e$ without LULUCF), which is higher than the value of 4786 $MtCO_2e$ used in our study. Personal communications with EEA staff suggest that the difference is due to the more complete accounting of industrial process emissions in the EEA inventory: including process emissions from the chemicals and iron and steel sectors and emissions of fluorinated gases — areas that were not covered in detail in our study.

[11] Our estimates of Europe's GHG emissions as well as those presented in the IEA, EC and EEA reports are all production-based estimates of the emissions occurring within the borders of the EU. They all exclude the "embedded emissions" — those occurring in other countries in order to manufacture goods consumed in the EU, that would be reflected in a consumption-based estimate. Recent estimates of embedded emissions show that they are both significant and growing. A recent SEI study for the UK Government calculated that consumption-based accounting of UK emissions would yield far higher estimates of emissions — rather than going down by five per cent between 1992 and 2004 as is commonly estimated, the UK's CO_2 emissions have actually gone up 18 per cent on a consumption basis (Wiedmann, 2008). While we have not been able to include these embedded emissions in our analysis, it should be recognized that their exclusion does seriously underestimate the emissions for which Europe's citizens are responsible.

land use change, solid waste, agriculture) – areas that were excluded from the EC study and the IEA data set. For this reason, our baseline scenario results are more complete but not directly comparable either to the IEA's energy statistics or to those in the EC energy study. Our energy projections are extrapolated to 2050 using standard assumptions about population and economic growth, technology change and shifts in economic structure.[12]

Our **mitigation** scenario is a normative scenario, which examines the technical feasibility of achieving deep cuts in Europe's greenhouse gas emissions in the coming half century. Specifically, it is driven by the goal of reducing GHG emissions domestically by about 40 per cent in 2020 and as far as possible by 2050 relative to 1990 values. The scenario achieves these cuts by a combination of radical improvements in energy efficiency, the rapid phase out of fossil fuels and a dramatic shift toward various types of renewable energy. It also examines the role that equity and sufficiency can play in helping meet these targets.

In the following sections we explain how such reductions might be achieved and what such a scenario might cost. Before we do that a few caveats need to be stated:

- Firstly, our mitigation scenario should not be viewed as a recommended pathway. It represents only a technical existence proof: a way of testing whether the type of deep cuts that science tells us are needed could possibly be achieved. We hope the following sections will show they can indeed be achieved, but at the same time we recognise that this study is only an initial exploration. We are confident that it can be further refined to provide a more detailed and more economically efficient plan of action.

- Secondly, our mitigation scenario is not constrained by short run political plausibility of options in the current context of the climate stalemate. Instead it is intended to explore what might be possible under the major assumption that Europe and the wider world commit to a concerted mobilisation that can genuinely meet the climate challenge.

- Thirdly, it is tempting when constructing scenarios that look as far into the future as 2050 to rely too much on yet-to-be-developed technologies. Inevitably there will be huge advances in technology by 2050, and assuming a massive climate mobilisation it is to be expected that technologies will arise by 2050 that can address the climate mitigation challenge in ways that are hard to imagine now. Indeed looking back 40 years to 1969, many of the energy technologies being implemented today had barely been conceived (wind, wave, solar PV and solar thermal, efficient natural gas, energy efficiency technologies). Nevertheless, capital stocks have very long life times in the energy sector so even if unimagined new low carbon energy technologies arise in the coming decades, it will be hard for them to make a significant contribution due to the slow turnover of stock. In our mitigation scenarios, we take a deliberately conservative approach, and have only included technical options that are either already commercially available, or that are reasonably well-developed now and are expected to become commercialised in the coming 20–30 years. Thus, we have excluded potentially major pathways such as hydrogen fuel cells and nuclear fusion, which appear to be many decades away from the market, while we have included options such as solar energy and electric vehicles as major components, but only in the later years of the scenario.

- Fourthly, we have also followed the maxim put forward by David MacKay in his recent book (MacKay, 2009), that a key attribute of any energy plan is that "it must add up". Specifically, we have focused on whether sufficient renewable energy resources are available to meet the requirements of the scenario in each EU country. Unfortunately a key uncertainty in ensuring a plan adds up is the huge gulf between estimates of technical and economic potential for the key renewable energy sources. We have therefore taken a conservative approach with respect to renewables and have considered only the currently estimated economic potential, even though the renewable resources deemed economic in a world that is focused on climate protection are likely to be far larger than those under current market conditions.

- Finally, it is of course vital to understand the cost of any options being considered. Unfortunately estimating costs is a far more difficult challenge than merely estimating whether a scenario is technically achievable. There are many sources of uncertainty in any such analysis including estimating future fossil fuel prices in a world determined to eliminate fossil fuel use, and what

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[12] For more detailed results, please review the LEAP data set accompanying this analysis (available at www.energycommunity.org).

the costs of technologies will be in a world with unprecedented levels of research, development and dissemination of low carbon technologies. We have therefore attempted only a very rough estimate of the economic costs of our mitigation scenario: limiting our estimates only to the period to 2020. While we have not been able to put costs on every aspect of the scenario, we have attempted to use fairly conservative estimates of likely cost reductions and thus our estimates of the economic costs (presented in Section 4.10) should thus be thought of as a likely upper bound estimate.

3.1 EXCLUDED OPTIONS

At the request of Friends of the Earth Europe, this analysis is designed to explore whether the specified levels of emissions reductions can be met without resorting to certain options that are potentially significant but controversial. In particular, we assume no new nuclear power, the phase out of existing nuclear power facilities, no carbon capture and storage (CCS) for fossil-based electricity generation and no biofuels (often referred to as agrofuels), whether produced within the EU or imported. Even without these mitigation options, Europe is still able to fully meet its 2020 target of 40 per cent solely through domestic options, *i.e.*, with no international offsets. Beyond 2030, there is still no use of offsets, but the scenario does include solar-based electricity from international sources (in the Middle East or North Africa).

These excluded options would otherwise tend to ease the challenge of meeting the CO_2 mitigation goals of the scenario, particularly since some of them could provide base load power that could help alleviate the major challenge of the variability of the supply of wind, solar and other renewables. However, they have been excluded due to a variety of concerns about their wider safety and sustainability and due to the desire to explore whether renewables and efficiency combined with a set of significant structural changes could be sufficient to meet the emissions reduction challenge of the scenario.

Concerns about nuclear power include its potential for contributing to the proliferation of nuclear arms, the safety of nuclear generation and the ability to safely dispose of and store nuclear waste over very long time scales (thousands of years). It remains an open and controversial question whether these issues could be adequately addressed given sufficient efforts. Historically, nuclear power has also been seen as being too costly a source of electricity relative to other generation options such as coal and natural gas. While this remains true, it is less of a concern in the context of our mitigation scenario, which itself envisages the introduction of many new technologies some of which will inevitably be significantly more expensive to operate than current fossil-based technologies.

Coal-fired generation coupled with carbon capture and storage (CCS) has also been excluded from this study due to various concerns about the technology. Specific technical concerns include the unproven nature of the technology, the limited number of suitable locations for storing CO_2, and concerns about whether CO_2 storage will prove reliable. CCS also faces serious questions about whether it can be commercialised rapidly enough given the need to quickly phase out existing fossil plants. A more general concern is that the promise of CCS may be being used primarily as a public relations exercise, in order to gain permission from governments to build a new generation of so called “CCS ready” coal-fired power plants. The concern is that once these plants have been built (initially without any significant ability to capture CO_2) it will prove exceedingly difficult to require utilities to add CO_2 capture and storage at a later date.

But perhaps the major concern about coal-CCS is that climate change may turn out to be an even greater problem than is currently expected. Achieving very low atmospheric concentration levels of CO_2 will eventually require actively sequestering CO_2 from the atmosphere. In such a situation, CO_2 storage sites will be a precious resource. Using these sites to store CO_2 from coal combustion may come to be seen as the squandering of a precious resource.

Another major concern about nuclear and coal CCS are the high levels of research and development (R&D) funding they require. This R&D expenditure may crowd out the required levels of investment in renewable energy (RE) and energy efficiency (EE) development. Advocates for RE and EE technologies are concerned that they will not receive sufficient attention if nuclear and CCS technologies move forward on a large scale.

Biofuels have also been excluded in the mitigation scenario due to concerns that currently they have little if any GHG mitigation benefits, especially when emissions from land-use changes are taken into account. Second generation biofuels are also excluded up to 2050 due to FoEE’s concerns over their land-use implications and the competition with land for food and natural habitat. However, they remain an important option to be considered, perhaps after 2050.

Finally, there is a more fundamental tension between those who wish to see a future based on small-scale decentralised energy systems and those who are open to more integrated and regionally interconnected energy systems. For proponents of small scale systems, large scale generating systems like nuclear and CCS are fundamentally inappropriate. However, in our scenario we have included a number of potentially large scale energy systems such as large scale solar energy from North Africa. Moreover due to the high levels of renewable energy introduced in the scenario by 2050, we expect that a variety of options will be required to balance supplies and demands including greater regional interconnections, and localised energy storage options for RE to reduce transmission and distribution capacity (such as pump storage, compressed air energy storage, fly wheels or storage in electric vehicles and other battery systems). Our view is that the pros and cons of decentralised versus integrated strategies requires much more detailed study: a task that goes beyond what could be accomplished in this study.

Needless to say, offsetting is excluded from our EU reduction scenario since – by definition – the focus of this study is domestic European measures to reduce GHG emissions. Offsetting is not a mitigation measure, per se, it is simply a mechanism for shifting reductions to some other location. As such, it would simply allow the EU to defer the urgently needed transformation described in this scenario.

3.2 THE ROLE OF SUFFICIENCY AND EQUITY

Our baseline scenario posits a 2050 in which Europe's GDP will be more than 1.8 times its size in 2008. By 2050 the difference in average income levels between the richest and poorest EU27 nations increases dramatically, in spite of faster *rates* of income growth in the poorer states. In 2008, the poorest EU country, Bulgaria, had average income levels of only €3,350 per capita, while its richest, Luxembourg, had an average income of €75,600: a difference of €72,250. By 2050, the difference in the baseline scenario increases to €148,000. Even excluding Luxembourg, the difference increases from €44,000 to €64,000 over the scenario period.

Why are these huge levels of growth and huge disparities among countries important? In the mitigation scenario, the link between GDP and GHG emissions is broken so that huge emission reductions are achieved even while GDP growth also increases dramatically. Thus, on the face of it there is no need to consider lower levels of GDP as a significant lever for achieving emissions reductions. However, climate is only a part of the wider sustainability crisis facing the planet (Rockström *et al.*, 2009), making it clear that consumption of resources cannot continue to expand indefinitely. Sooner or later the richer countries and people of the world will need to find new ways of living that recognise the importance of sufficiency: living well without expecting ever continuing growth in consumption.

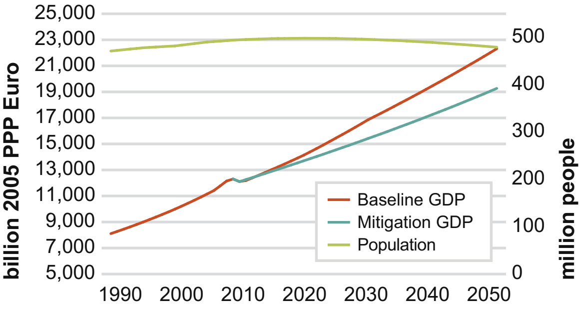


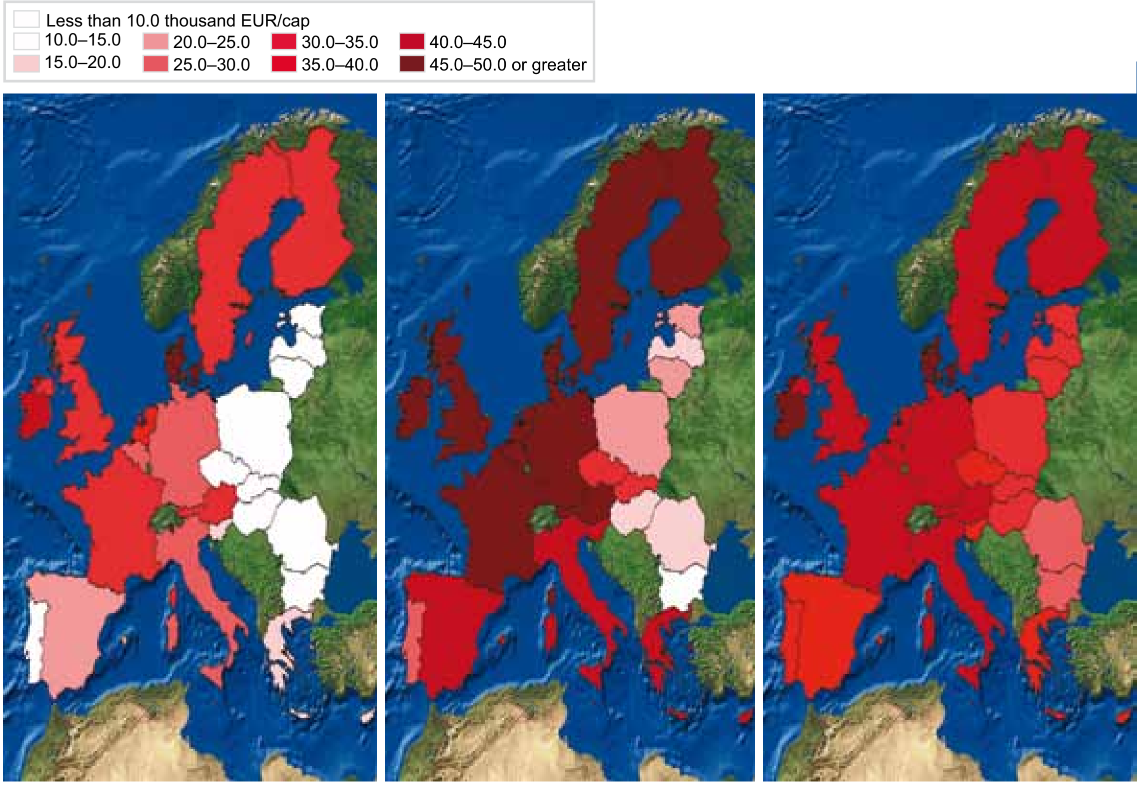
Figure 3: Population and GDP in the two scenarios

Population shown on the right axis is the same in both scenarios, GDP on the left axis shown in constant 2005 PPP Euros is higher in the baseline scenario: on the assumption that Europe begins recognising the need to limit overall levels of consumption.

In our mitigation scenario we reflect this concern over sufficiency by assuming modest reductions in overall GDP growth in the mitigation scenario under the assumption that Europe and the wider world *start* acting upon the need to live sustainably within the overall carrying capacity of the planet. Specifically, total EU27 GDP grows by a factor of "only" 1.6 from 2008 to 2050 in the mitigation scenario versus the 1.8 times growth seen in the baseline.

Figure 3 compares the overall growth in EU GDP in the two scenarios and also shows EU population growth which is assumed to be the same in both scenarios.

In addition to concerns about sufficiency, addressing the climate crisis will also require addressing the issue of equity as noted earlier in Section 3. Reducing GHG emissions by almost 90 per cent in 2050 will require a concerted mobilisation in every EU country. Yet even today, achieving consensus on how to share the burden of acting to address climate change is proving elusive. Doing so in an environment where differences between rich and poor countries are widening even further will be exceedingly challenging.



2010

2050 Baseline

2050 Mitigation

Figure 4: Average incomes across Europe in 2010 and in 2050 in the Baseline and Mitigation scenarios

These maps illustrate the differences in average income levels among countries in the two scenarios. While incomes grow from 2010 in both scenarios, the baseline map clearly shows how countries have diverged in 2050 in terms of average incomes, while the second mitigation map shows a much more equal Europe, as incomes converge toward a target of €46,000 in 2060.

For this reason our mitigation scenario also assumes different patterns of growth from the baseline scenario. We assume that significant fiscal or other appropriate policies are put in place to promote a convergence in income levels among the countries in Europe. This represents a continuation of the wider goals of the EU, which since its inception has sought with much success to help its poorer states catch up with the levels of development seen in the wealthier member states. But it also represents a real change in practice, to ensure that convergence happens much more rapidly than would happen in a baseline scenario.

The results of these assumptions are shown in the figures below, which compare our income projections in the two scenarios. Figure 4 shows how, in the baseline scenario, average incomes diverge in absolute terms in spite of faster growth rates in the new member states. In the mitigation scenario, the average EU income rises gradually from today's value of about €24,000 to €40,000 in 2050. This is a somewhat slower rate of growth than is assumed in the baseline scenario, in which average income rises to €47,000 by 2050. However, while the mitigation scenario describes lower average EU-wide GDP growth than the baseline (though still with substantial increases relative to today), GDP is after all merely a proxy for overall levels of economic consumption, not a direct indicator of welfare. Higher GDP cannot by any means be assumed to imply greater human welfare, especially given that income is quite poorly correlated with welfare in wealthy nations (Diener and Suh, 2000). So, while the mitigation scenario might have slightly lower economic consumption than the baseline scenario, it can still be assumed to enjoy higher welfare through positive lifestyle changes such as more leisure (nonworking) time, better health, and greater opportunities for satisfying social connections (Layard, 2003, 2005; Kahneman *et al.*, 1999)

3.3 LIFE IN A DECARBONISING WORLD

Europe, if it is to meet the challenge of substantially reducing its carbon footprint within the constraints outlined in the previous section, must make substantial changes to the way that it produces and consumes. The changes are not bad ones: were a contemporary European to be placed suddenly into the Europe of 2050 as envisaged in our mitigation scenario, we are confident they would find life rather pleasant.

In our scenario 2050 is an economically much more equal Europe. This economic convergence would be a consequence both of the ongoing effort within the EU to reduce disparities in living standards between its member states and also the practical effect of a pan-European effort to achieve large reductions in greenhouse gas emissions through public investment. On a day-to-day basis, streets would be easier to navigate for pedestrians and cyclists, while public transportation would be more readily available and convenient, and traffic congestion would be substantially reduced. Europe's inhabitants in 2050 would have convenient access to the places they wished to go, albeit often by a different mode than they are used to today. Living area per person would be about the same as it is today. Moreover, while average levels of material consumption would be roughly the same as today (but significantly higher for those residing in the new member states), health care, local leisure opportunities, and other less materials intensive services would be substantially better for all.

However, today's Europeans do not have the option of being suddenly placed into that future and a question of immediate concern is what the transition between now and then would look like for the people of Europe. It is clear that the transition put forward here is a huge undertaking that will entail significant costs and a huge mobilisation of efforts across Europe.

The changes will require that huge amounts of infrastructure is replaced or retrofitted and new industrial processes are developed, and modes of production and consumption become significantly less material-intensive than today.

In this section, we present a picture of how such a transition might be viewed by the citizens of Europe and how they might react to it. It is important to remember the context of these changes: namely that Europeans have generally committed themselves to respond to the climate mobilisation challenge. What is more, there is an unseen alternative pathway that the people of Europe will not experience, one in which increased energy dependence creates economic and political uncertainty, and in which Europeans become increasingly aware of the massive climatic changes they have helped to set in motion and bequeathed to the next generation in Europe as well as in regions even less able to cope.

The transition features a major public-works programme in which some transport infrastructure is removed while other infrastructure is built; some houses are retrofitted while others are replaced, household heating systems are replaced with efficient options such as CHP, solar thermal and heat pumps, and almost the entire electric system is replaced by renewable energy technologies. These efforts would be added to the usual turnover of Europe's capital and vehicle stock, and are likely to offer expanded employment opportunities. For the most part, the day-to-day experience of these jobs would be similar to the past, and most people are likely to view this aspect of the transition positively. In addition to construction and manufacturing jobs, engineers and designers would have employment opportunities and engaging challenges for the further development of energy and carbon-saving technologies that are currently at the pilot stage.

While the availability of jobs is likely to please many, in a region as diverse as Europe, it is inevitable that there will be some who are upset by the transition, either because they do not accept its necessity or because they are unhappy with one or another specific change in their lives. In particular, higher tax burdens of one type or another may be needed to support the transition. However, the tax impacts can at least partially be offset through the use of ecological taxation: that is a shift in the tax structure to reduce taxes on "goods" such as employment but increase taxes on "bads"' (*e.g.* through carbon taxes).

For the large majority that views climate change as a real and imminent threat, this transition is likely to be comforting and even inspiring, as it gives them a new sense of urgency in the face of a substantial danger, not unlike the mobilisation for a defensive war. However, the threat of climate change is different than the threat of war, in that it is intangible until it happens, and ironically a key goal of the endeavour is to keep it intangible forever. Thus, the minority who do not believe that climate change is a threat, and who therefore do not accept the need for a public mobilisation, are likely to be vocal in their opposition.

People will see changes both in their jobs and in their homes, and these changes are likely to elicit a range of responses, both positive and negative. Retrofitting older homes to be much more energy efficient is likely to be seen positively by most people, as they retain the home that they are used to while also seeing their energy bills go down while being supported by subsidies, albeit perhaps with an increased sense of government regulations, and mandates intruding on their lives. Similarly, the building of new homes to passive house standards will be seen positively by most people. The replacement of older, less efficient cars with substantially more efficient cars is also likely to be seen as largely positive. However, managing the transition to greater use of public transport and less use of cars will need to be handled with great care since it will inevitably require measures such as reduced (and higher priced) parking opportunities, road pricing, zone restrictions, traffic-calming measures, and increased fuel prices, that are seen as infringing on an individual's basic freedom to travel. Thus, any such restrictions will need to be balanced by much more convenient and higher quality public transport services, significant reductions in congestion, and the redesign of urban areas to make them much more attractive for pedestrians and cyclists.

Changes in diets would clearly be beneficial for the health of Europeans. However, significant efforts will likely be needed to wean consumers away from unhealthy patterns of consumption. Government policies can play a significant role in this by encouraging producers to make and sell more healthy products and by labelling and pricing food in a way that encourages consumption of more healthy and less meat intensive alternatives.

The extensive building of new infrastructure and renewable energy plants required by the mitigation scenario is likely to lead to substantial new employment opportunities, particularly over the period 2010–2030 when current fossil plants need to be replaced (see Section 4.6). However, these large infrastructure projects will create daily inconveniences during their construction, and will result in a change in formerly familiar landscapes. The new energy infrastructure is likely to be especially disconcerting because it is a departure from the past. If housing and transport are to rely heavily on electricity, and most electricity is to be provided by renewable energy, then wind and solar power plants and their associated transmission lines will inevitably intrude more into Europe's landscape. However, the aesthetic impacts of these technologies can to a large extent be minimised if Europe invests significantly in offshore wind and wave power. In addition, some of the adverse responses to onshore wind can be blunted through careful planning. For example, onshore wind turbines could be excluded from national parks or sited sensitively with respect to aesthetics and environmentally sensitive areas. More localised ownership of renewable facilities (*e.g.* having turbines owned by the farmers on whose land they rest) will also help to increase local acceptance. This is a concept that is already being widely practiced in Denmark.

On balance, while such a transition will require careful planning and sympathetic support for those whose lives are affected, the endpoint – once it is reached – is highly likely to be seen positively by most, if not all.

4 TECHNICAL DESCRIPTION OF THE SCENARIOS

This section provides a technical description of our baseline and mitigation scenarios for Europe. We start by describing the main final energy **consuming** sectors in the economy: buildings (households and services), agriculture, industry and transport. Energy use in these sectors causes direct emissions (*e.g.* through the combustion of petrol in cars or the use of natural gas in boilers), but it also creates a demand for electricity, heat and other secondary fuels that are produced in the electric generation, district heating, oil refining and other **transformation** sectors, where additional emissions of GHGs occur. To these energy sector emissions must be added the net emissions of CO_2 and other GHGs from the **non-energy sector** including emissions from industrial process emissions (most notably from the cement sector), from solid waste, from agriculture and from land-use change.

In the following sections we describe the main data, methods and assumptions underlying our energy projections in each of the main sectors: energy consumption, energy transformation and non-energy sector emissions for both our baseline and mitigation scenarios.

In every sector, energy consumption and production are projected using straightforward projections of historical trends for economic activities and energy intensities combined with standard IPCC Tier 1 emission factors for greenhouse gases. All of this historical data and the projections to 2050 in the two scenarios for all 27 EU countries were developed and managed within SEI's LEAP modelling system: an accounting tool for energy policy and GHG mitigation assessment (see Annex 9.1). For additional detail on these scenarios, please download and review the associated LEAP data set.

In each section below, we also mention some of the key policy options for realising the technical options in the mitigation scenario. For more information on policy options to promote a low carbon economy in Europe, refer to the recent SEI report "A European Eco-Efficient Economy". (Nilsson *et al.*, 2009)

4.1 BUILDINGS

Buildings – and the appliances and other equipment within them – consume significant quantities of energy. Heating and cooling systems, appliances, home and office electronics, and lighting are the largest consumers of energy in this sector.

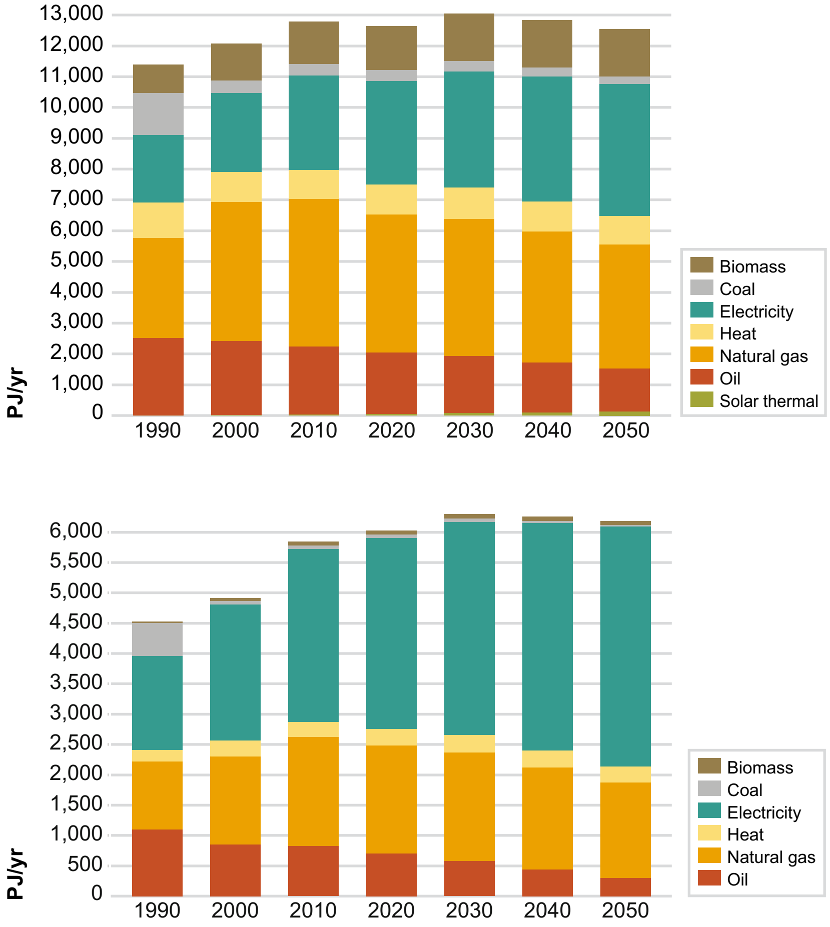
In recent decades, home energy use has increased faster than population growth as income levels have increased and populations have tended to heat and cool their homes more, and have widely adopted relatively energy intensive technologies such as refrigerators, washing machines, tumble dryers and larger televisions. In the services sector, energy use has also increased in absolute terms, but has declined relative to the level of economic activity; construction of relatively efficient commercial office space since 1990 has helped slow growth in energy consumption in this sector. Looking forward, increases in average dwelling size and greater penetration of electronics and cooling appliances will continue to put upward pressure on building energy demand, while continued increases in energy performance of new buildings, appliances, and equipment (and a continued switch away from oil as a heating fuel) keeps building energy use and emissions from rising dramatically in our baseline scenario.

The overall trends in energy use in the household and services sector in our baseline scenario are displayed in Figures 5 and 6.

4.1.1 Key mitigation options

Attaining large cuts in GHG emissions will require dramatic decreases in energy use in the buildings sector beyond baseline trends. Fortunately, several opportunities exist to reduce energy use further, including many options that increase efficiency and which pay for themselves (by saving on energy costs) in only a few years. These include leaps in building shell efficiency and increases in lighting and appliance efficiency.

Our estimates of potential energy savings and GHG mitigation in Europe's building sector were conducted by assessing the potential for diversion from baseline trends. For residential buildings, we started with population, housing, and energy consumption data, plus information on the existing number and floor area of housing stock from the latest survey of housing statistics in the European Union. (Federcasa, 2006) We then built a stock turnover model to estimate the impact of new construction and housing retrofits on the overall level of building efficiency of Europe's residential building stock each year. Our assumptions regarding retrofits and new housing efficiency rely on an aggressive schedule of retrofits of most housing to passive house levels. In addition, we also assumed increased efficiency of building systems (including heating, cooling and lighting) and appliances based on



Figures 5 and 6: Energy demand in the household and services sectors in the Baseline scenario

These two charts show direct (final) demands for various energy forms. "Heat" is centrally produced (district) heating piped into buildings; "solar thermal" is primarily solar hot water panels (used mainly in Greece and other Mediterranean states); "biomass" is direct use of biomass (mainly firewood) in homes, which remains important, particularly in some of the less affluent states. The fuels used to produce electricity and heat are examined later in sections 4.6 and 4.7.

studies by the International Energy Agency (2008a), Vattenfall (2007), and McKinsey (2009a). Similarly, for emissions reductions estimates in the service sector, we applied reduction potentials identified by Vattenfall (2007) and the IEA (2008a).

Our mitigation scenario assumes an aggressive effort to retrofit housing to close to "passive house" standards, similar efforts to improve building shell efficiency in the services sector. Recent pilot programs in Europe have demonstrated the feasibility of very low energy "passive" houses. Heating energy consumption in new housing can attain 15 kWh/m^2 (or less) annually, a mid-range "passive house" standard, largely through building shell improvements (*e.g.*, insulation, triple-pane windows) (IEA, 2008a). We assume that new homes can average 15 kWh/m^2 of heating energy beginning in 2011. Existing homes will, in most cases, require substantial retrofits. Because attaining the same energy performance of a new building would be difficult, and some historic structures may not be able to be retrofit, we assume that 90 per cent of existing residential structure can be retrofit (at the rate of five per cent per year, a transition that would take 18 years) and attain an average heating energy consumption of 27 kWh/m^2. [13]

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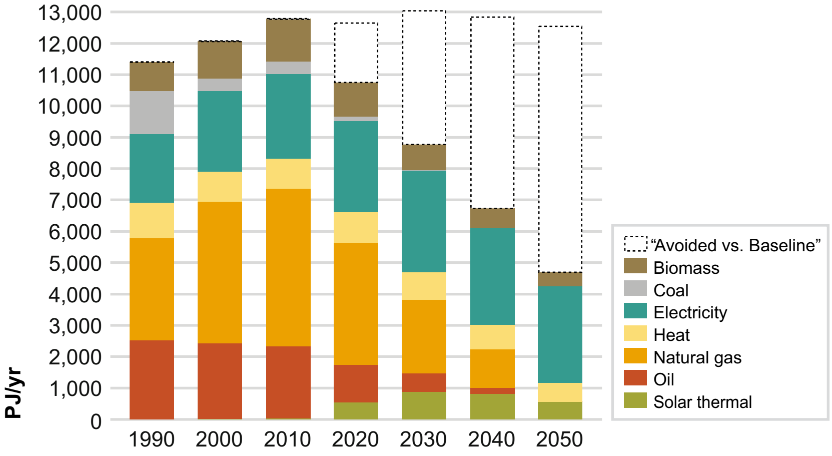
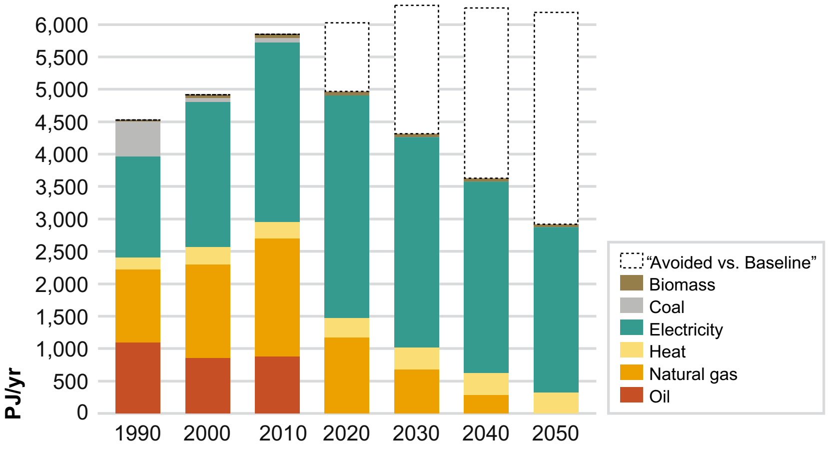
[13] 27 kWh/m^2 is the mid-range "Level II" retrofit in McKinsey & Company (2009) and is also the modelled heating energy use of a demonstration retrofit in Passive House Institute (2009).





Figures 7 and 8: Energy demand in the household and services sector in the Mitigation scenario

The dashed bars represnts the energy consumption avoided versus the baseline scenario – in other words the overall efficiency gains of the scenario. Energy consumption in 2020 decreases by 16 per cent for households and by 16 per cent for services compared to 2010. By 2050, it declines 63 per cent for households and by 50 per cent for services compared to 2010. This corresponds to an annual rate of reduction of 2.5 per cent/year for household and 1.7 per cent for services.

We also assume a dramatic shift away from the direct use of fossil fuels in buildings in favour of increased use of heat (from Combined Heat and Power), electricity (especially in the form of electric heat pumps) and solar power. As building shell retrofits are undertaken, households can also switch away from fossil fuels for home heating (which currently occupies about 75 per cent of energy use for home heating) toward the use of heat from CHP, direct use of electricity in the form of ground- and air-source heat pumps, passive solar designs, and solar thermal hot water heating.[14]

District heating, an option often cited as offering potential efficiency gains, will increase in many areas, but would likely be uneconomic to extend to areas which currently have no CHP infrastructure, due to the reduced energy demand for heating resulting from the aggressive efficiency improvements in the scenario.

Gains in appliance efficiency will offset the increasing use of consumer electronics and other appliances. Over time as incomes increase in both scenarios, European

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[14] Source: McKinsey & Company (2009a) or lower end of range cited in IEA (2008). By adopting heat pumps, which effectively boost the ambient energy conditions, the electricity consumption for heating can drop by at least half relative to electric resistance heating, cutting electricity use for heating below the 27 kWh/m^2 retrofit and 15 kWh/m^2 new build passive house standards.

households can be expected to acquire greater quantities of household appliances and electronics. In the absence of strong policies, electricity consumption for appliances would rise rapidly. However, application of the best available technologies in the mitigation scenario offsets these increases and result in no net increase in per-household electricity consumption for electronics (IEA, 2009).

Finally, we also consider to some degree the issue of sufficiency. After trending up for decades, the mitigation scenario assumes that home sizes gradually return to 2005 levels by 2050. The average floor area per household in the EU27 has risen steadily from about 76 m^2 in 1990 to 87 m^2 in 2005. We assume this upward trend continues in the near term (peaking at 100 m^2 in 2020) but that greater urban density together with increasing social awareness of the environmental impacts of larger homes gradually reduces the average house size back to the 2005 level of 87 m^2 by 2050, about the level currently observed in Finland. The average occupancy rate (people per household) continues a downward trend from 2.7 people per household in 1990 and 2.4 people per household in 2005 to 2.1 people per household in 2030, based on underlying demographic changes projected by the United Nations.

The collective effect of the policies above is to dramatically reduce residential energy consumption and gradually shift the remaining consumption to electricity, CHP-based district heat and solar thermal energy, and away from fossil fuels. Figure 7 displays the resulting shift in residential energy consumption in the mitigation scenario, while Figure 8 shows equivalent results for Services. Notice the bars plotted with open dotted lines showing the energy use avoided in the mitigation scenario versus the baseline.

4.1.2 Key policies

The European Directive on Energy Performance of Buildings (EPBD) and related EU Action Plan on Energy Efficiency (APEE) have set the stage for dramatic improvements in the energy performance of buildings and appliances, and efforts in individual countries are starting to yield dividends. While the scope of our assessment did not extend to a full assessment of possible improvements or increased application of the EPBD or Action Plan, it is clear that these policies in themselves are not enough to attain 40 per cent or more reductions in greenhouse gas emissions in European's building stock by 2020. Policies such as the following would in addition be needed to bring about the transition:

- **The EU's Energy Performance of Buildings Directive could be extended to all buildings and its standards tightened.** Achieving the rapid (5 per cent per year) retrofitting of nearly all (90 per cent) existing buildings to passive house or equivalent standards would require the EPBD to be extended to all buildings (even those below current size thresholds of 1000m²) a tightening of its standards to passive house levels through codes and retrofit standards, and for all European Union countries to adopt these (or equivalent) policies. In any revision of the EU Action Plan on Energy Efficiency (APEE) it is important that binding energy efficiency targets are set that are in line with achieving the domestic target of 40 per cent emission cuts by 2020. This is a crucial over-arching measure needed to ensure that energy savings are achieved all over not only in buildings but also in industry, transport and agriculture.

- **Access to Capital to Finance Retrofits and Scale-up Efficiency Measures.** Significant barriers to making investments in building energy efficiency have involved lack of access to capital, short pay-back requirements of homeowners and investors, "split incentives" between building owners and renters, and lack of qualified contractors. Low-cost capital and other financial incentives will be needed to address these concerns and provide certainty to the market, and technical assistance is needed to help the retrofit industry expand rapidly to fill the need. The program to retrofit 90 per cent of Europe's housing stock to passive house standards will require a program to disseminate best practices on passive house retrofits to contractors throughout Europe and assist new businesses in getting established through employee training and technical assistance programs.

- **Performance targets for Appliances and Standards for the Use of Renewables and Heating and Cooling.** Building on the APEE, the Directive on End-use efficiency and energy services, and the Directive on Energy using products, specific energy consumption standards will need to be set, with specific timetables, to set an aggressive timetable to meet best available technology standards. Standards would need to apply to equipment used in residential, commercial, and agricultural applications. To achieve this, more coherent legislation needs to be established to close gaps and set clear responsibilities. A legal framework is needed which ensures that all relevant legislation contributes fully to reaching the 2020 target of the scenario.

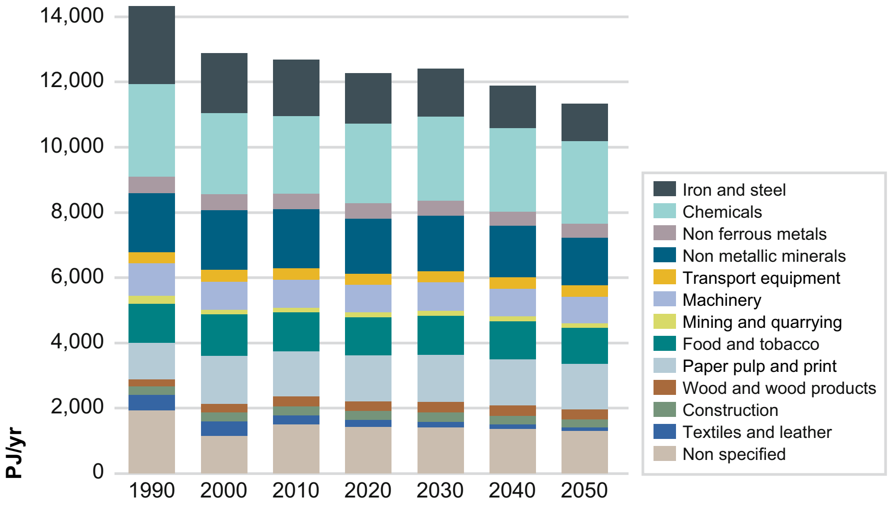

Figure 9: Baseline industrial energy demand by sector

A few key heavy industries currently account for a large fraction of industrial energy use: Iron & steel, chemicals, non metallic minerals (including cement), and paper & pulp together accounted for 67 per cent of final industrial energy consumption in 2005. Note that "non metallic minerals" is itself dominated by cement manufacture. In our scenario analysis we assume the relative importance of these industries remains largely unchanged into the future. The chemicals sector energy use shown here does not include energy use for oil refining – oil refining is treated as a "transformation" sector.

4.2 INDUSTRY

In 2005, direct CO_2 emissions from industry (not including emissions from the generation of electricity and heat used in industry) accounted for about 12 per cent of all energy sector GHG emissions in Europe.[15] But achieving deep cuts in industrial emissions will be challenging since the industrial sector will in some areas need to be expanded to provide the infrastructure upon which the mitigation scenario depends.

Figure 9 shows baseline industrial energy demands by sector. Notice that energy consumption (and thus GHG emissions actually decline slightly between today and 2050). This in part reflects continuous "autonomous" improvements in energy intensity (*i.e.* improvements not requiring any additional active policies) and a tendency for all states to approach the best available industrial energy use practices but it also reflects a continued decline in the size of the industrial sector in Europe, which is itself partly attributable to the continued off-shoring of industrial production to countries outside Europe (countries whose industrial sectors often operate at higher energy and carbon intensities than those within Europe). In other words, the figures shown here *underestimate* Europe's industrial energy use and GHG emissions (see also the footnote on this page).

4.2.1 Iron and steel

Steel will be required for building the new transport infrastructure, vehicles, and buildings that form part of the mitigation scenario in other sectors. Steelmaking involves multiple stages each of which operate at high temperatures and require huge energy inputs. In each of these stages there are opportunities for efficiency improvements. Our baseline scenario already assumes significant efficiency improvements, and the mitigation scenario therefore assumes only modest additional improvements. More important for the mitigation scenario is the opportunity for fuel switching. One of

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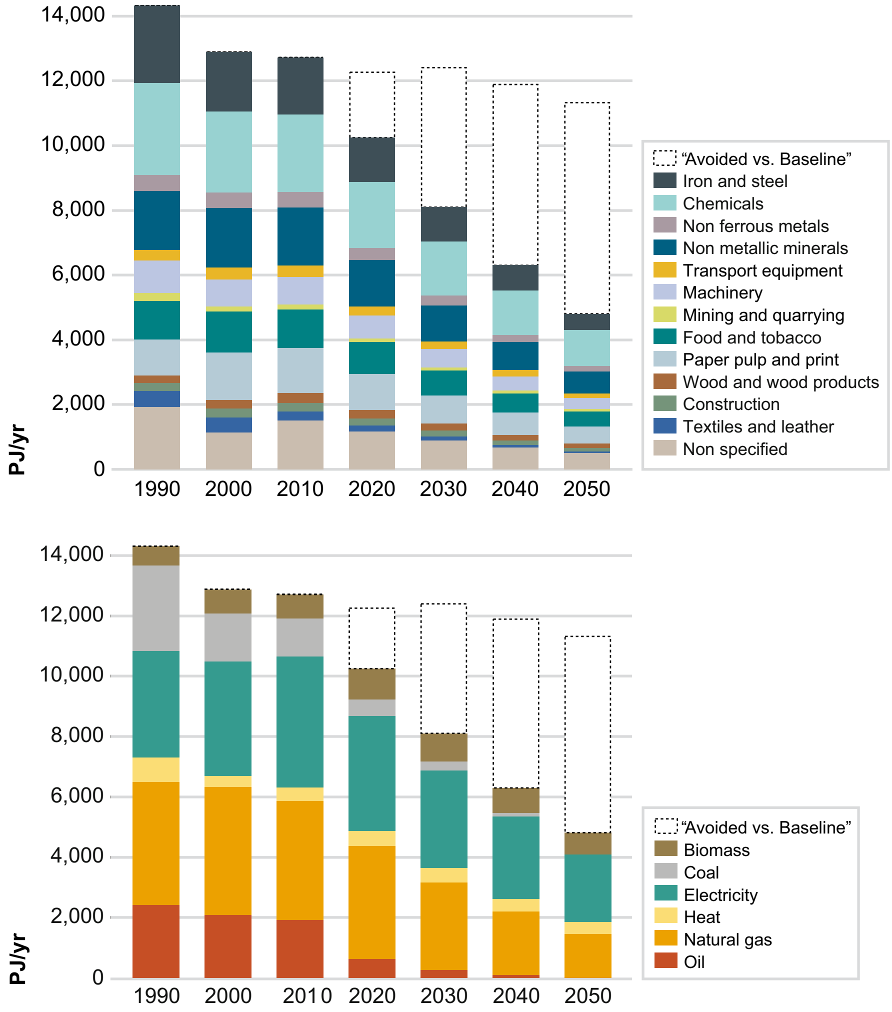
[15] In this report, we account only for energy use and emissions occurring within Europe's borders: a so-called production-based approach. This approach was chosen for simplicity and because it is corresponds to the way in which national energy statistics are recorded by the IEA and others. A second approach estimates emissions based on the consumption of products in Europe regardless of where they were produced. This approach (which would actually be more appropriate for the purposes of this study) assigns responsibility for emissions to consumers instead of producers. A recent SEI study for the UK Government calculated that consumption-based accounting of UK emissions would yield far higher estimates of emissions. The report showed that rather than going down by five per cent between 1992 and 2004 as is commonly estimated, the UK's CO_2 emissions have actually gone up 18 per cent on a consumption basis (Weidmann, 2008).



Figures 10 and 11: Mitigation industrial sector energy demand by sector and by fuel

Energy demands are reduced significantly versus the baseline scenario across all major industrial sectors and there is a significant shift away from using fossil fuels toward greater use of process heat and electricity. Overall industrial energy demand decreases by 62 per cent by 2050 compared to 2010. This corresponds to an annual average reduction of 2.4 per cent/year between 2010 and 2050.

the problematic issues in steelmaking is the reducing agent for making iron. The most common agent today is carbon from coke, and its reduction results in CO_2. In the past a common reducing agent was carbon from charcoal, and this and other options are possible for the future, including natural gas, hydrogen or reduction through electrolysis without a reducing agent. All these options allow iron to be reduced with much lower levels of CO_2 production.

Aside from switching the reducing agent, CO_2 emissions can also be reduced through fuel switching. Perhaps the most promising route is to replace blast furnace iron with direct-reduced iron (DRI). Unlike the iron from a blast furnace, DRI can be used by electric arc furnaces (EAF) to make steel. EAF can also make use of scrap iron, which can significantly reduce the amount of energy needed in steel production. In the mitigation scenario, iron and steel production shifts gradually from the mix seen in 2006 toward DRI fuelled by natural gas or biomass, both of which would feed into electric arc furnaces (EAF). CO_2 emissions could also be further reduced in these processes through greater use of scrap metals. In such a process, the natural gas and biomass provide the reducing agent that is needed by the DRI process to convert iron oxides to iron. EAFs are in wide use today, and produced 40 per cent of Europe's total steel output in 2007 (World Steel Association, 2008). They are mostly used for processing scrap, and there is little penetration of direct reduced iron (DRI) despite nearly a century of development of the process, largely due to its cost.

However, a number of DRI technologies have recently been developed, and it may gain in importance in the future as it provides a promising route for reducing greenhouse gas emissions.

The main constraint on switching to biomass-based DRI is the availability of the biomass resource. This is a significant constraint, making it difficult to achieve 100 per cent reductions in emissions from iron and steel production by 2050. In our mitigation scenario it is assumed that biomass-based DRI produces 40 per cent of Europe's iron and steel by 2050, with another 50 per cent coming from natural gas based DRI. Existing technologies account for the remaining 10 per cent in 2050.

4.2.2 Nonmetallic minerals including cement

As with iron and steel production, cement manufacture requires high temperatures and involves a chemical transformation that releases CO_2 from the raw material. In fact the non-energy chemical process emissions from cement are a very important source of CO_2, accounting for approximately 2/3 of all emissions from cement production. Cement production thus poses huge challenges for reducing emissions. At the same time, cement is essential for constructing the transportation infrastructure and buildings that are called for in the mitigation scenario.

However, there are several options for improvements in current cement-making processes as well as for substituting waste material for virgin feedstocks (IEA, 2007, 2008a). However, the most that these options can offer is a reduction in CO_2 emissions, rather than a fully CO_2-neutral product. More recently, the possibility of producing cement alternatives with the potential to sequester CO_2 have begun to be explored (Biello, 2008, ENR, 2009, Hirschler, 2009, Pearce, 2002). However, these remain very far from commercialisation and are likely to face huge hurdles before being widely adopted in part because of understandable concerns in the construction industry over the structural safety of building products.

It is also possible to reduce carbon dioxide emissions in the cement sector by replacing calcium carbonate clinker with substitutes such as slag from iron and steel production. In our mitigation scenario we assume that some of the carbon-sequestering cement alternatives do reach production, but not at large enough scale to be a net sink. In combination with substituting clinker with waste materials, this leads to an assumed 12 per cent reduction in process emissions by 2020 relative to the baseline, and 42 per cent reductions relative to the baseline in 2050.

Improvements in energy intensity in the cement sector in our mitigation scenario reflect the adoption of best practices so that energy use is 15 per cent below the 2020 baseline and 55 per cent below the 2050 baseline values. Fuel switching also plays an important role in reducing the CO_2 intensity of cement production with natural gas, biomass and combustible wastes gradually replacing coal and oil use in the sector.

4.2.3 Chemicals

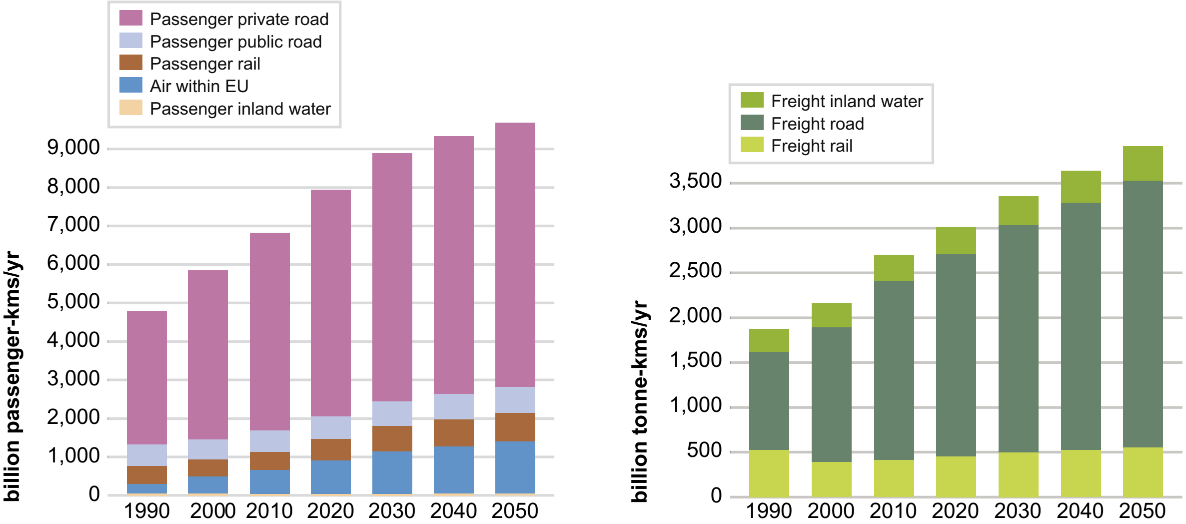
The chemical industry is another of the major contributors to carbon emissions within the industrial sector. The emissions are due in large part to the direct use of fuels for generating the heat required to carry out chemical transformations, with much of the energy being used to create basic chemical constituents to be used as building blocks for a variety of products (IEA, 2007, 2008a).

In our mitigation scenario the energy intensities offered by the best available technology today are reached by 2020, a roughly 15 per cent saving (IEA, 2007) versus 2006 values. Thereafter, we assume that intensities continue to decline to about 30 per cent of their 2006 values in 2050.

The scenario also assumes a transition away from coal and oil to biomass, natural gas, electricity and increased use of heat from biomass-fired CHP, reflecting how natural gas can substitute for oil, and biomass for coal, in many chemical processes, and how heating can be done using process heat or using efficient ultrasound or microwave-based electrical heating.

4.2.4 Other industrial subsectors

Remaining industries contribute less to GHG emissions. For this reason and due to the limitations of this study, they are developed in less detail in our mitigation scenario. However, there is a general feature of industry that was highlighted in each of the preceding industrial subsectors: namely that industrial processes often rely on chemical or physical changes that occur at high temperatures requiring large amounts of energy. For this reason, just as in the chemical industry, we assume that biomass-fired CHP-based process heat and various forms of electrical heating can substitute for coal, oil and natural gas and that energy efficiency can be improved well beyond the levels in the Baseline scenario. Energy intensities in these sectors decline to 14 per cent below baseline levels by 2020, and 45 per cent below baseline levels by 2050.



Figures 12 and 13: Passenger and freight demand in the Baseline scenario

These two charts illustrate the significant growth expected in both passenger and freight transport in the Baseline scenario. Overall, passenger-kms grow at about 0.9 per cent per year, and freight grows slightly more slowly at 0.7 per cent/year, with the most significant growth seen in private cars and air travel.

4.2.5 Results

Energy consumption for the industrial sector as a whole drops dramatically by 2050 as shown in Figures 13 and 14.

4.2.6 Key policies

- The scenario sees major changes in the industrial production methods. In the case of the iron & steel industry the required technologies have been available for some time, but are not yet in widespread use. In the chemical industry the principles of green chemistry and electrical heating are well understood but more experience is needed before they can have a major impact. For cement, the alternatives are in the very earliest stages of development and much research is required before they can be widely used. With this in mind, the recommended policies are:

- **Need for regulations and subsidies that help to change production techniques** by setting *e.g.* standards for production , by prohibiting the most polluting production techniques or by subsidising the right ones by *e.g.* tax incentives

- **Accelerated research and development of new techniques and testing of new materials.** The burden of testing and development cannot fall entirely onto start-up firms. If promising new techniques and materials are to reach broad acceptance in the time frame of this scenario then they must be able to demonstrate their usefulness extremely rapidly. This will likely require governmental support for demonstration projects and testing facilities.

- **Basic research into alternative chemical feedstocks.** The chemical industry today relies heavily on a few basic “building block” chemicals that are synthesised from petroleum products, while a biomass-based chemical industry is likely to make use of a broader chemical palette (Clark & Deswarte, 2008). To be as effective as the current chemical industry in developing new products these biological constituents must be better understood.

- **Incentives to shift toward less fossil-intensive techniques.** So far the European Emission Trading Scheme ETS has yet to deliver substantial emissions cuts. To make the system deliver and to trigger the necessary changes in production techniques, the overall cap of the system should be set in line with what is needed for a domestic 40 per cent target within the EU by 2020. In addition, various loopholes need to be closed, and problematic features such as the lack of auctioning of pollution permits should be re-examined. This latter change would also provide a means for raising part of the finances needed for tackling climate change. In addition to strengthening the ETS, additional measures are also likely to be needed including carbon taxes.

4.3 TRANSPORT

Transportation of people and goods is responsible for 32 per cent of the European Union's CO_2 emissions in 2010 and is the sector with the fastest growing emissions. Most forms of transport directly burn fossil fuels, while those that use electricity (such as passenger and freight rail) often rely indirectly on coal or nuclear fuelled electricity. Transport-related emissions have also grown rapidly from 915 $MtCO_2e$ in 1990 to 1221 $MtCO_2e$ in 2005. Two important trends help explain this rise: goods and people are travelling further, and they are doing so increasingly by car and lorry rather than by rail. Additionally, passengers have been making an increasing percentage of their travel by aeroplane: eight per cent passenger-kilometres in 2005 compared to five per cent in 1990.

Unless dramatic shifts in transportation habits and technologies are implemented, these increases in passenger and freight travel are likely to continue for many years since there are few signs of saturation in the demand for transport in most European countries. Our baseline scenario indicates that given a continuation of the trends described above, transportation emissions will grow to 1335 $MtCO_2e$ in 2020 and 1441 $MtCO_2e$ in 2050.

Figure 12 displays the overall projected increase in passenger transportation in the baseline scenario divided by major mode (road, rail, air and water). Figure 13 shows the same trends for freight transport in the baseline scenario.

4.3.1 Key mitigation options

Momentum is gathering to reduce emissions from transportation in the European Union, and recent and ongoing efforts to increase fuel economy standards for vehicles, implement high-speed rail, and electrify the rail infrastructure are all likely to yield benefits. Yet current and planned efforts are not likely to be sufficient to substantially reverse the trend of dramatically increasing transportation emissions.

Reducing emissions from transportation in the European Union will not happen quickly, as infrastructure and evolving urban forms in most countries all tend to support the continued dominance of road and air transport. Our scenario envisions a strong departure from this trend, bringing transportation energy demand back to 1990 levels by 2020 while continuing to support a highly mobile European populace.

Our projections of mitigation potential in the transport sector build from historical data from the IEA and EUROSTAT (EC, 2009) and projections of baseline passenger and freight travel from the European Commission (EC, 2008). Based on these projected trends, we assess the potential for mode shift, increases in vehicle efficiency, and the penetration of hybrid and electric vehicles based on various studies. In particular, we adopt technical potentials for vehicles directly from the International Energy Agency (IEA, 2008) and also assume a rapid shift to these technologies will occur as soon as they become available, assisted perhaps by government financial incentives, where necessary. We allow overall levels of intra-EU passenger travel to increase as incomes rise, although overall levels of per capita passenger transport are lower than in the baseline scenario: reflecting policies to reduce overall transport demand such as better urban planning, the promotion of bicycles and walking and policies to discourage air travel. For freight, logistical improvements and general dematerialisation of the economy leads to much more modest increases in freight travel compared to our baseline scenario.

4.3.2 Passenger transport

Our mitigation scenario calls for dramatic shifts in passenger transport. In particular, it includes the following:

- **Passengers make a greater proportion of their trips by rail instead of in personal vehicles or by air.** A large expansion of the rail network (over double the current infrastructure by 2050) and increases in service frequency and quality enable a strong shift in trips from road and air to rail. While 72 per cent of trips within the European Union were made by car in 1990 and 75 per cent in 2005, this share is reduced to 69 per cent in 2020 and 43 per cent in 2050 in our mitigation scenario, with these trips instead occurring by a mix of bus and rail. Furthermore, by 2050, 80 per cent of intra-EU flights under 1000 km switch to rail by 2050.[16] The norm for rail in the future is speed, safety, comfort, and convenience that make rail preferable to cars or aeroplanes for most journeys.

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[16] 1000 km is assumed to be the upper end of where high speed rail could compete with air based on duration of the trip and customer convenience. Approximately 80 per cent of the passenger-km travelled on the top 20 air travel routes in the European Union are on routes under 1000 km, based on our analysis of data published by EUROSTAT (EC, 2009). Some trips will still be made by air (*e.g.* trips to vacation islands for example) so we do not assume 100 per cent of the under-1000 km airline trips can be substituted by rail.

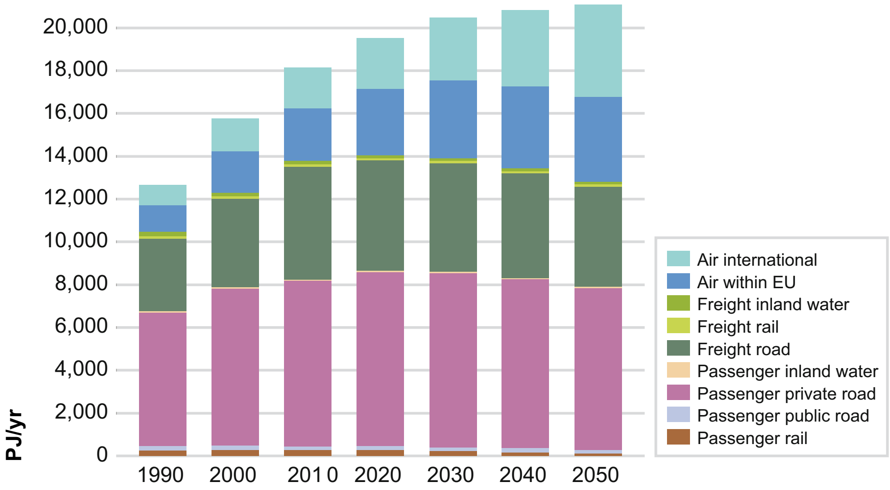

Figure 14: Transport energy demand in the Baseline scenario

While the demand for transportation increases this is expected to be partly offset by improvements in fuel economy, particularly in road transport. However, overall energy use continues to grow throughout the scenario period, with the largest growth coming from air travel. Note: this chart excludes energy use for international maritime bunkers. Overall energy use for transport grows by 16 per cent versus 2010 levels.

- **Passenger travel distances continue to grow through 2020 but stay constant thereafter.** Increasing intra-European transit connectivity and economic liberalisation will continue to provide expanded opportunities for Europeans to travel. While per-person passenger travel has been rising consistently since 1990 this trend abates by 2020, as people become satisfied with a level of personal mobility over 50 per cent higher per-person than in 1990. Any increases in personal mobility and travel for pleasure beyond 2020 are assumed to be offset by reduced business travel in favour of virtual meetings using "telepresence" technologies, reduced transit distances in urban areas due to increasingly compact communities, and increasing number of personal trips by foot or by bicycle.[17]

- **Consumers shift to hybrid and electric cars as soon as they become available and the retirement of older vehicles is accelerated.** Hybrid technologies are now well-established and rapidly gaining market share in Europe and the USA. If manufacturers are required to phase-out larger internal combustion engine vehicles, implement rapid hybridisation and electrification of the private vehicle fleet, and consumers retire their older vehicles at a moderately accelerated rate, the stock of vehicles in 2020 could be approximately 21 per cent hybrids, two per cent electric, and 78 per cent internal combustion engine vehicles. The energy intensity of the fleet of internal combustion engine cars also becomes about 30 per cent less energy intensive by 2020: a significantly more aggressive target than the current EU regulations on CO_2 which call for a 19 per cent decrease in energy intensity for new vehicles by 2015 vs. current values.[18] This transition concludes so that by 2050, virtually all cars on the road are fully electrified.[19]

- **Carpooling increases modestly.** The average number of passengers per vehicle (the load factor) was 1.7 in 1990, declining to 1.6 in 2006 (EC, 2009). Increased use of carpooling (and the

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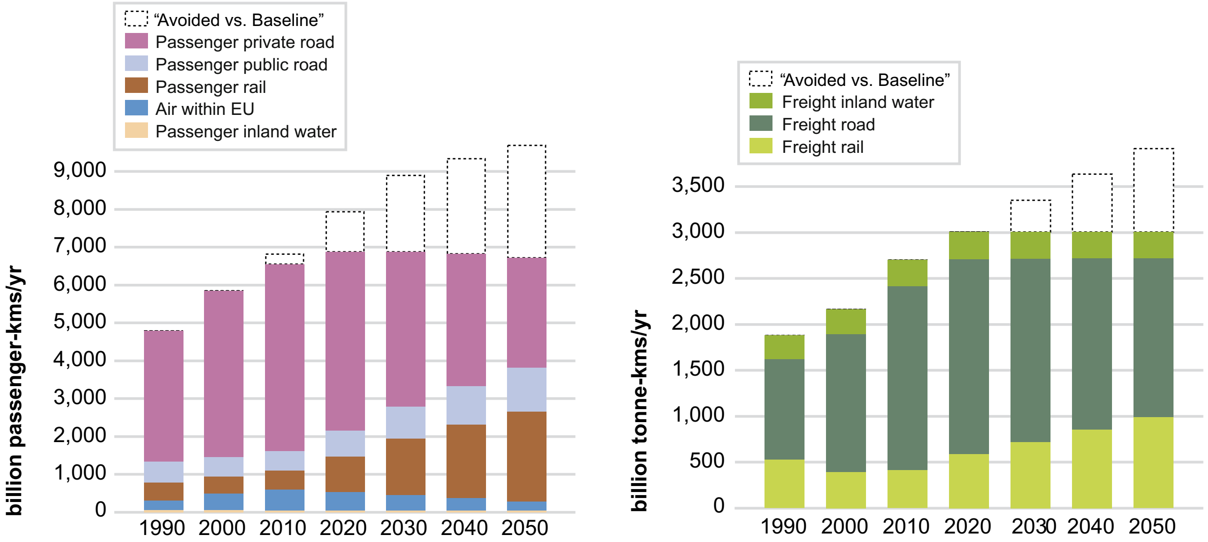
[17] Trips by foot and bicycle are not included in standard transport statistics. As a result, increasing trips by foot and bicycle, in effect, reduces overall passenger travel but is not directly represented in our analysis. Although they are expected to remain a fairly small share of overall passenger travel, increases in foot and bicycle travel do help to lower the overall passenger-km projections in our mitigation scenario.

[18] Current EU regulations call for fleet average emission factors for newly registered vehicles of 130 grams/vehicle-km by 2015, compared to the current EU wide average in 2008 of about 160 grams/vehicle-km: a decrease of about 19 per cent. Note however that this decrease is for new vehicles only. The stock average will decrease much more slowly.



Figures 15 and 16: Passenger and freight transport in the Mitigation scenario

Both passenger and freight show a reduction in overall activity versus the baseline scenario, with the significant growth seen in the baseline scenario eliminted after 2020. This is partly due to the lower overall level of economic activity foreseen in the mitigation scenario (reflecting our assumptions about the beginning of a transition to a more sustainable and less consumption-oriented future). But it also reflects specific policies to reduce travel. Apart from the overall reductions, the scenario also shows significant modal shifts: away from private road and air travel and toward rail travel. The modal share of passenger cars decreases from around 75 per cent in 2010 to 69 per cent in 2020 and 43 per cent in 2050. Passenger rail increases from eight per cent today to 14 per cent in 2020 and 35 per cent in 2050. The modal share of air travel within the EU remain roughly constant at seven per cent in 2020 but falls to four per cent by 2050. Similar patterns are seen from freight transport with the modal share of road transport falling from 74 per cent in 2010 to 70 per cent in 2020 and 58 per cent in 2050. Rail freight increases from 15 per cent in 2010 to 20 per cent in 2020 and 33 per cent in 2050.

declining ownership of personal vehicles) reverses this trend, such load factors rise gradually, reaching 1.75 in 2050.

- **Rail becomes fully electrified.** The trend in the EU27 has been for rail to be electrified, with 58 per cent of rail lines being electrified in 1990 and 68 per cent in 2006 (EC, 2009). In our mitigation scenario, this trend concludes with all rail electrified by 2030.

- **By 2050, 65 per cent of buses are electrified.**

- **Aeroplanes and ferries become more efficient.** Fuel use per passenger-km in aircraft decreases by a further nine per cent in addition to the 29 per cent decrease in intensities seen in the baseline scenario between 2010 and 2050. Similarly, the energy intensity of passenger travel by ship decrease by 28 per cent between 2010 and 2050.

4.3.3 Freight transport

Like passenger transport, freight transport has seen dramatic rises in both the overall level of activity (as measured in tonne-km) and the proportion of that activity occurring by road. A future low-carbon Europe will require both a slowing (if not reversing) of these trends as well as much lower energy and emissions intensities. Such a shift is accomplished in our mitigation scenario by the following measures:

- **Transport of goods, which has increased rapidly in recent years, levels out.** Increasing levels of product consumption in the European Union has led to steady increases in shipping of freight. While economic convergence in Europe suggests that, for

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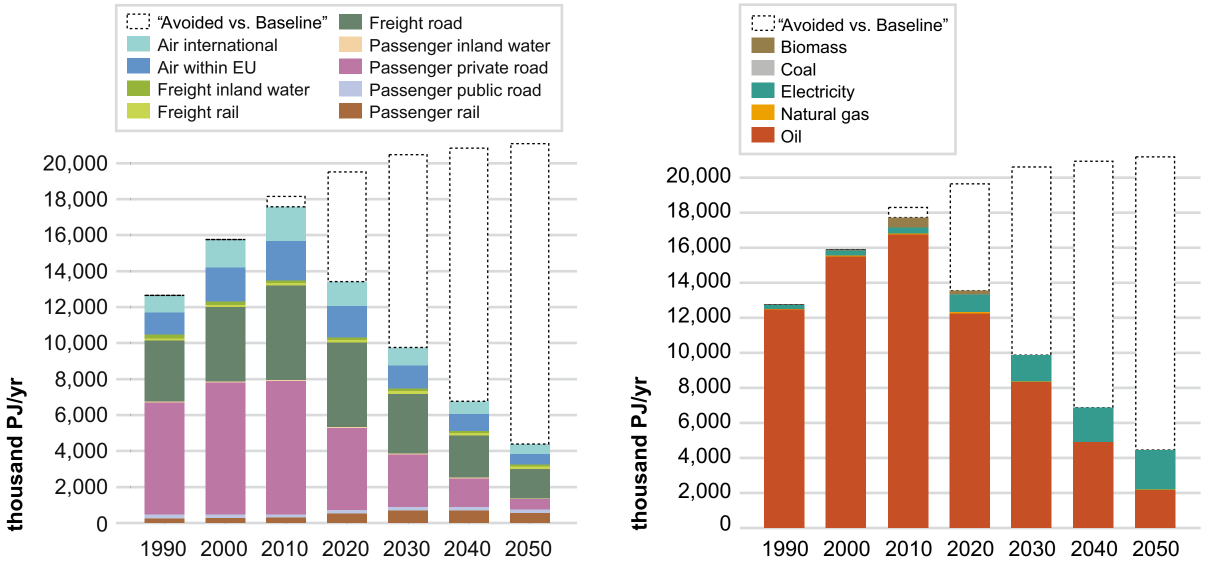
19 The transition to electric vehicles in our mitigation scenario is modelled after that of the "Electric Vehicle Success" Scenario of the International Energy Agency (IEA, 2008a). However, our penetration of electric cars is accelerated versus the IEA's scenario. We assume that electric vehicles use one-quarter the energy per vehicle-kilometer of a standard internal combustion engine based loosely on MacKay (2008).



Figures 17 and 18: Transport energy demand in the Mitigation scenario

Two charts showing how transport energy use is dramatically reduced in the mitigation scenario, due to reductions in overall activity, shift to less energy intensive modes (rail over road and air travel) and the introduction of much more energy efficient and much less carbon intensive technologies such as electric vehicles and fully electric rail travel. Note the growth in the reliance on electricity and the significant decrease in oil consumption but no growth in the use of biofuels. Excludes international shipping energy use.

some segments of the population, this consumption will continue rising, we assume that due to gains in logistical efficiency and dematerialisation (lower levels of material consumptions), this upward trend slows to a maximum of 5,600 tonne-km per person in 2010 and beyond, an increase from its current level of 5,000 tonne-km per person but a strong departure from the ever-increasing trend in consumption of recent decades.

- **An expanded rail infrastructure enables more goods to be shipped by rail instead of by road.** Road haulage has represented an increasing share of freight transport since 1990, reaching 73 per cent of tonne-km in 2005. Driven by the expanded rail infrastructure, this trend begins a reversal such that the shares of rail in freight transport increase from 20 per cent in 2005 to 35 per cent in 2050.[20]

- **Lorries become more efficient and electrified or hybridised and all rail freight is electrified.** By 2050, half of all lorries are electrified or hybridised, with conversion to hybrids beginning slowly in 2015, and then ramping up considerably after 2030. The existing trend towards electrification of rail continues such that rail is fully electrified by 2020. Lorries become 20 per cent more efficient in 2020 than today.[21]

- **Ships on inland waterways become more efficient.** The energy intensity of shipping declines by 28 per cent between 2010 and 2050.[22]

The shifts described above for freight transport are significant, but attainable with a significant technology and societal mobilisation. The gradual halt in growth in freight transport in the future, in particular, reflects a levelling out of consumption in Europe. It can be attained through goods that last longer, use less material, and travel shorter distances.

4.3.4 Key policies

Many trends are underway in Europe that can be expanded to help bring about the transitions described above. For example, high-level policy discussions are underway in the European Commission regarding vehicle fuel economy standards, expanding, electrifying,

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[20] Based on the theoretical shift potential of road transit in Zimmer and Schmied (2008)

[21] Assumptions adapted from those of the International Energy Agency (2008), although we assume a faster growth (and deeper penetration) of electrified lorries than IEA, 2008a.

[22] Based on assumptions in IEA, 2008a

and improving rail infrastructure and improving freight logistics. All of these activities provide a strong platform for the even bolder actions needed to attain the transition described above. While a detailed catalogue of policy actions needed is beyond the scope of this study, bringing about the transition would clearly need to involve at least the following policies:

- **Aggressive vehicle performance and technology standards** for passenger and freight vehicles to bring about a rapid, near-term transition to advanced internal combustion engine vehicle technologies (including, but not limited to, hybrids) and lower prevalence of large cars. Simultaneous to the improvement in vehicle efficiency (which could be accomplished by further strengthening existing emission performance standards for vehicles), assertive policy action would be needed to support the transition to electric vehicles, such as legislation requiring that all cars sold in 2035 must be fully electric.

- **Build-out of the electric transportation infrastructure, including vehicle charging stations.** In concert with manufacturer efforts to aggressively develop electric cars, European governments will need to put in place the infrastructure needed to charge electric vehicles and allow these vehicles to provide excess electricity back to the grid at times of high demand. In addition, electric infrastructure for rail, buses, and freight vehicles (including both wire and charging infrastructure) will be needed.

- **Scale-up of the rail infrastructure, including high-speed rail.** A highly connected transit system is fundamental to economic competitiveness and employment in Europe, a fact recognised by the European Commission when it established the Trans-European transport network. The European Commission has already identified an estimated € 500 billion in investment between 2007 and 2020 on expanded trans-Europe infrastructure. Meeting the goals of our mitigation scenario would require the bulk of this effort to focus on rail infrastructure, and that the Commission and member countries put in place a long-term plan to more than double the rail infrastructure by 2050 while making significant comfort, efficiency, speed, and convenience improvements to the existing infrastructure in the near term.

- **Removing Subsidies for Air Transport:** Direct and indirect subsidies for air transport such as tax exemption for Kerosene, and indirect subsidies to build airports and aeroplanes make flying comparatively cheap. These subsidies need to be abolished to level the playing field with other less damaging forms of transport.

- **Urban planning and land use standards to support transit-, bicycle-, and pedestrian-friendly communities and more transport-efficient urban forms.** Urban transportation plans will be needed to expand, streamline, and improve transportation systems and both invite and accommodate increased use of transit instead of cars. In addition, land use zoning will need to support these compact, transit-friendly, walkable communities instead of development that expands and sprawls into the countryside.

- **Other Measures:** Introducing congestion charges, car free city zones, road pricing, freight charges and weight taxes and in general cutting fossil fuel subsidies are additional measures to channel efforts to the development of public transport.

4.4 AGRICULTURE

Energy demand for agriculture is less than 2.2 per cent of total final energy demand in the EU and few studies of GHG mitigation address agricultural energy use in any detail. For this reason we have not examined this sector in detail in this study. Reduction options are in some cases limited by the distance from electricity infrastructure (thereby limiting fuel-switching possibilities), but opportunities do remain. Adapting assumptions and extrapolating from Brown and Elliott (2005), we assume that increasing efficiency in irrigation pumps, motors, and other agricultural machinery can yield 16 per cent reductions in energy use in 2020 and 35 per cent in 2050, both relative to projected baseline demands. We also assume that significant oil- and diesel-using equipment switches to electric-powered versions by 2050.

In addition to the small level of energy use in the agriculture sector, the IEA energy statistics also includes line items for "non-specified" fuel use, which in 2006 accounted for only 1.6 per cent of total final energy demand in the EU27. This sector also has not been examined in any detail. Instead, the energy intensity in this sector (per unit of GDP) is assumed to decrease at the same rate as in the industrial sector as a whole (see below). Finally, non-energy use of fuels (*e.g.* as feedstocks in the petrochemical sector) is included in our analysis for completeness but is assumed to have no associated GHG emissions.

4.5 NON-ENERGY SECTOR EMISSIONS

While land use in Europe is currently a sink for CO_2 emissions (that is it actively sequesters CO_2), the agriculture, forestry and solid waste sectors are by contrast significant sources of the highly potent greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O). Industrial processes (*i.e.* other than the direct combustion of fuels) are another significant source of CO_2 emissions. In particular, the production of cement, already mentioned in terms of its energy requirements in Section 4.2.2 is a major source of CO_2.

Our mitigation scenarios projections of non-CO_2 greenhouse gases (*e.g.*, methane, nitrous oxide) are based on a recent study for the European Commission (Amann, 2008). That study relies on baseline-like projections of energy use, agricultural activity, and other trends as provided by individual member countries or by leading models where individual countries did not supply data. From these projections, the study assesses more than 60 individual measures to control methane emissions, 10 measures to control nitrous oxide emissions, and 15 measures to control other high global warming potential gases. It assesses potential baseline adoption of these practices based on the latest policy conditions and then assesses mitigation potential above-and-beyond the baseline for the year 2020. We have adopted these potentials for 2020 and, given the high levels of uncertainty have conservatively assumed that the mitigation potentials can be increased a further 10 per cent over those found in the study by 2050.

4.5.1 Land use

Land use, land use change, and forestry (LULUCF) are fundamental to decreasing global greenhouse gas emissions and to removing CO_2 from the atmosphere. Yet of all the options to reduce or remove GHG emissions, those associated with land use can be among the most controversial, particularly as the accounting of how much CO_2 has been removed is very complex and there are competing uses of land from food production through to biodiversity protection. Our baseline estimates of net LULUCF sequestration through 2007 are taken from the latest European Community Greenhouse Gas Inventory (EEA, 2009). The net removal (*i.e.*, sequestration) of emissions from the atmosphere by LULUCF is primarily through the growth of trees but also, to a smaller degree, due to sequestration of carbon in agricultural and grassland soils. Projections for net removals due to LULUCF from 2008 and beyond rely on Europe-specific modelling results from the IMAGE model as reported in the IPCC's *Fourth Assessment Report* (IPCC, 2007). These projections show a decline in net sequestration in Europe's forestry sector through 2033, presumably due to saturation of carbon sequestered in trees and a slowing of the rate of reforestation in Europe. We adopt this same trend in our projected baseline for LULUCF emissions.

As for mitigation potential in forestry, the studies summarised in the IPCC's *Fourth Assessment Report* suggest a potential on the order of 90 $MtCO_2e$ to 295 $MtCO_2e$ annually in the medium term (2030 to 2040). However, these same underlying land resources that would provide the increased sequestration potential (*e.g.*, timber thinnings, marginal lands, agricultural lands) could also be used for biomass production. Given the need to avoid double-counting of the biomass potential from these land resources, we conservatively assume that no additional sequestration will occur in Europe's LULUCF sector as compared to the baseline. This assumption would allow for the production of biomass up to the environmentally-compatible potentials derived by the European Environment Agency (EEA, 2006) and would more than suffice for the biomass required in our scenario (which is used primarily as a feedstock for CHP plants). In reality, there may be additional opportunities to sequester carbon that would not compete with biomass production (such as some forms of soil sequestration through a shift to agro-ecological farming on agricultural lands). However, we have not attempted to assess or include these options.

4.5.2 Agriculture

Most emissions from agriculture result from fertilising fields, which generates emissions of nitrous oxide (N_2O), and farming livestock, which generates emissions of methane associated with enteric fermentation and manure. Technical strategies to reduce emissions from agriculture therefore focus primarily on fertiliser and livestock practices. Mitigation practices included in our scenario include: [23]

- Installation of anaerobic digesters to treat animal manures, primarily from cattle and pigs.

- Altered livestock feeding practices to reduce emissions from enteric fermentation. Changes in feed can reduce the production of methane in ruminant livestock's unique digestive tract.

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[23] All of these technical mitigation strategies are adopted directly from Amann *et al.* (2008).

- Alterations in fertiliser amounts and timing. Reductions in fertiliser use, improved timing of fertiliser application, "precision farming", and use of more-advanced fertilisers with nitrification inhibitors can dramatically reduce N_2O emissions from agriculture.

- Phase-out of agriculture on histosols, which are peaty or boggy soils very high in organic matter.

In addition to these technical measures, our scenario envisages a switch in European's diet to a less meat-intensive and healthier diet. The climate and other environmental impacts of raising livestock have long been well established. Similarly, the adverse health impacts of meat are well known. By switching to a less meat-intensive diet, Europeans could be healthier and contribute to reduced GHG emissions. We assume that by 2020, Europeans have, on average, switched to a healthy level of meat consumption.[24] This type of diet is approximately 60 per cent less meat-intensive than today's for the average European.[25] Adopting such a diet would not only result in reduced direct methane and N_2O emissions from livestock, but would also reduce N_2O emissions from fertilising crops used to feed the animals. Furthermore, reducing meat production could potentially free up large quantities of land (both direct pasture land but also the land needed to grow feed crops) that could be redirected to growing biomass crops or used for carbon sequestration.[26]

Additional GHG mitigation potential is likely possible in the agriculture sector, beyond what we have included in our mitigation scenario. In particular, our scenario does not include expansion of no- or low-till practices that may sequester carbon in agricultural soils beyond current levels. Although the effects of such practices could be significant, uncertainty concerning the permanence of carbon sequestered in soil leads us to ignore this option. In addition, advances in polyculture or permaculture farming techniques, where multiple crops are grown on the same land and waste inputs from one practice are used as direct inputs to another, could reduce emissions further and also potentially allow land to be more productive, freeing up even more land either for GHG sequestration (such as growing trees to absorb CO_2). Neither of these options is included in our scenario.

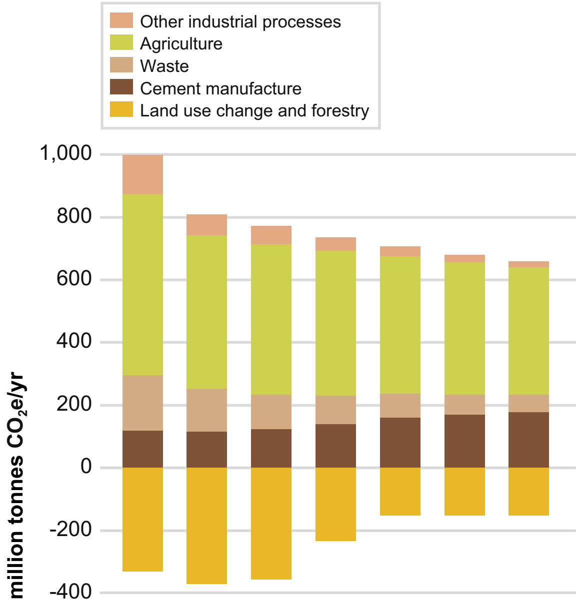

Figure 19: Non-energy related GHG emissions in the Baseline scenario

Includes CO_2, CH_4 and N_2O emissions. Excludes high GWP gases (HFCs, PFCs, SF_6). "Cement" includes process related emissions from cement manufacture. These emissions are in addition to the energy-related emissions from cement manufacture described in Section 4.2.2). Note how land-use change is a significant but declining net sink for CO_2.

4.5.3 Waste and wastewater

Landfill and wastewater treatment plants are significant sources of methane (CH_4). According to a report by the US EPA, emissions of methane from landfills in Europe could be reduced by nearly 90 per cent (US EPA 2006). Mitigation options for waste included in our scenario include recovery and flaring or energy use of methane at landfills, recycling of paper and wood waste, composting and biogasification of food waste, and waste incineration. Mitigation options for wastewater include improved treatment of urban wastewater at

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[24] Specifically, we adopt the "healthy diet" of Stehfest *et al.* (2009).

[25] In particular, we assume that meat and egg consumption falls from its current level of 245 grams per person per day (as defined by FAO (2007) and including pre-consumer wastes) to 102 grams per person per day as in Stehfest, *et al.* (2009), with the steepest reductions occurring in pork consumption (an 87 per cent decrease) and beef/mutton/goat (a 69 per cent decrease) followed by poultry and eggs (a one per cent decrease).

[26] The stated diet shift could release nearly nine million hectares of land, after considering increased land use to produce the grain and pulse crops needed to supplement the lost protein from meat. Our assumptions regarding land demands for each type of animal are also taken from Stehfest *et al.* (2009).

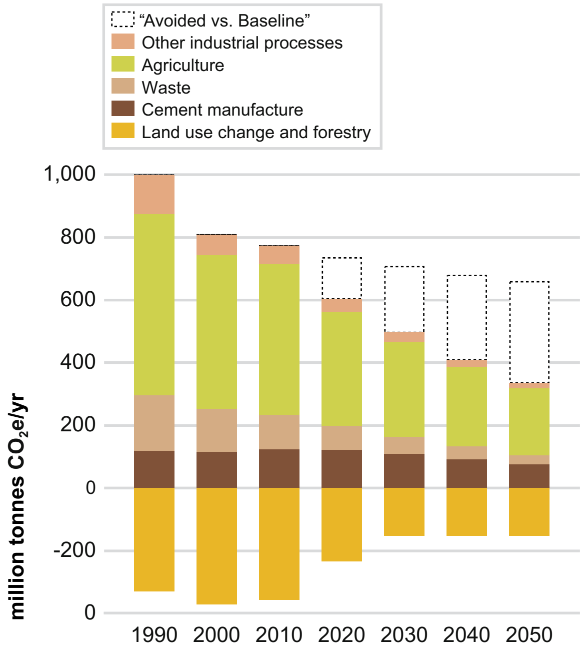

Figure 20: Non-energy related GHG emissions in the Mitigation scenario

Land use change sinks are conservatively assumed to remain unchanged versus the baseline scenario. Reductions in net emissions come from cement, waste and agriculture.

treatment plants (including methane capture), rural wastewater treatment in latrines and septic tanks, and improved treatment and methane capture at industrial wastewater facilities. The majority of these measures can be implemented by 2020.[27]

4.5.4 Industrial non-CO_2 emissions

Several industrial sectors and practices generate methane (CH_4), nitrous oxide (N_2O), or other more potent greenhouse gases. Options in our mitigation scenario for these gases include the capture of methane from coal mines and oil and gas sector facilities, and upgrading of natural gas distribution networks.

4.5.5 Results

The results of our scenario indicate that non-energy sector GHG emissions could be reduced from 670 $MtCO_2e$ in 1990 to approximately 370 $MtCO_2e$ in 2020 and 183 $MtCO_2e$ in 2050, representing a reduction of 73 per cent, compared to 1990 or 64 per cent versus the net 2050 emissions in the baseline scenario.

Figure 20 depicts the aggregate effects of the measures described above on non-energy sector emissions in the mitigation scenario.

4.5.6 Key policies

To a large degree, reductions in non-CO_2 emissions to date have occurred due to market and economic factors. Many of these reductions are expected to continue. Policies will be needed, however, to increase the efficiency with which the market can offer and implement the technologies and practices, as well as to advance practices that are unlikely to be enacted without regulation or further market support. In particular, performance or process standards and incentives for particular emission sources and practices may be needed. For example:

- Our scenario indicates that methane emissions from livestock raising and the level and timing of fertiliser emissions are two areas with significant potential for emission reductions. Government plans and regulations could set ever-tightening standards for these emissions and/or offer financial incentives for desired practices. In addition, government technical support for precision farming and other N_2O-reducing techniques and technologies (such as nitrogen inhibitors and GPS-enabled fertiliser application equipment) could help speed implementation of good practices.

- The planned 2013 reform of the EU's Common Agriculture Policy could be used as an opportunity to develop a new food and farming policy for Europe that shifts political and financial support away from climate unfriendly intensive agriculture towards more sustainable forms of farming (*e.g.* based on agro-ecology and the support of biodiversity).

- Food pricing and labelling can be used to encourage the adoption of healthier and less meat intensive diets and thus to reduce livestock emissions.

- The EU Landfill Directive could be expanded to mandate the capture of methane from all landfills and wastewater treatment plants and to maximise diversion of materials that contribute to methane production.

- In oil, gas, and other industrial facilities, standards could be strengthened to limit use and/or release of certain highly potent greenhouse gases.

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[27] All options for waste are taken from Amann *et.al.* (2008).

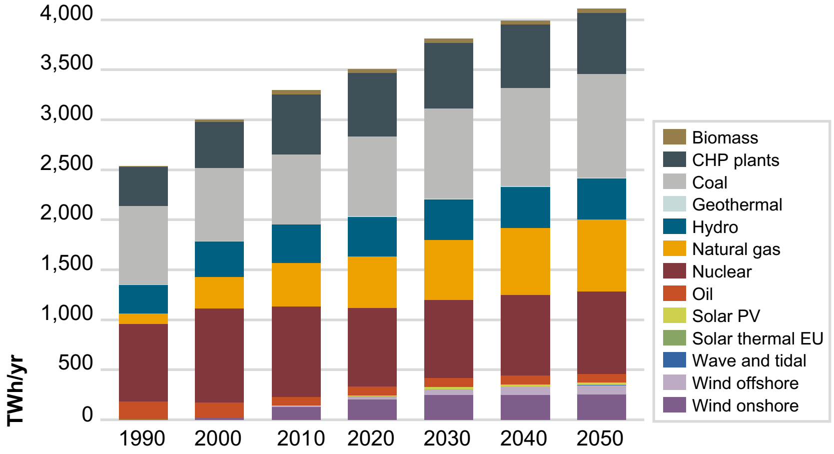

Figure 21: Electric generation in the Baseline scenario

As the demand for electricity increases, so does electric generation. While the baseline sees some growth in wind, fossil fired generation remains dominant. No significant growth is expected in hydro or fossil plants. Thus Europe is expected to become increasingly dependent on imports of energy for electricity generation, although it is questionable if such large supplies of gas will be readily available. This chart includes electricity from CHP plants, which in the baseline scenario are fired by various fuels including coal, natural gas and biomass.

4.6 ELECTRIC GENERATION

4.6.1 Baseline trends

Our baseline scenario reflects historical trends in the electric generation sector extrapolated to 2050 under the assumption of the continued dominance of fossil fuels (primarily coal and natural gas) and the continuation of each country's current stated policies on nuclear power. Gradual efficiency improvements are assumed for fossil generation consistent with the introduction of new efficient generating technologies like integrated gasifier combined cycle for coal power plants and the general adoption of best practices throughout the EU. However, no major shifts in feedstock fuels are assumed and no major new technologies such as carbon capture and storage are included.

Figure 21 shows the resulting baseline generation divided into the major technologies up to the year 2050 and including electricity generated from CHP heating plants (see also: Section 4.7).

Coal, hydro power, nuclear power and natural gas remain the main sources of electricity in the region, but there is also significant diversity in how different European countries generate their supplies of electricity. For example: while in many countries there has been a "dash for gas", in France nuclear power remains the dominant source of base load power. The recent growth of natural gas and wind is expected to continue in the baseline scenario, while nuclear remains an important source, in large part due to its dominance in the mix of the French electric sector and a reinvigoration of interest in nuclear power in some other EU countries such as the UK. Figure 22 shows the baseline generation mix projected for major EU blocks of countries in 2050.

4.6.2 Key options in the mitigation scenario

In order to meet the stringent emissions goals set for the mitigation scenario, Europe will need the complete and early phase out of all coal and oil fired power generation, while natural gas will be relegated to being used only as a backup source of power. As noted earlier, at the request of Friends of the Earth, a number of potential mitigation options have been excluded from consideration. Excluded options include nuclear power and coal-fired generation coupled with carbon capture and storage (CCS). Large-scale use of biomass is also restricted to the amount that can be grown sustainably within Europe and its use is restricted only to CHP plants that can produce both electricity and heat.

With these options ruled out, the mitigation scenario relies heavily on renewable sources of electric generation, such as wind, solar, hydro, geothermal, wave and tidal power. A key question to be addressed therefore is whether these sources of generation can feasibly provide the amounts of electricity required in the mitigation scenario.

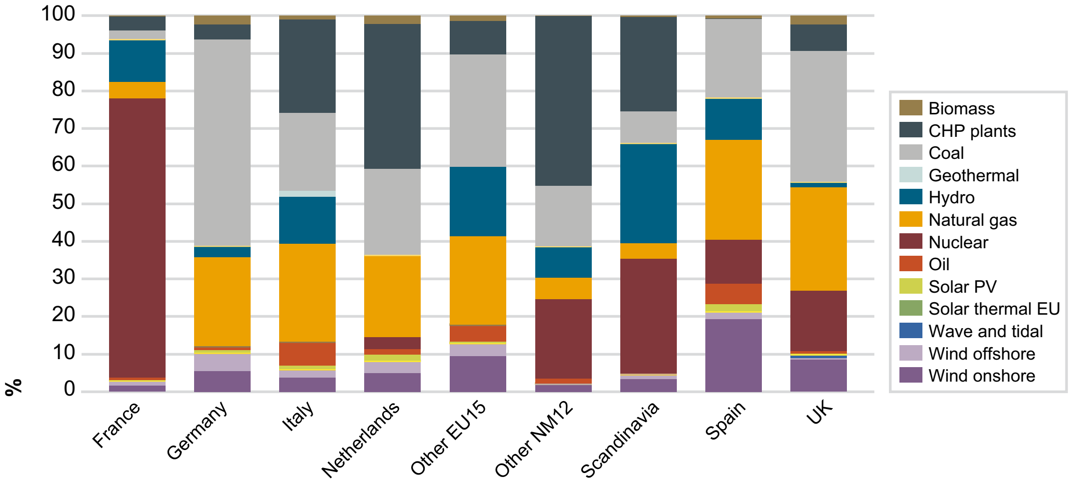

Figure 22: 2050 projected electric generation mix by region in the Baseline scenario

Bars shows the signifucant difference between regions in their reliance on CHP and on different feedstock fuels: particularly coal, natural gas and nuclear.

There are a number of important aspects to answering this question, including:

- Can efficiency measures sufficiently reduce the demand for electricity?
- Are renewable resource potentials sufficiently large to meet the electricity requirements?
- Can the problem of the inherent variability of wind, solar and other intermittent sources of electricity be overcome?
- Can new renewable resources be constructed quickly enough to fill the unmet demands left by fossil plants as they are rapidly retired?

The mitigation scenario addresses each of these questions.

Firstly, in thinking about energy efficiency it is important to note that our mitigation scenario reflects extremely ambitious but we believe plausible assumptions about how much energy efficiency can be achieved by 2050 in all of the final consumption sectors of the economy (buildings, industry, transport and agriculture). However, the scenario by design also reflects an overall strategy of electrification, whereby localised combustion of fossil fuels is eventually eliminated in many sectors in favour of direct consumption of electricity and heat. So for example, in the transport sector electric vehicles replace gasoline and diesel vehicles; while in the buildings sector, heat from CHP systems and electric powered ground-source heat pumps provide most of the heating and cooling loads remaining after massive efforts to improve building shell energy efficiency. The benefits of this strategy are two-fold: firstly it eliminates many small-scale sources of CO_2 emissions and secondly it provides a huge new potential for storing electricity (in the form of electric car batteries).

Thus, while the mitigation scenario reflects huge efficiency improvements (see earlier sections describing energy demands) it also reflects a "race" between efforts to increasingly electrify the final consumption of energy. A key aspect of our scenario is that, by design, we have not allowed electricity demands to grow too quickly, especially in the first two decades of the scenario since that is the period when fossil and nuclear power plants are also being rapidly phased out. Allowing electricity demands to increase too rapidly in this period (*e.g.* by pursuing a vehicle electrification strategy too rapidly) would require wind and other renewable forms of generation to be built at an implausibly high rate. Because our mitigation scenario assumes that the electrification of transport ramps up significantly only after 2030, it posits much lower and thus much more plausible build rates for wind and other renewables. In the mitigation scenario, the decade requiring the fastest rate of addition of wind power is 2020–2030 during which time, new wind power is required to be built at a rate of 25 GW/year across all of Europe. While this is an extremely rapid and completely unprecedented rate of addition it is perhaps plausible under an assumption of an emergency global climate mobilisation. Assuming future wind turbines will be similar in size to the very largest being built today (5 MW) this figure implies the need to build 5,000 turbines each year during this period. Also for comparison, in the last decade China has been adding coal power plants at rates as high as 100 GW/year. The highest rate of wind power additions would likely be seen in the UK given its abundant potential for wind generation. In the UK, our mitigation scenario requires peak rates of addition of wind power of 5 GW/year, with total wind capacity reaching 44 GW in 2020 and 92 GW in 2030.

4.6.3 Renewable energy potential

In the household sector, electricity consumption grows by eight per cent in 2020 and by 14 per cent in 2050 compared to 2010 as increased incomes and increased appliance ownership outweighs increased efficiency. In industries, electric consumption decreases by 12 per cent in 2020 and by 49 per cent in 2050 compared to 2010 due primarily to major efficiency gains. In the Transport sector, electricity consumption increases enormously as electric vehicles and electrified rail travel become ubiquitous. Consumption in this sector increases by 219 per cent in 2020 and by 606 per cent in 2050 compared to 2010. Overall, electric demands increase by six per cent in 2020 and by 24 per cent in 2050 compared to 2010.

Given the electricity requirements shown in Fig 26, the design of the mitigation scenario begins by reviewing the likely potential of renewable technologies in each EU27 country as shown in Table 1. This data is drawn from a range of sources. One comprehensive study published in 2006 by the German Aerospace Centre (DLR, 2006) compares the economic potential of each major resource category across each EU27 country. In general we adopted the values from this study due to its comprehensiveness. The exceptions are the cases of wind power and biomass where we drew upon the results of more detailed analyses conducted in 2009 and 2006 respectively by the European Environment Agency (EEA, 2009 & 2006). It is worth noting however that the EEA and DLR studies come up with very different estimates of wind potential in Europe. The DLR study puts wind's economic potential in the EU27 at about 1,332 TWh while the EEA study puts it at 25,102 TWh for onshore wind plus another 3,400 TWh for offshore wind: more than 20 times higher than the DLR study. The difference appears to be due in part to assumptions of higher mean wind speeds and larger turbines, which together increase the energy available per unit land area. They may also reflect very different assumptions about the land area that might potentially be used for wind generation. To evaluate onshore environmental constraints, the EEA study excludes Natura 2000 and other designated natural areas and only considers sites that are economically competitive or likely to be competitive by 2030 (those likely to have production costs less than 6.7 cent/kWh). However, the EEA study appears to place no general limit on the fraction of the total remaining land area that might be developed for wind power. It thus appears that the quoted total onshore economic potential of 25,102 TWh could only be generated if all suitable available land areas were utilised, including urban areas, forests, and agricultural areas (which it is assumed can simultaneously be used both for agriculture and for wind generation). This vision of wind power blanketing much of Europe is unlikely to be socially or politically or environmentally acceptable.

Nevertheless we feel it is more reasonable to make use of the EEA study as a basis for a general assessment of wind energy potential, due to its greater level of transparency and its far more detailed documentation. To account for its very high estimate of available land for wind, we have designed our scenario so that only a very small fraction (5.6 per cent or about 1600 TWh) of the EEA's estimated economic potential for wind would actually be developed.

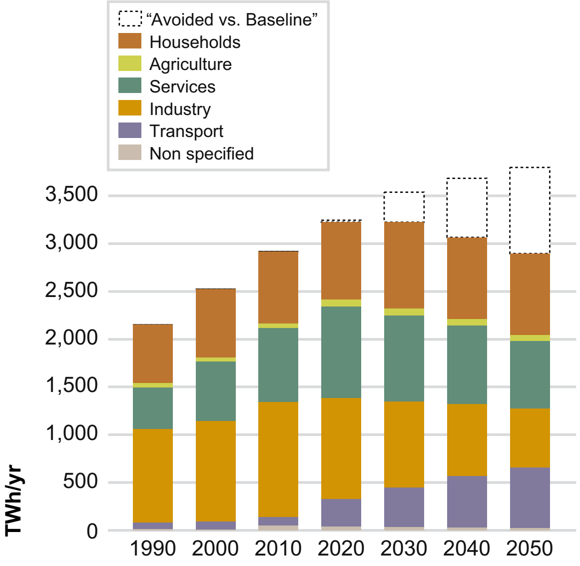

Figure 23: Projected electricity demands by sector in the Mitigation scenario

Up until 2020, electricity demand grows at almost the same rate as in the baseline scenario as increases in consumption due to electricity replacing the direct use of fossil fuels in many sectors is balanced by decreases due to efficiency. After 2020 the continued large increases in efficiency lead to an overall decrease in consumption in spite of the growth of electric vehicles and other electric technologies.

Table 1: Renewable energy potentials in the EU27 countries by 2030

2030 Economic Potential (TWh/yr) Country	Hydro	Geo-thermal	Biomass	Solar thermal	Solar PV	Wind onshore	Wind offshore	Wave & tidal	Total
Austria	56.0	4.1	101.2		2.9	56.0	–		220.2
Belgium	0.5		26.7		2.1	425.0	30.0	0.2	484.6
Bulgaria	12.0	0.8	–		2.0	112.0	22.5		149.3
Cyprus	1.0		3.5	20.0	0.1	25.0	3.0	0.2	52.8
Czech Republic	3.0		58.2		1.1	85.0	–		147.3
Denmark	–		29.1		1.3	751.0	420.4	2.2	1,204.0
Estonia	0.4		30.2			597.0	105.1		732.7
Finland	20.0		109.3		1.7	3,359.0	210.2	2.0	3,702.2
France	72.0	14.1	551.3		23.4	3,115.0	300.3	12.0	4,088.0
Germany	26.0	28.2	502.4		23.4	2,467.0	270.3	7.0	3,324.3
Greece	12.0	9.4	44.2	4.0	3.9	372.0	120.1	4.0	569.6
Hungary	4.0	51.9	65.1		2.0	1.0	–		124.0
Ireland	1.3		15.1		1.1	1,315.0	150.1	4.0	1,486.7
Italy	65.0	19.6	288.4	7.0	17.6	334.0	127.6	3.0	862.2
Latvia	4.0		27.9			593.0	90.1		715.0
Lithuania	1.5	0.8	115.1			442.0	11.3		570.7
Luxembourg	1.0		–		0.8	10.0	–		11.8
Malta			0.5	2.0	0.1	7.0	–	0.1	9.7
Netherlands	0.1	1.3	27.9		4.3	533.0	345.3	1.0	912.9
Poland	7.0	1.7	457.1		3.1	2,609.0	75.1	1.0	3,153.9
Portugal	20.0	14.1	47.7	142.0	3.9	152.0	52.6	7.0	439.2
Romania	18.0	1.0	–		2.0	99.0	15.0		135.0
Slovakia	6.0	3.1	41.9		2.0	11.0	–		64.0
Slovenia	8.0	0.4	20.9		1.0	2.0	–		32.3
Spain	41.0	28.2	291.9	1,278.0	19.5	682.0	75.1	13.0	2,428.7
Sweden	90.0	1.3	157.0		3.7	2,539.0	225.2	2.0	3,018.2
United Kingdom	8.0	0.3	284.9		7.8	4,409.0	750.7	60.0	5,520.8
Total EU27 Potential	477.8	180.3	3,297.6	1,453.0	130.8	25,102.0	3,400.0	118.7	34,160.2
2006 Production	307.7	5.6	46.3	2.5	2.5	82.0		0.5	447.1
2050 Mitigation Production	399.2	68.7	1,393.1	295.0	104.3	898.2	700.0	46.6	3,905.1
2050 Mitigation Production/Potential (%)	84%	38%	42%	20%	80%	4%	21%	39%	11%

Sources/Notes: EEA (2006) for biomass, EEA (2009) for wind, German Aerospace Centre (DLR, 2006) for all other technologies. The "Solar Thermal" column indicates the potential for large scale concentrating solar power (CSP) facilities. It does not include the potential for solar hot water heating in buildings. The table also does not include the potential of CSP from the Middle East and North Africa estimated by DLR at several hundreds of thousands of TWh/yr.

4.6.4 Addressing the variability of renewables: the need for storage

While the renewables resource base in Europe is huge, the largest renewables options, wind and solar, as well as wave and tidal power suffer from the inherently intermittent nature of the resources they rely upon. This makes them difficult to rely upon as base load plant since they can only make a small contribution to firm capacity. It also increases the cost of transmission since for a given type of intermittent renewable technology, sufficient transmission capacity must be built to handle the peak production of a given system – even though that power may only be available for a very limited number of hours in the year.

In addition to the problem of short term intermittency due for example to short lulls in the wind or short periods of cloudiness (for solar power), there is a second problem of longer term lulls. It is not unknown for wind farms to go five days or more with almost no significant generation (MacKay, 2009). Seasonal variations in demand are a third type of problem. For example wind availability tends to be higher in winter months, whereas peak demands may be higher in the summer due to air conditioning loads.

To address these concerns it will be important that any future electric generation system has a balanced design with a mix of renewable technologies that can complement each other both seasonally and geographically, and with large amounts of storage that can offset prolonged periods when renewable resources might be unavailable. Fortunately, a wide range of options are being developed that can address this challenge. These options include:

- **Electric Vehicles:** The CO_2 emissions reductions benefits of plug-in hybrid and pure electric cars are reinforced by the potential that this technology presents as a store of electrical energy. Cars not being actively driven could be designed to feed energy back into the grid at times when renewable sources are unavailable. Assuming one third of the 263 million electric vehicles required by 2050 in our mitigation scenario are available as a source of power at any given time, and assuming they can supply power back to the grid at the same 2.5 KW rate at which they are likely to be charged, we estimate they could provide about 217 GW of power to the electric system: more than 50 per cent of the likely peak power requirements on the European system.

- **Demand Side Management (DSM):** new electrical devices and facilities which can be switched down or off when supplies are short also have a large potential to help balance short term slews in the demand for electricity. Refrigeration, air conditioning, wet appliances and ground source heat pumps are all good candidates for advanced technology centrally controlled DSM and could contribute to significant load levelling, at least for short-term slews in demand.

- **Geographic Balance and Resource Diversity:** A key characteristic of Europe's renewable resources are that different resources and different demands are concentrated in different regions of the continent. In particular, much of Europe's hydro resources are located in Scandinavia and Iceland, much of its solar potential is located in Southern Europe (and beyond the EU's borders in the Middle East and Northern Africa – see below), and much of its geothermal potential is located in the Mediterranean, the Balkans and the easternmost countries of the EU. Similarly, there are regional variations in demand particularly in terms of cooling and heating loads, although these climatic differences will become somewhat less important by 2050 once building shell efficiencies improve dramatically. These geographic variations create opportunities for better management of loads. For example, wind resources which are more reliable in winter months can be complemented by solar energy which is more reliable in the summer months. Similarly, peaks in demand occur at different hours and in different seasons in different countries of the EU. Taking advantage of these geographic variations will require a major upgrade to electric transmission systems in Europe. High voltage alternating current (HVAC) transmission systems suffer from too high losses to be economic for transporting country-size amounts of power over long distances; but high voltage direct current (HVDC) systems have the potential to operate as EU-wide electricity "superhighways" helping to stabilise loads and transport large supplies of power over very long distances with less than half the electrical losses per km of current HVAC systems. Such HVDC systems will also be required if solar generated electricity is to be imported from the Middle East or North Africa (see below). Of course a major expansion of transmission lines will be costly and may prove very unpopular due to its aesthetic impacts and the demands it places on land use.

- **Renewables with Storage:** As noted above, the existing designs for wind and other intermittent renewables are a problem for two reasons: not only is power sometimes unavailable when it is needed, but transmission systems must also be oversized to accommodate the times when power is available. Since renewable resources are often far from centres of demand the costs of constructing new transmission lines can thus be a decisive factor making them uncompetitive. Coupling renewable generation with localised and relatively long-term energy stores can help overcome this problem: transforming intermittent sources of power into a reliable, dispatchable and therefore much more valuable source of base-load power. Many promising local storage options are currently being actively developed including fly-wheels, vanadium and other battery storage options, and molten salt storage tanks for use in conjunction with concentrated solar power facilities. One particularly promising option, which has already been commercialised, is the use of compressed air energy storage (CAES). CAES makes use of salt caverns, aquifers or other underground geological features to store compressed air at times when the wind is blowing. The compressed air can subsequently be used in conjunction with small quantities of natural gas to drive a steam or combustion turbine to provide power at the times when no wind is available. CAES systems are considered very promising for a variety of reasons. Firstly, CAES is a proven and reliable technology with plants already operating as peak shaving plants in both Europe and the US. Secondly, CAES requires minimal additional land area (only 15 per cent more than a standard wind farm) since the storage is located underground. Thirdly, preliminary assessments estimate there is generally a good match between the availability of suitable geological areas for CAES and areas of high wind potential (although much more study is required of this in Europe). Fourthly, even when using natural gas in the CAES turbines, CO_2 emissions from Wind/CAES plants are very low: about 20 per cent of those from a high efficiency natural gas combined cycle (NGCC) power plant. However, natural gas could eventually be replaced by limited amounts of biomass to further reduce emissions. Finally, the cost of CAES is expected to be competitive with coal fired pants using carbon capture and storage. Onshore wind with CAES technology has been studied in this scenario in more detail to be able to give cost estimates. CAES however could also be replaced by other technologies such as pumped storage or flywheels.

- **Imports of Solar Energy from The Middle East and North Africa:** While the wind potential in Europe appears to be very large, it is dwarfed by the technical potential for solar energy in the Middle East and North Africa (MENA), which by one estimate could be several hundreds of thousands of Terawatt hours (DLR, 2006) — enough in theory to supply all Europe's energy needs many times over. The use of concentrating solar power (CSP) in conjunction with relatively low (15 per cent) loss HVDC transmission links to Europe could provide significant quantities of electricity by 2050. Heat from CSP systems can be stored in the form of molten salt during the day to power steam turbines during the night or when there are peaks in demand. The waste heat from CSP plants could be also used for the desalination of water – important in a region where conflicts over scarce water resources are a growing problem. This concept has recently received a lot of attention, to the point where a foundation, called DESERTEC has been formed to promote it. The DESERTEC foundation estimates that solar CSP could provide as much as 100 GW of power to Europe and the MENA region. CSP is attractive not just because of its huge potential but also because it gives a technological, seasonal and geographical balance to the development of wind and hydro in the north of Europe. Moreover, the basic technological components of such a system are already relatively well proven and commercialised. The capital cost of such a system would be huge although likely to decline markedly over time with sufficient research development and demonstration efforts. Disadvantages of such a system include its huge initial capital cost; its location outside of Europe, which leads to concerns about security of supply; and the sheer scale of the project. If implemented badly such a huge project could lead to the type of corruption and governance problems that have historically been associated with oil, hydro and other large energy schemes. Similarly, while the possibility of making large supplies of desalinated water available could be a huge development boon, concerns remain that such a large-scale system would be implemented almost exclusively for the benefit of European people and businesses, implemented in huge enclaves with few meaningful benefits for the local population in the MENA region. In spite of the potential drawbacks, a system with such enormous potential cannot easily be ignored. Thus, in our mitigation scenario we have included it as one important option after 2030 for renewable electric generation providing

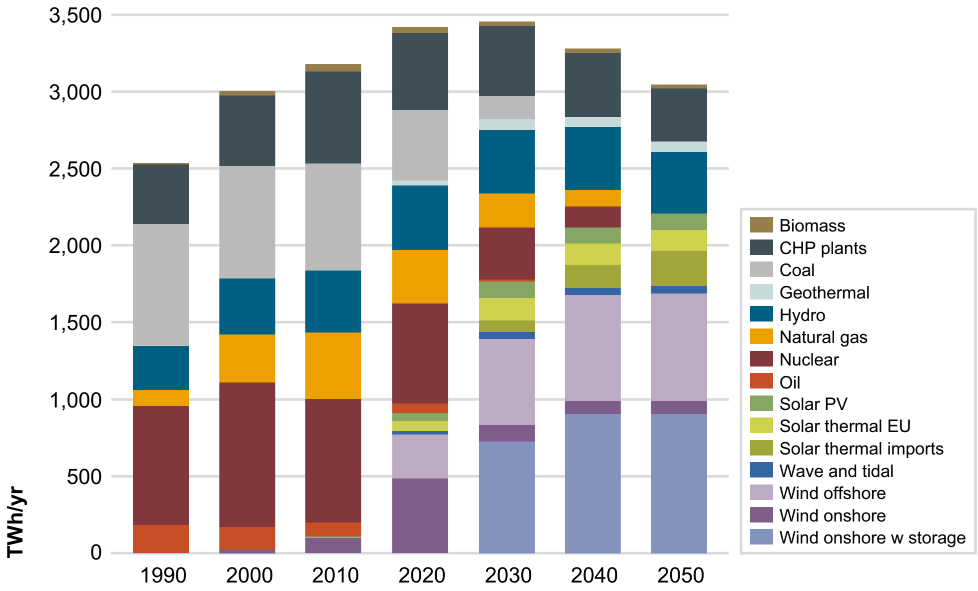

Figure 24: Electric generation in the Mitigation scenario

The generation mix shifts dramatically as coal and nuclear plants are rapidly decommissioned and large amounts of renewables are introduced. In the scenario, all coal is retired by 2035 and all nuclear power by 2050. Wind (including wind-CAES) increases its share of the generating mix from only 3.3 per cent in 2010 to 22 per cent in 2020 and 55 per cent in 2050. Solar (including imported solar CSP) increases its share from close to zero in 2010 to 2.5 per cent in 2020 and 15 per cent in 2050. The share of electricity from CHP decreases from 19 per cent in 2010 to 14 per cent in 2020 and 11 per cent in 2050. However, by 2050 CHP is fully biomass based.

approximately 7.5 per cent of total electricity generation in 2050.

- **Natural Gas as a Backup Source of Power:** A final but important option for helping overcome the intermittency and storage limitations of solar power is to continue using natural gas for electric generation, but only as an emergency or peak source of power. Although highly efficient natural gas has significantly lower emissions per KWh than either coal or oil fired generation, the extremely low emissions targets in our mitigation scenario preclude it from being used as a base load source of power. However, in our mitigation scenario natural gas continues to be required in Wind/CAES systems to help provide backup power at times when wind energy is unavailable. Similarly, limited amounts of natural gas backup is expected to be required to allow solar thermal imports to function as a base load source of power. This natural gas could eventually be replaced by biomass fuels after 2050. This has not been considered in our mitigation scenario due to the overall resource limits place on biofuel consumption in the scenario.

While there are numerous promising technical options that could be included in a renewables based mitigation scenario it remains difficult to predict which of these options will emerge as the eventual winning technologies. Significant uncertainty remains about the costs, technical suitability and social acceptability of many of these options. For this reason our mitigation scenario tries to reflect a balanced development of different renewable technologies: including tidal, wave, geothermal, biomass and municipal solid waste (MSW), solar photovoltaic and solar thermal (both domestic and imported from the Middle East and North Africa), and both onshore and offshore wind.

The diversity of the mix also provides a good level of balance between technologies with better availability in different seasons and between resources that are available more in the North of Europe (wind, hydro, wave and tidal power) and those that are available more in the south (solar power, geothermal energy).

4.6.5 Results

Figure 24 shows the development of electric generation in the mitigation scenario (measured in Terawatt hours). Notice how coal, gas, oil and nuclear power are quickly phased out with generation from renewable

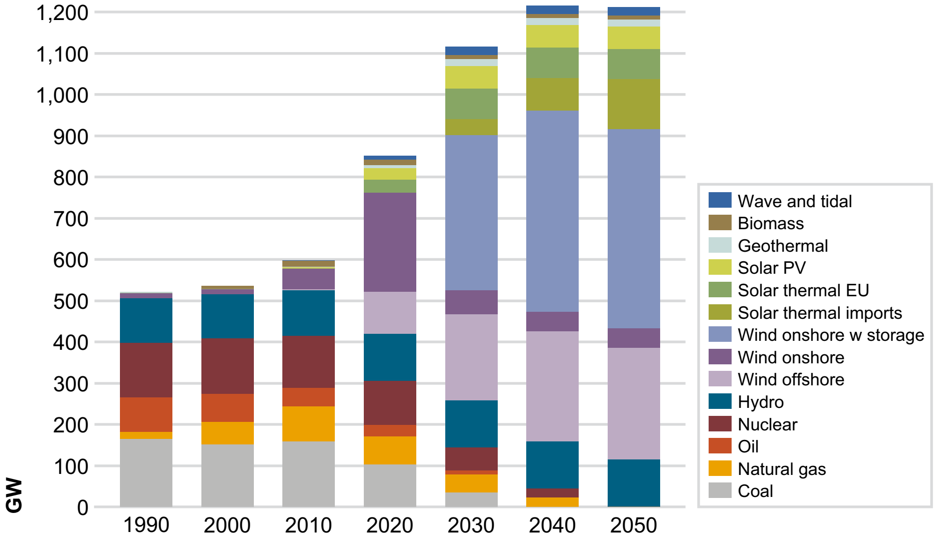

Figure 25: Electric generation capacity in the Mitigation scenario
Because of the shift to intermittent renewable forms of electric generation, the capacity of the electric system will need to grow by a factor of over two, from around 600 GW in 2010 to 850 GW in 2020 and 1200 GW in 2050. These figures do not include the capacity of CHP systems. In the first 10 years of the scenario standard intermittent renewables (without built-in storage) can be added to the system. In the later years of the scenario there will be an increasing need for renewable systems with some form of storage. We assume that wind farms can be upgraded to include this storage after their initial build date.

sources assumed to rapidly grow in their place to meet requirements. It is also worth noting that unlike in other scenario studies, we do not expect to see a huge decrease in overall levels of generation relative to the baseline scenario. In fact, generation in the mitigation scenario is similar to the baseline scenario up to 2030, in spite of huge improvements in energy efficiency on the demand side. This is due to the overall electrification strategy employed in the scenario design, whereby localised combustion of fossil fuels is eliminated wherever possible.

After 2030, efficiency measures become dominant so that overall levels of generation decline slightly. This decline might be used as an opportunity to export power to other regions or it could be used to power the production of zero carbon energy carriers such as hydrogen, which when substituted for any remaining fossil fuel use would allow for additional reductions in the overall GHG emissions seen in the scenario. Note however that this possibility has not been quantified in our scenario.

In terms of the power plant capacity (measured in Gigawatts) required in our mitigation scenario the required growth of capacity looks daunting but ultimately achievable. Due to the intrinsically low availability of wind, solar, wave and tidal resources, large amounts of capacity will be required as fossil and nuclear facilities are required to shut down as shown in Figure 25. Overall the capacity of the EU's electric system (including solar thermal imports from the Middle East and North Africa) would need to more than double, with the vast majority of the additions coming from wind and solar thermal power. After 2025 it is assumed that the majority of wind and solar installations would include localised storage options so that they can serve as base load sources of power and in order to keep the need for new transmission lines down to a minimum.

As noted above, our scenario is designed to keep the levels of generation below the economic potential for each major type of renewable in each country (as shown earlier in Table 1). Nevertheless as noted earlier the rate at which those renewables would need to be built presents a formidable challenge, particularly since huge levels of additions would be required fairly early on in the scenario (between 2020 and 2030).

4.7 COMBINED HEAT AND POWER (CHP)

Our mitigation scenario includes significant demand for centralized production of heat as shown in Figure 26. These demands include both low temperature district

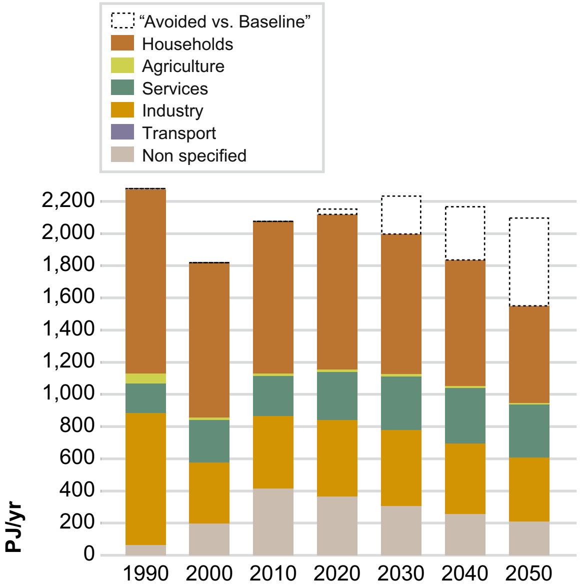

Figure 26: Demand for heat in the Mitigation scenario

The demand for heat actually declines in the mitigation scenario relative to the baseline scenario due to huge efficiency gains, and in spite of major efforts to expand the use of district and process heat wherever possible.

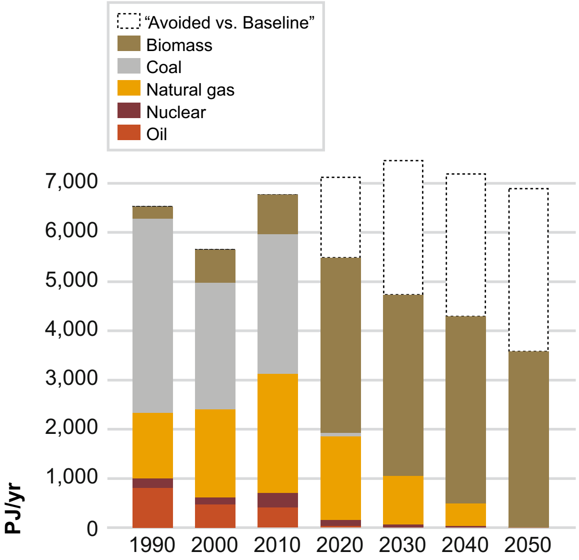

Figure 27: Feedstocks for CHP in the Mitigation scenario

The mitigation scenario reflects a major effort to switch all heat production away from dedicated (*i.e.* non CHP) systems and away from fossil fuels so that by 2050, all heat is produced from biomass-fired CHP.

heat used in buildings for heating (and potentially also for cooling) and high temperature process heat used in industrial processes. As described in earlier sections, our mitigation scenario is designed to maximise the demand for heat by assuming that, wherever possible, buildings and industry switch away from the direct combustion of fossil fuels in favour of heat, particularly in countries where CHP or district heating has a well established infrastructure. In spite of this approach, the high levels of efficiency gains in the mitigation scenario mean that the overall demand for heat from CHP declines markedly in the later years of the mitigation scenario.

Nevertheless, CHP represents a key low carbon technology in our mitigation scenario for three main reasons:

- Firstly, CHP is a high efficiency technology able to generate both heat and electricity at combined electric plus heat generating efficiencies approaching 80 per cent by 2050. This can be compared to current advanced electric-only fossil power plants that generate power at about 40 per cent thermal efficiency. Thus while CHP plants are assumed to be operated to meet the demand for heat in our mitigation scenario, they also provide significant supplies of electricity (as shown earlier in the electric generation charts in Section 4.6).

- Secondly, as shown in Figure 27, CHP becomes entirely biomass fired in our mitigation scenario: thereby providing heat and power with near zero GHG emissions. We assume that all countries convert or otherwise re-fire their heating systems to be entirely CHP based, and to entirely use biomass by 2050. This task will be largest in some Eastern European countries like Poland and Bulgaria where central heat systems are currently dominated by coal and where some plants are dedicated (heat only) systems that do not generate any electricity. It is likely that these countries will need financial assistance from their EU neighbours to undertake such a change. Note also that the amounts of biomass required for such a system would remain well within the limits for biomass production listed earlier in Table 1). However, it is important to recognise that inevitable climate change (especially reduced rainfall) combined with growing global populations are liable have a big impact on the ability of Europe to either produce or import its food requirements. This will create additional competition for land between food and bioenergy in Europe. Some of these pressures may

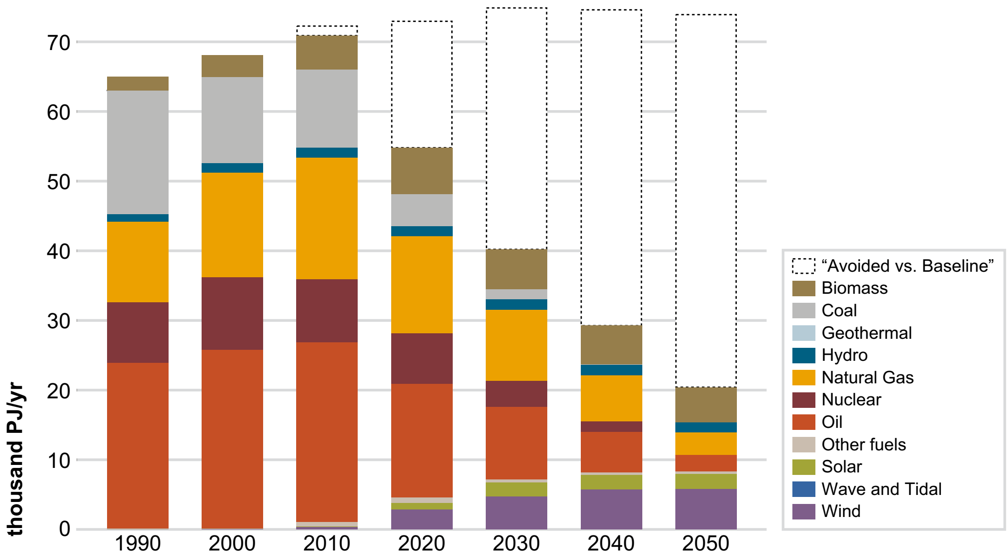

Figure 28: Primary energy requirements in the Mitigation scenario

The final result of all of the energy efficiency and fuel switching measures in the mitigation scenario on both the demand and supply-side are reflected in the huge reductions seen in primary energy requirements and the switch away from fossil fuels to renewable energy. Total primary energy requirements initially remain about constant are reduced from around 71,000 PJ in 2010 to 55,000 PJ in 2020 and 21,000 PJ in 2050. Coal and nuclear are eliminated entirely and renewable forms of energy increase their share of primary energy from 10 per cent in 2010 to 22 per cent in 2020, finally reaching 71 per cent in 2050. Note: following standard energy accounting conventions, wind, wave, hydro, and solar energy are represented here in terms of the electricity they produce. If they were instead measured in terms of the equivalent amount of fossil energy that would otherwise be required to produce them, then the renewable share of primary energy would instead be 35 per cent in 2020 and 85 per cent in 2050.

be offset by increased yields from CO_2 fertilisation and better seeds, but the critical factors of rainfall/irrigation/more extreme weather incidents are likely to far out-weigh these positive factors. This is an area that needs much greater research before any large-scale increase in biomass production within Europe can be assumed.

- Thirdly, at least in seasons when heating is required, CHP will provide the equivalent of base load electrical power, something that will be very valuable in the later years of the mitigation scenario, helping to reduce the amount of intermittent renewables that will need to be built.

4.8 PRIMARY REQUIREMENTS

Figure 28 presents the primary energy requirements of our mitigation scenario: a direct result of all of the preceding scenario assumptions and calculations. Nuclear is quickly phased out except in a few key countries such as France where a longer period of adjustment will be needed. Coal is entirely removed by 2035. By 2050 oil consumption is eliminated except for a few key transport sectors (air travel, shipping, buses and road freight). Natural gas remains in 2050 but is restricted to being used only as a backup fuel for a primarily renewable based electric system. Generation from hydro power stays roughly constant over the entire study period, as does biomass consumption: with natural decreases in biomass use in poorer households, roughly balanced by the increases in use in CHP systems. The remaining primary requirements are all different types of intermittent renewables, with onshore and offshore wind by far the largest options. For each renewable resource annual requirements remain well below the economic potential for the EU27 as a whole and within each country (as shown in Table 1).

4.9 EMISSIONS RESULTS

As shown earlier in Figure 2 our mitigation scenario results in a huge decrease in GHG emissions. This of course is not surprising since the scenario was explicitly designed as a "backcast", in which emission targets were set as the main design criterion of the scenario.

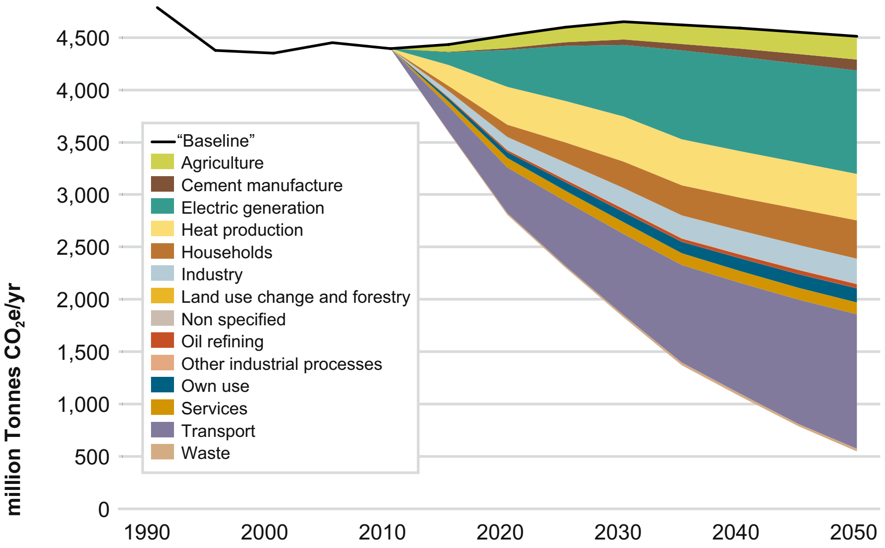

Figure 29: GHG mitigation wedges by sector
The top line of this chart shows baseline scenario GHG emissions. Below that is displayed a series of "wedges" that show the contribution of each the various sectors to reducing the baseline emissions down to the final level seen in the mitigation scenario. Each sector plays an important part in the reduction but the largest reductions come from measures in the transport and electric generation sectors.

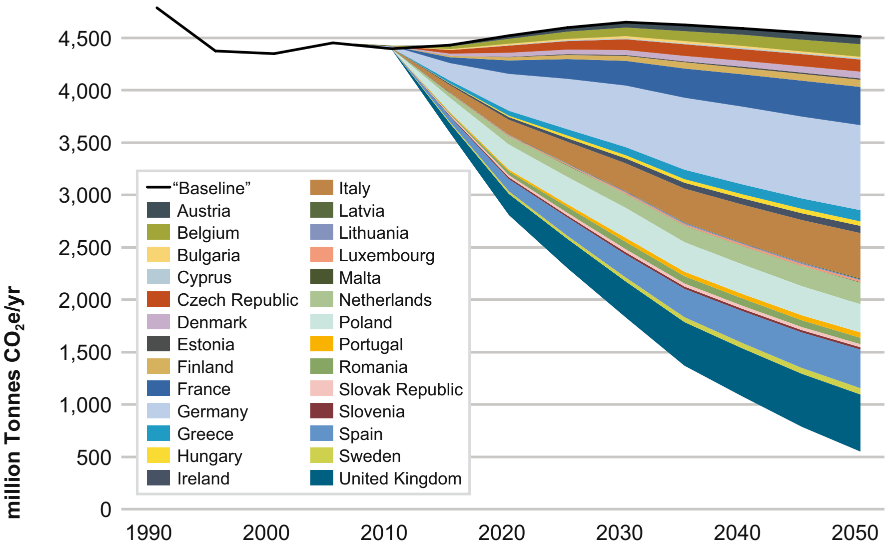

Figure 30: GHG mitigation wedges by country
This second form of the "wedges" chart shows the same reductions as Figure 29, but this time the wedges are each of the EU27 countries. As would be expected the largest contribution are seen in the largest and most carbon intensive economies: Germany, the UK, Italy, Spain and Poland.

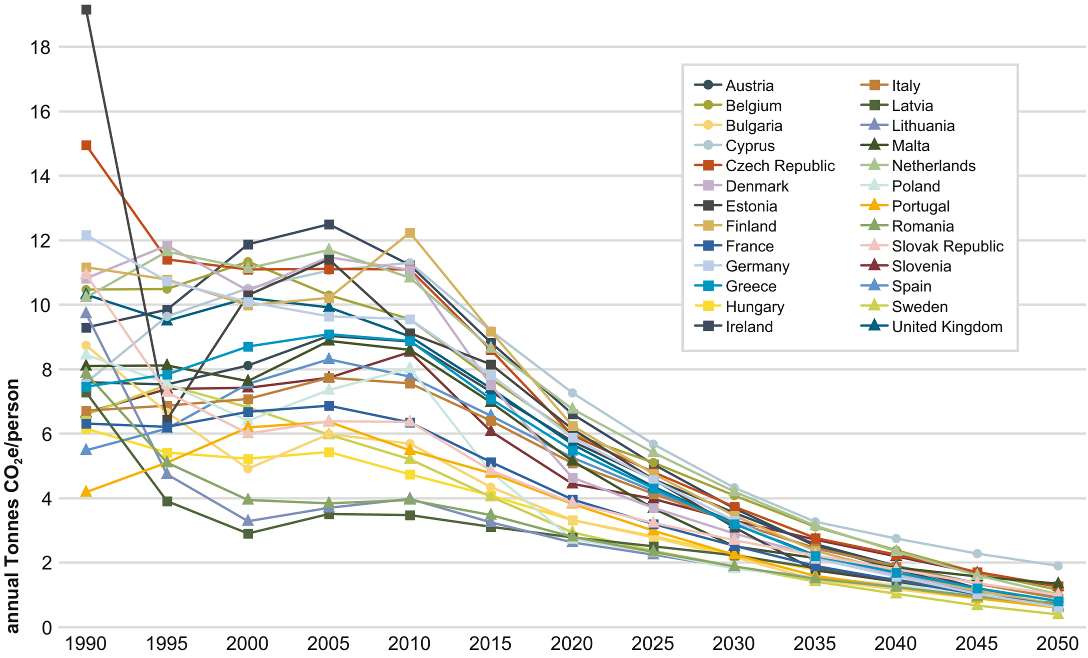

Figure 31: Energy sector GHG emissions per capita

This final chart shows how emissions per capita are reduced over time in each country. Notice how all countries rapidly converge to similar levels of per capita emissions of around 0.9 MtCO$_2$e/yr.

Overall GHG emissions decrease by 40 per cent versus their 1990 values in 2020 and by 90 per cent in 2050. Figure 29 shows the contribution of different sectors to this overall reduction, with the largest decreases coming from the electric generation, transportation and heat production sectors. Figure 30 shows the same reductions but this time displaying the amounts achieved in each country. Not surprisingly the biggest reductions are achieved in the largest and currently most carbon intensive countries including Germany, the UK, Italy, Spain and Poland. France, although a large country, has less potential for GHG reductions than the UK and Germany since its electricity is already dominated by nuclear power.

Figure 31 displays how per capita energy sector emissions decline in the mitigation scenario in each EU27 country. Notice how all countries' emissions contract and converge toward very low annual GHG emissions of around one tCO$_2$e per capita. Differences among countries remain in 2050, in part because of the different starting points and the different resource base in each country. Note also that this technical analysis does not explicitly address the issue of burden sharing among EU27 countries. Our mitigation scenario is only intended to show the technical possibilities. The issue of fairness within the EU would need to be addressed separately.

4.10 COSTS OF DOMESTIC ACTION

While this report is not intended as a detailed economic assessment of the costs of the mitigation scenario, here we present our partial calculation of the costs of the scenario. We have made an estimate of the incremental net present value of the mitigation scenario relative to the baseline value between 2010 and 2020. Estimating the future costs of technologies and fuels is difficult even over a fairly short time frame (witness the failure of any energy modellers to predict the most recent oil price spike and its subsequent collapse). Attempting to predict costs and prices over the period to 2050 is perhaps an order of magnitude more difficult. For this reason here we attempt only a very approximate estimate of the costs of our mitigation scenario for the period 2010–2020.

Our estimate is partial in that it only includes estimates of measures for some demand sectors. It includes estimates of incremental capital and operating and maintenance costs for households, services and transport but does not include the industrial, agriculture and non-energy sectors which are more difficult to estimate and subject to even greater uncertainties. On the supply side it includes estimates of capital and operating maintenance costs for electric generation and for transmission and distribution but does not include costs or benefits in the CHP and refining sectors.

Our cost estimates are based on global average fuel price projections from the IEA (IEA, 2008d) combined with estimates of current and future technology costs drawn from a variety of sources including the IEA's *Energy Technology Perspectives Report* (IEA, 2008a), supplemented with estimates from the IAEA (Howells, 2009), the German Aerospace Centre (DLR, 2006), and McKinsey & Company (McKinsey, 2009a and 2009b).

The standard accounting calculations for costs and benefits in the LEAP modelling system were used to calculate the incremental cumulative discounted costs of our mitigation scenario relative to the baseline scenario. A five per cent real discount rate was applied to all costs after 2010.

The total Net Present Value (NPV) of our mitigation scenario relative to the baseline scenario through 2020 amounts to €1.94 trillion.

This is comprised of the following sectoral sub-totals (all figures in trillions of 2005 Euros):

Demand-side efficiency investments:	€1.84
Transmission and Distribution:	€0.05
Electric Generation:	€0.59
Fuel Savings:	-€0.54
Total NPV	€1.94

This value is about 1.7 per cent of the NPV of Europe's GDP between 2010 and 2020 (€111 trillion) in the mitigation scenario. As noted above, this is a partial and approximate estimate that is highly sensitive to estimates of costs (particularly fuel costs).

These estimates are consistent with a variety of other studies, such as those recently reviewed and discussed by Ackerman and colleagues in the recent report, *The Economics of 350: the Benefits and Costs of Climate Stabilization* (Ackerman *et al.*, 2009): In that report, the authors state that:

> *There is a wide range of estimates of the costs of greenhouse gas abatement scenarios. At one extreme, some business lobbies have argued that even the moderate reductions called for in recent U.S. legislation would be crippling to the economy. At the other extreme, some environmental advocacy groups have argued that an extensive agenda of reductions (although still more moderate than is required for stabilization at 350 ppm CO_2 in the next three centuries) could save money overall by reducing fuel costs. Between these two extremes, there is a body of research finding that…the much more ambitious reductions in emissions required to reach 350 ppm CO_2 might have net costs of 1 to 3 percent of world output.*

It is useful to put this value into perspective. Assuming that the costs of climate action lie toward the upper end of that range at, say, 2.5 per cent of GDP, one can ask: "Is this a large cost?" To answer this, we again quote Ackerman *et al.* (in slightly edited form):

> *In an economy that is growing at 2.5 per cent per year… spending 2.5 per cent of GDP on climate protection each year would be equivalent to skipping one year's growth, and then resuming. Average incomes would take 29 years to double from today's level, compared to 28 years in the absence of climate costs.*[28]
>
> *Consider another comparison: military spending is greater than 2.5 percent of GDP in 68 countries around the world... It is difficult, therefore, to believe that we are unable to remove this amount from current consumption in order to defend against a remote but dangerous threat to our way of life. On the strength of a different narrative about potential dangers we already do so, year after year.*

This 1–3 per cent range can also be compared against estimates of the costs of not acting to protect the climate. The Stern review on climate change (Stern, 2006), perhaps the most authoritative source in this regard, estimates that losses to global GDP will amount to at least five per cent but perhaps more then 20 per cent. Thus, the cost of uncontrolled climate change will be significantly higher than the scale of financial contributions discussed today to address the financial crisis. Moreover, delay in implementing significant GHG reductions is likely to increase these costs.

So in short, no, 1–3 per cent of EU GDP is not (in this context) a large cost, assuming that we are prepared to take seriously the clear and dire risks of climate change.

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[28] NB: This does not mean skipping one year of GDP: it merely means skipping one year of growth in GDP.

5 OPTIONS FOR DEEPER EMISSIONS REDUCTIONS

As described in Section 4, our mitigation scenario shows that dramatic reductions in GHG emissions by 2050 are technically feasible and economically manageable. However, it is quite possible that even these levels of reductions will not be sufficient to safeguard the planet's climate. Perhaps the world will need to drive toward for even deeper reductions, aiming to bring atmospheric concentrations more quickly back down toward 350 ppm CO_2. So what more could be done to reduce our emissions?

A number of options are immediately apparent that have not been included in our mitigation scenario. Most have serious drawbacks associated with them, but it seems useful to at least list them as possible fallback options for the future, if greater efforts are ultimately found to be necessary, beyond the full utilization of the options already included in the mitigation scenario:

- First, second generation biofuels could emerge as a significant option for eliminating remaining fossil based emissions in the transport sector (primarily in road transport, aviation and shipping). Evaluations by the European Environment Agency (EEA, 2006) suggest that sufficient quantities of second generation biofuels can be grown sustainably within Europe's borders to meet the remaining needs suggested by our mitigation scenario. While biofuels currently remain undesirable to many in the environmental community, in part because of concerns over the potential for the economic and environmental exploitation of developing nations, they do appear to be a promising long-term domestic option, particularly if the science tells us that the climate crisis is deepening still further.

- Second, while carbon capture and storage (CCS) has not been considered in this scenario it may be worth re-evaluating biomass-based CCS as an option for later deployment in conjunction with CHP systems, since it has the potential to actively sequester CO_2 from the atmosphere and could thereby be one option for reducing atmospheric CO_2 concentrations, albeit slowly. This, of course, will only be an available option if the existing geological sequestration capacity has not already been consumed for use with fossil fuels. Another option for which research is only in its infancy is chemical air capture combined with CCS.

- Third, various options are available for enhancing natural GHG sinks in Europe and elsewhere. These options have not been included in our mitigation scenario but it is likely that better management of land use and forestry could actively sequester much higher levels of CO_2. However, a major caveat here is that impending and to some extent already unavoidable climate change may severely impact European forests, reducing or even reversing the ability of forests to sequester CO_2.

- Fourth, in the coming decades, it is highly likely that many new low carbon technologies will emerge. It is hard to foresee what shape these new technologies will take, but possibilities include new types of carbon absorbing "green cements", and hydrogen fuels derived from a further expansion of renewable electric generating technologies.

There are good reasons to not pursue these options at present since they will require huge levels of research and development funding, which would be very likely to crowd out the needed development of options that have a higher chance of generating the emissions reductions that are needed in the coming decades.

Finally, the issue of sufficiency could again be revisited if the emissions reductions achieved by 2050 are not sufficient to protect the planet. It is of course important to point out that compromise on the science of climate change is not possible. As leading experts have pointed out "we cannot negotiate with nature". Since the scenario already assumes the emissions intensities of most activities have been radically reduced, additional sufficiency measures would most usefully be targeted at the remaining intensive parts of the economy. One of the most obvious areas for this would be further per capita reductions in air travel.

6 INTERNATIONAL OBLIGATIONS: SHARING THE BURDEN

A meaningful solution to the climate crisis must induce an urgent and sweeping transformation of the *global* emissions trajectory, not just Europe's. But, such a global transformation will be practically viable and politically acceptable only if it does not compromise development. Even in the face of a pressing climate crisis, developing countries continue to face a poverty and development crisis that is no less urgent or severe. Given this, developing countries can be expected to reject any climate regime that jeopardises their efforts to eradicate poverty and to advance the standard of living of their people.

The logical implication of this is that a climate regime must be based on a burden-sharing approach that explicitly safeguards development while transparently defining the scale of different countries' carbon mitigation responsibilities. In particular, such an approach must ensure that developing countries are not asked to bear costs of the global climate transition that would undermine development prospects.

Below we explore for Europe the implications of one such burden-sharing approach – the Greenhouse Development Rights (GDR) framework[29] – that is explicitly designed to safeguard the right to development. The GDRs framework is an approach that aims to ensure on the one hand that global emissions are cut with the urgency called for by the climate crisis, while on the other that developing countries' right to development is safeguarded. It achieves the latter by defining burden-sharing among nations in a manner intended to shield those individuals that fall below a specified "development threshold". People below the threshold are taken as having development as their proper priority, and are thus not saddled with obligations related to keeping society as a whole within its sharply limited global carbon budget. People above the threshold, on the other hand, are taken as having realised their right to development and as bearing a duty to preserve that right for others. Empirical research suggests a development threshold of about US$20 per capita per day (about €13)[30] would correspond to the income level at which the classic plagues of poverty – malnutrition, high infant mortality, low educational attainment, high relative food expenditures – have typically largely disappeared.

The GDRs framework calculates obligations for countries under a global burden-sharing framework by appealing to the fundamental principles underlying the United Nations Framework Convention on Climate Change – that countries should protect the climate "on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions". Given the fundamental importance of this declaration as a starting point for all positioning and negotiations on the obligations of Parties – the GDRs framework uses straightforward methods to quantify the *responsibility* and *capacity* of countries.

As is commonly done, the GDRs approach interprets responsibility as signifying contribution to the climate problem, and adopts cumulative GHG emissions[31] as an appropriate indicator; and it interprets capacity as signifying the financial wherewithal to invest in climate solutions, and adopts income as an appropriate indicator of capacity. However, the GDRs approach differs from other proposed climate frameworks in that it interprets both of these indicators with respect to the aforementioned development threshold. More specifically, it defines capacity as *income above the development threshold*, and responsibility as emissions corresponding to *consumption above the development threshold*.

These burden-sharing principles provide the basis for an explicit quantitative analysis of each Annex 1 country's obligation under a global climate regime. In this coming phase of the international climate regime, the developed countries are going to be

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[29] For a full explanation of the Greenhouse Development Rights framework, see Baer *et al.*, (2008), and the resources available at www.GreenhouseDevelopmentRights.org

[30] Note, this income level is on a purchasing power parity basis (PPP), and thus converts to a lower income level in a local developing country currency than if it were converted at market exchange rates. See Baer *et al.* (2008) for a more complete explanation of this choice of development threshold.

[31] For this analysis, we have taken 1750 as the start date for accounting cumulative emissions. This is the beginning date for the most comprehensive database available (see http://cdiac.ornl.gov), and it captures the full industrial era during which virtually all fossil fuel emissions have occurred. The choice of a different start date could be argued, but would not significantly alter the allocation of responsibility among the Annex 1 countries.

judged carefully as to whether they are fulfilling their commitment, enshrined in the UNFCCC, to “take the lead in combating climate change and the adverse affects thereof”. During this coming period, the developed countries will have had ample opportunity to provide the non-Annex 1 countries with plenty of evidence that both poverty and carbon-based growth can be left behind.

Table 2 below shows the results of the GDRs analysis for each of the EU27 countries for the year 2020. The column labelled “RCI” gives the average of responsibility and capacity for each country, as a percentage of the total for all Annex I countries. Multiplying this RCI indicator by the total amount of mitigation that is needed globally in 2020 (nearly 15 $GtCO_2e$), yields the emission mitigation obligation for each country (shown under the column heading “Total Obligation”). Total obligation is shown in absolute terms ($MtCO_2e$), and also in terms of a required percentage reduction below 1990 emissions. (This takes into account the expected baseline emissions change between 1990 and 2020 for each country, which is positive for some countries and negative for others). For the EU27 as a whole, the implied total mitigation obligation for 2020 is 103 per cent below 1990 levels.

This level of emissions reduction of course seems radical when compared to the 20 per cent target adopted by the European Union for 2020, or even the somewhat more ambitious target of 30 per cent offered under a suitable international agreement. Clearly, a mitigation obligation of this scale is only meaningful if it is understood as a two-fold obligation to, on the one hand, undertake mitigation domestically and, on the other, invest in mitigation internationally.

It is this logic that underlies initiatives, such as the **Big Ask Campaign** launched by Friends of the Earth, which has been rallying civil society support for both deep domestic mitigation in industrialised countries and international mitigation support. In Europe, the campaign has demanded a 40 per cent emission cut domestically in the EU by 2020, along with adequate levels of international support. Consistent with industrialised countries’ obligations under the UNFCCC, this support is intended to deliver new and additional public finance, capacity building and technology covering the agreed full incremental costs of developing countries’ measurable, reportable and verifiable (MRV) nationally appropriate mitigation actions (NAMAs) as well as support for adaptation to the impacts of climate change. This money is intended to be additional to the EU countries’ existing commitments to reach 0.7 per cent of GNI as Official Development Assistance (ODA).

Table 2 shows, under the heading “Domestic Reduction” the end result of the mitigation analysis presented in Sections 3–5, showing emission reductions achieved by 2020 in each of the EU countries consistent with the overall 40 per cent target for the EU. For each country, it shows the reductions relative to the baseline in $MtCO_2e$, and also as a percent reduction below 1990 levels.

The domestic reductions necessary for the EU to reach a 40 per cent goal (1713 $MtCO_2e$ in aggregate) are barely one-third of the EU’s total reduction obligation (4685 $MtCO_2e$) implied by the GDRs analysis, leaving a significant amount of additional effort required in the form of finance and technology for international mitigation. This is true of each country individually as well (with the interesting exceptions of Poland and Romania, whose domestic mitigation contributions toward the EU’s 40 per cent goal are large enough to exceed their respective total obligation; thus, not only would they have no international financing obligations, they would also be eligible for compensating support from the rest of the EU). Table 2 also shows the “International Obligation”, the remaining mitigation that would have to be achieved through international financial and technological assistance, also shown in $MtCO_2e$.

While it would be useful to know the exact scale of this international mitigation obligation in financial terms, there remains uncertainty about the cost of reductions. Table 2 therefore presents the potential costs of the international mitigation obligation in terms of two plausible average cost levels for emission reductions in 2020: €50/tCO_2e and €150/tCO_2e. These are reasonable bounds that correspond to the average costs if aggregate climate mitigation costs were one per cent or three per cent of Gross World Product, respectively. The net result is a bottom line cost to the EU of about €150 billion per year in 2020 in the case of the lower cost estimate, and €450 billion per year in the case of the higher estimate, which translates into approximately 1.1 per cent and 3.3 per cent of the EU’s projected 2020 GDP, respectively.

It is worth noting that the vast majority of the total cost to the EU is born by the fifteen original (and wealthier) EU member states (EU15). The international obligation of the EU15 is more than 95 per cent of the total cost to the EU as a whole. This simply reflects their much higher capacity and responsibility and their correspondingly greater share of the obligation to support a global climate transition.

Table 2: Results of the GDRs analysis for each of the EU 27 countries for the year 2020

		Total Obligation		Domestic Reduction		International Obligation			
Country	**RCI %**	**MtCO$_2$**	**% below 1990**	**MtCO$_2$**	**% below 1990**	**MtCO$_2$**	**Additional % below 1990**	**Billion € (assuming €50/tCO$_2$)**	**Billion € (assuming €100/tCO$_2$)**
Austria	0.6%	91	118%	30	17%	61	100%	3.0	6.1
Belgium	1.0%	140	110%	48	37%	92	73%	4.6	9.2
Bulgaria	0.2%	23	95%	11	83%	12	11%	0.6	1.2
Cyprus	0.0%	6	-24%	5	-50%	1	26%	0.1	0.1
Czech Republic	0.7%	108	82%	69	59%	39	23%	2.0	3.9
Denmark	0.6%	81	112%	37	51%	44	61%	2.2	4.4
Estonia	0.1%	12	105%	5	81%	7	24%	0.3	0.7
Finland	0.4%	63	106%	31	44%	32	61%	1.6	3.2
France	4.2%	616	136%	130	33%	486	104%	24.3	48.6
Germany	7.3%	1,078	116%	351	51%	727	65%	36.4	72.7
Greece	0.5%	81	57%	45	20%	36	36%	1.8	3.6
Hungary	0.3%	40	78%	16	50%	24	28%	1.2	2.4
Ireland	0.3%	48	48%	25	5%	23	43%	1.1	2.3
Italy	3.4%	493	107%	142	18%	351	89%	17.5	35.1
Latvia	0.0%	7	327%	3	243%	5	83%	0.2	0.5
Lithuania	0.1%	12	92%	6	76%	6	16%	0.3	0.6
Luxembourg	0.1%	12	36%	6	-33%	6	69%	0.3	0.6
Malta	0.0%	2	73%	1	-5%	1	78%	0.1	0.1
Netherlands	1.4%	199	90%	80	30%	120	60%	6.0	12.0
Poland	1.1%	159	44%	241	67%	-82	-23%	-4.1	-8.2
Portugal	0.3%	45	64%	14	13%	31	51%	1.5	3.1
Romania	0.2%	34	69%	37	71%	-3	-1%	-0.1	-0.3
Slovak Republic	0.2%	30	75%	21	61%	9	14%	0.5	0.9
Slovenia	0.1%	16	54%	15	49%	1	5%	0.0	0.1
Spain	1.9%	281	49%	116	-16%	165	65%	8.3	16.5
Sweden	0.8%	111	239%	25	33%	85	207%	4.3	8.5
United Kingdom	5.7%	835	132%	202	41%	633	90%	31.6	63.3
Total EU27	31.9%	4,685	103%	1,713	41%	2,972	62%	148.6	297.2

Results are shown as a "Total Obligation" in both MtCO$_2$e and as a percent reduction below 1990. The "Domestic Reduction" is taken from the results of the mitigation analysis presented in Sections 3–5. The "International Obligation" shows the additional mitigation, beyond the domestic reductions, that each country would have to undertake through international finance and technology cooperation to meet its "Total Obligation".

It is also worth noting that even if the amount of necessary international support turns out to be at the higher end of the range – €450 billion per year in 2020 – it is a cost that the EU is capable of absorbing. In the EU15 countries, costs would be on average less than €3 per person per day. In the EU12 countries, the average cost per person would be considerably less.

Given the current status of EU policy-making, a 40 per cent emission cut across Europe, plus international mitigation assistance worth between one and three percent of global GDP, appears politically unrealistic today. However, the science makes clear that a 2°C threshold is likely to be exceeded without reductions on this scale in the industrialised world. And the reality of the global crisis of poverty and underdevelopment makes it similarly unlikely that the developing world will elect to bear much more than its fair share of the climate burden, and to dramatically reduce its emissions without major levels of support from the developed world. The lesson in all this is that, if the EU wants to honour its commitment to maintain a safe planet for the next generation, and to keep warming below 2°C, it will only happen if our definition of "politically realistic" gets recalibrated to the reality of the climate and development predicament facing our world.

7 CONCLUSIONS AND RECOMMENDATIONS

Even while science is unambiguously telling us that even 2°C of warming would be highly dangerous for our planet, many people are rapidly losing all confidence that we will be able to prevent this level of warming, or even far more. But a climate catastrophe can be averted. Doing so demands political leadership and courageous policy initiatives, both of which go well beyond politics as usual.

In this report, we used the Greenhouse Development Rights (GDRs) framework as a basis for establishing how the burden of addressing the climate challenge can be shared fairly among countries, with specific calculations reported for Europe. We showed that Europe has a total mitigation obligation of 103 per cent below 1990 levels by 2020 — far more than the target adopted by the European Union for 2020. Clearly, this figure is only meaningful if it is understood as a two-fold obligation to, on the one hand, undertake mitigation domestically and, on the other, invest in mitigation internationally. Our analysis suggests that the EU can meet a domestic target of 40 per cent cuts by 2020 and at least 90 per cent cuts by 2050 versus 1990 levels. Our calculations also suggest that the EU's needs to commit to meeting its international financing obligations, which based on our GDRs analysis would likely be between €150 billion and €450 billion in 2020 depending on the average cost of mitigation, or approximately 1.1 per cent to 3.3 per cent of projected 2020 GDP in the mitigation scenario, the overwhelming majority of which (more than 95 per cent) would be the responsibility of the comparatively wealthier EU15 member states.

We also examined whether and how Europe could embark on its own transition to a low GHG future – enabling it achieve the domestic emission reduction targets identified above. We concluded that such a transition is technically feasible, without international carbon offsetting schemes and whilst phasing out nuclear power facilities, and without resorting to carbon capture and storage (CCS) for fossil-based electricity generation or agrofuels for transportation.

However, our report should not be read as an exclusive endorsement of this particular mitigation pathway. While it shows that the deep cuts that science tells us are needed can indeed be achieved without undue economic pain, they might equally be achieved through other pathways, some of which may well be socially, economically and politically preferable to those identified here.

Whatever pathway is chosen, one point is absolutely clear: it will not happen spontaneously. It will require major and brave political leadership and a major mobilisation of effort of the type normally only seen in wartime.

Current EU climate and energy policies do not give any promising signals showing that such a major shift in policies is underway. They are rather characterised by weak targets that either fail to conform to the 2°C rhetoric or are simply "aspirational", a lack of overarching climate measures mainstreamed into the whole economy, a reliance on offsetting emission reductions rather than cutting emissions within the EU and a lack of public financing and technology to enable and support mitigation and adaptation in the global south. In short a combination of policies that puts us firmly on course to exceed 2°C of warming.

If the EU is to turn this trend around and assume a position of climate leadership, then the introduction of incentives that tackle the climate challenge must promptly become the guiding principle in all EU policy making, from housing to transport, and from agriculture to energy generation. The EU would need to adopt an overarching "climate protection framework" comprised of well-coordinated measures – such as those discussed and analysed in this report – that can rapidly deliver meaningful emission cuts.

Such a framework can ensure that member states introduce strong national climate legislation regulating GHG emissions in all parts of the economy at the national level. These climate laws would ensure that emissions are brought down year-by-year with the speed that is needed. It will achieve greater climate justice by obliging governments to pay their fair share of the finances needed for supporting developing countries to tackle climate change and to adapt to its consequences. Addressing the climate crisis will require addressing the issue of equity both within the EU and internationally. The framework should thus make sure that it addresses the disparities both between EU countries and within EU countries.

While there clearly has been a massive surge in interest in addressing the climate crisis in recent years, we are still very far from doing what is needed. Moreover, the needed mobilisation needs to start immediately so that global emissions can start to decline in this decade. Failure to act quickly and decisively will virtually guarantee dangerous warming far above 2°C.

The initial cost the domestic mobilisation in Europe (between 2010 and 2020) is likely to be within the range of one per cent to three per cent of EU GDP. In addition to this, the cost of the necessary international support for mitigation in developing countries may be another one per cent to three per cent of EU GDP. While this is not a trivial sum by any means, it also is not a prohibitive cost. In fact, it can even be considered a small cost when viewed in the context of the dire crisis we are facing. Even the upper end of this cost range would still be less – and possibly much less – than the cost of inaction.

As this study has shown, the technological opportunities are waiting to be exploited, the economic costs are eminently bearable. It appears to be only the lack of political will that prevents Europe from assuming a position of global climate leadership.

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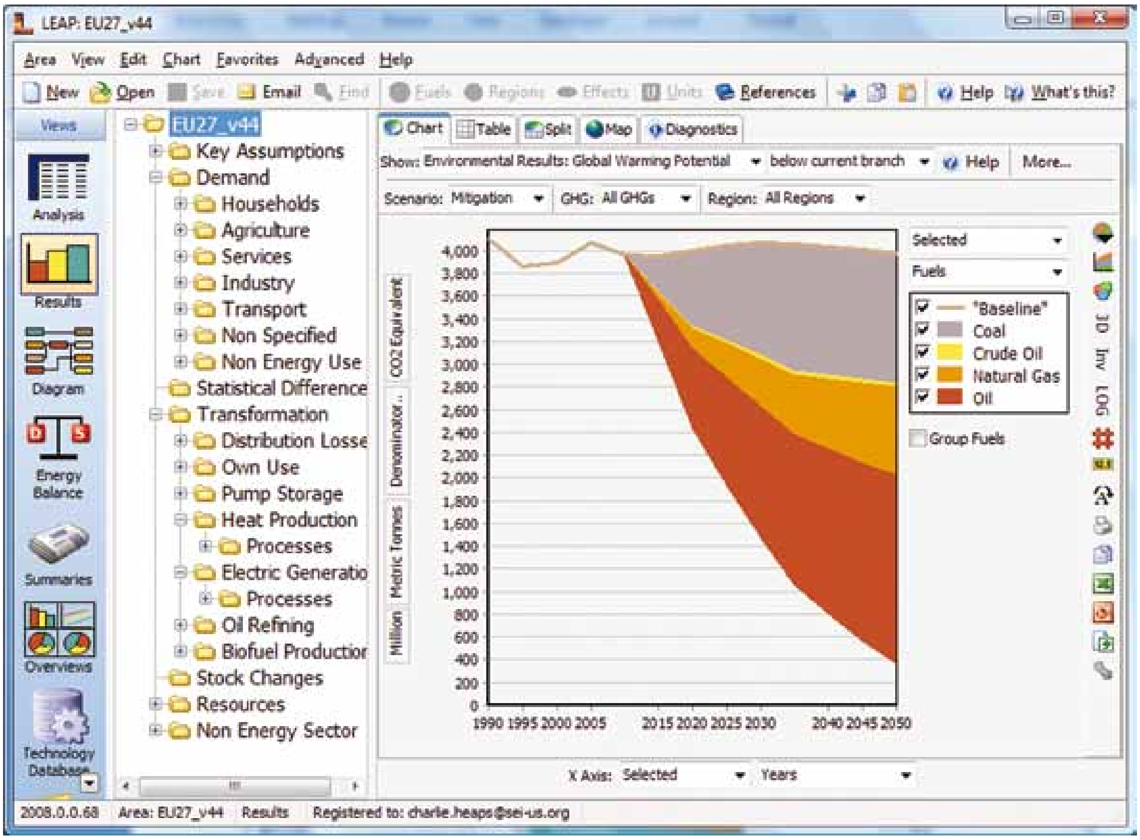
9 ANNEXES

9.1 SEI'S LEAP ENERGY MODELING SYSTEM

The scenarios described in this study have been developed using SEI's LEAP energy modelling system (Heaps, 2008). LEAP has been used as the main organising framework for analysing the energy consumption and production, GHG emissions, and costs and benefits for the baseline and mitigation scenarios described in this study. The LEAP data set we developed includes detailed information on all 27 EU countries and is capable of showing results for any one of these countries or for Europe as a whole.

More information on LEAP is available at www.energycommunity.org. Both LEAP and the LEAP data set containing these scenarios are being made freely available for download at the LEAP web site or by emailing leap@sei-us.org.



Show: Environmental Results: Global Warming Potential ▾ below current branch ▾

Scenario: Mitigation ▾ GHG: All GHGs ▾ Region: All Regions ▾

X Axis: Selected ▾ Years ▾

2008.0.0.68 Area: EU27_v44 Results Registered to: charlie.heaps@sei-us.org

Figure 32: LEAP: the Long-range Energy Alternatives Planning system
A transparent and user-friendly accounting-based software tool for scenario-based energy analysis and GHG mitigation assessment. Developed at SEI, LEAP has been the main organisational framework used for this analysis.

9.2 SUMMARY TABLES FOR SCENARIOS

	Historical			Baseline		Mitigation	
Indicator	**1990**	**2000**	**2010**	**2020**	**2050**	**2020**	**2050**
Population(Mill)	471	482	495	498	480	498	480
GDP (Trill 2005 PPP Euros)	8	10	12	14	22	14	19
Avg. Income (Thou 2005 PPP Euros)	17	21	24	28	47	27	40
Final Energy by Sector (Thou PJ/yr)							
Households	11	12	13	13	13	11	5
Agriculture	1	1	1	1	1	1	0
Services	5	5	6	6	6	5	3
Industry	14	13	13	12	11	10	5
Transport	13	16	18	20	21	14	4
Non Specified	1	1	1	1	1	1	0
Non Energy Use	4	5	5	5	5	5	4
Total	49	52	56	57	58	46	22
Final Energy by Fuel (Thou PJ/yr)							
Biomass	2	2	2	2	3	2	1
Electricity	8	9	11	12	14	12	10
Heat	2	2	2	2	2	2	2
Natural Gas	10	11	12	11	10	10	2
Oil Products	23	26	28	28	28	19	6
Renewables	–	–	–	0	0	1	1
Solid Fuels	5	2	2	2	1	1	–
Total	49	52	56	57	58	46	22

	Historical			Baseline		Mitigation	
Indicator	**1990**	**2000**	**2010**	**2020**	**2050**	**2020**	**2050**
Electric Generation Capacity (GW) not including CHP							
Biomass	3	7	15	15	15	12	9
Coal	165	151	164	185	246	103	0
Geothermal	1	1	1	1	1	8	17
Hydro	108	108	111	114	115	114	115
Natural Gas	17	55	88	100	145	67	0
Nuclear	133	134	125	111	114	106	0
Oil	83	68	46	46	46	30	0
Solar PV	0	0	4	7	11	27	55
Solar Thermal EU	0	0	0	0	0	32	73
Solar Thermal Imports	0	0	0	0	0	0	121
Wave and Tidal	0	0	0	1	2	10	21
Wind Offshore	0	0	2	9	37	101	270
Wind Onshore	13	13	70	110	133	241	47
Wind Onshore w Storage	0	0	0	0	0	0	484
Total	523	537	626	699	865	851	1212
Electric Generation (TWh/yr)							
Biomass	9	25	45	46	45	38	26
CHP Plants	387	457	599	630	611	497	346
Coal	790	730	698	799	1,039	457	-
Geothermal	3	5	6	6	7	35	69
Hydro	286	360	381	398	413	419	399
Natural Gas	102	314	437	509	716	347	–
Nuclear	778	938	901	791	824	651	–
Oil	179	147	87	87	90	60	–
Solar PV	–	–	7	13	22	53	104
Solar Thermal EU	–	–	–	–	–	65	139
Solar Thermal Imports	–	–	–	–	–	–	228
Wave and Tidal	1	1	0	2	4	22	47
Wind Offshore	–	–	6	25	93	285	700
Wind Onshore	1	24	128	203	250	487	85
Wind Onshore w Storage	–	–	–	–	–	–	904
Total	2,536	3,001	3,295	3,508	4,114	3,417	3,047

	Historical			Baseline		Mitigation	
Indicator	**1990**	**2000**	**2010**	**2020**	**2050**	**2020**	**2050**
Primary Energy (Thou PJ/yr)							
Biomass	2	3	5	6	7	7	5
Coal	18	12	11	12	12	5	–
Geothermal	–	–	–	–	–	0	0
Hydro	1	1	1	1	2	2	1
Natural Gas	12	16	18	18	18	15	4
Nuclear	9	10	10	9	9	7	–
Oil	27	30	30	30	30	20	6
Other fuels	0	–	1	1	1	1	0
Solar	–	–	0	0	0	1	2
Wave and Tidal	–	–	–	–	–	0	0
Wind	–	0	1	1	1	3	6
Total	69	73	77	78	79	60	25
GHG Emissions (MtCO$_2$e)							
Energy Demand	2404	2393	2469	2440	2288	1650	259
Households	525	487	484	450	369	332	4
Industry	657	526	458	416	310	294	77
Services	198	152	170	159	114	67	0
Transport	915	1136	1273	1335	1441	902	159
Other	109	92	85	80	53	54	18
Energy Transformation	1712	1519	1512	1580	1718	789	108
Electric Generation	1147	1084	1022	1064	1221	649	97
Heat Production/CHP	523	390	444	471	453	111	7
Oil Refining/Other	42	46	45	45	44	28	4
Non-Energy Sector	670	437	415	502	506	370	183
Cement Process Emissions	119	116	124	139	179	122	75
Other Industrial Processes	127	65	58	43	17	43	17
Agriculture	579	491	482	462	408	363	213
Land Use Change and Forestry	-330	-371	-357	-234	-153	-234	-153
Waste	176	136	109	91	55	77	30
Total	4786	4349	4396	4521	4511	2808	549
% Reduction vs. 1990	0%	9%	8%	6%	6%	41%	89%

	Historical			Baseline		Mitigation	
Indicator	**1990**	**2000**	**2010**	**2020**	**2050**	**2020**	**2050**
GHG Emissions (MtCO$_2$e)							
Austria	61	65	74	80	78	50	5
Belgium	126	136	121	127	137	79	20
Bulgaria	104	36	29	29	15	17	-1
Cyprus	5	9	11	13	15	8	3
Czech Republic	169	122	124	138	133	69	17
Denmark	72	69	73	72	73	35	9
Estonia	29	9	8	11	11	5	-1
Finland	52	40	53	60	68	29	-1
France	468	475	449	446	440	315	76
Germany	1117	930	894	902	897	551	84
Greece	99	117	120	123	122	79	18
Hungary	87	69	62	60	55	44	12
Ireland	54	68	74	76	83	51	13
Italy	396	419	473	467	493	324	58
Latvia	5	-14	-13	-5	-1	-8	-8
Lithuania	40	11	14	15	13	9	2
Luxembourg	9	11	17	18	19	13	2
Malta	1	1	2	3	2	1	0
Netherlands	198	216	215	218	239	139	30
Poland	356	265	317	359	304	118	34
Portugal	60	81	72	67	60	52	12
Romania	201	85	80	96	73	59	12
Slovak Republic	66	37	39	47	39	26	8
Slovenia	16	16	16	24	25	8	2
Spain	253	355	405	411	438	295	71
Sweden	41	49	45	53	64	28	3
United Kingdom	700	670	621	613	614	411	69
Total	4786	4349	4396	4521	4511	2808	549

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