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CEPS Policy Brief

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CENTRE FOR EUROPEAN POLICY STUDIES

No. 188/May 2009

Reaching the 2°C Target:

Technological Requirements, Economic Costs and Policies

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This paper presents ongoing research being carried out for the EU-funded ADAM project (Adaptation and Mitigation Strategies: Supporting European Climate Policy). Funded by the European Commission and coordinated by the Tyndall Centre for Climate Change Research in the UK, ADAM is an integrated research project running from 2006 to 2009 that will lead to a better understanding of the trade-offs and conflicts that exist between adaptation and mitigation policies. ADAM will support EU policy development in the follow-on stage of the Kyoto Protocol and will inform the emergence of new adaptation strategies for Europe. CEPS is one of 26 participating research institutes in the project (see http://www.adamproject.eu/).

Reaching the 2°C Target:
Technological Requirements, Economic Costs and Policies

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CEPS Policy Brief No. 188 / May 2009

Executive Summary

This policy brief builds on results arising from the mitigation and policy appraisal research domains of the ADAM project and addresses questions surrounding the European Union's proclaimed goal to stabilise the global mean temperature at less than 2°C above pre-industrial levels. Achieving the target is strongly related to the introduction of stringent mitigation policies at a global scale, which will require the emergence of an effective post-Kyoto climate agreement, for instance at COP15 in Copenhagen in December 2009. Whilst the European Union is only one among several major greenhouse gas (GHG) emitters in the world, its claim to act as global leader in climate policies requires proof that the Union and its member states can, in fact, deliver on the scale of GHG mitigation it has promised. Failing to do so is likely to dissolve the willingness of other countries, including major emerging countries, to invest in sustainable energy futures. It is against this backdrop of global implications that achieving its targets is of pivotal importance for the European Union's energy and environmental policies.

In Section 1 we explore the implications of the 2°C challenge in terms of GHG concentrations, emissions reduction and mitigation policies. Research indicates that uncertainties about future climate change are large. Even if GHG concentrations can be stabilised at 450 ppm CO_2 equivalents (CO_2e) through strong mitigation, there is a ca. 50% chance of overshooting the 2°C target. For stabilisation at 400 ppm CO_2e, this probability decreases to less than 30%. However, for the 400 ppm CO_2e scenario to be feasible, most probably negative emissions would be required by the end of the century, which could be achieved by combining the use of bio-energy and carbon capture and storage (CCS). Use of bio-energy will have important implications for land use. Both the 450 and the 400 ppm CO_2e scenarios show a global emissions peak around 2020, implying that all major emitting countries would reduce emissions by that time. This highlights the importance of (near) global participation as a major policy challenge of the coming decade.

Section 2 shows modelling results of mitigation option portfolios, their costs and technological challenges for different parts of the world. The ADAM analysis shows that a set of different models finds low stabilisation to be technically feasible. Depending on the stringency of the target, there are multiple possible technological mitigation pathways. According to the model analysis, the lower the targeted GHG stabilisation concentration, the more the energy sector depends on bio-energy and CCS. Possible constraints are that CCS technology is still in the demonstration phase and that the future availability of biomass for energy generation highly determines the global mitigation costs in the second half of this century. Nuclear power appears to be of minor importance for reaching low stabilisation. The cumulative GDP losses until 2100 are estimated to be below 0.8% and 2.5% for the 550 and 400 ppm CO_2e scenario, respectively. Costs vary considerably across regions and also between the models used.

Section 3 then describes the policies and measures that the European Union and its member states will have to implement in all energy-relevant sectors in order to reach its internal goals. Consistent with low stabilisation, European emissions in 2050 need to be reduced by 60% to 80% compared with 1990. This implies a total renewal of the European capital stock. Different instruments are needed to implement such an ambitious reduction target. The main instrument is likely to be the EU Emissions Trading Scheme (EU ETS), which is expected to become part of a worldwide ETS. In addition, sector and technology-specific policies and measures need to be introduced to overcome the inherent barriers and market imperfections.

Specific measures that will need to be taken include:

- In *buildings*, energy demand for heating and cooling needs to be reduced by almost 60% through the introduction of strict energy building codes for new buildings and retrofitting up to 90% of the existing building stock by 2050.
- In the *transport sector*, a variety of technological changes, introduced through incentives and regulations, can reduce emissions by 50% to 70% until 2050. A significant part of the emissions reduction can be achieved through

incentives to introduce intelligent transport management systems and change behaviour.

- In the *industrial sector*, emissions must be reduced by 30% to 40% by realising the large profitable potentials of energy and material efficiency and by introducing more renewables for process energy and heating/cooling. Major improvements are additionally possible through a mix of measures that include new technologies, more efficient management of production systems and rigorous efficiency standards for mass-produced electric drives and electric appliances.
- In the *energy conversion* sector, the ETS will provide the incentives and intensive R&D efforts to transform the present electricity generation system leading to a portfolio of carbon-lean technologies by 2050, including nuclear (20%), fossil (10%), and renewables (70%). A strong contribution also comes from energy efficiency improvements, leading to -25% reduction of primary energy demand by 2050.

In section 4, finally, we take a backward-looking approach to explore how we can learn from the European Union's past experiences with climate mitigation policies to ensure the delivery of better and more effective policies in the future. Studies assessing the effectiveness of current emissions reductions policies suggest that these policies can lead to a reduction of 3.6% in 2010 compared to 1990. By counting on additional measures, i.e. Kyoto mechanisms, and sinks, it is likely that the EU can meet its Kyoto target of -8%. Within the EU there is a very mixed picture between member states and also between sectors delivering (or not) on their individual targets. Studies show that European policies currently pay little attention to an evaluation of its effectiveness. As a result, the effectiveness of policy targets is often difficult to measure or even to evaluate; it remains to be seen whether the EU's mitigation policies can lead to a long-term change of behaviour. There are some positive experiences on specific policies such as the feed-in tariff for renewables, the progressive building standards or the new international standards of electric motors that induce substantial reductions of GHG emissions. However, the current understanding of the ways in which policies act is still limited, also due to many external factors (willingness of influential stakeholder groups not to support the changing policies) that make projections of policy strategies difficult.

Introduction*

The objective of international climate policy is to prevent "dangerous anthropogenic interference of the climate system" (UNFCCC, 1992). Translating this qualitative objective into quantitative targets for emissions, concentrations or even temperature increase is difficult as a result of uncertainties, but also subjective interpretations of factors such as risk and equity consideration (see, for instance, Schneider & Mastrandrea, 2004; Meinshausen et al., 2006; Hof et al., 2008). In general, the impacts of climate change become more severe with increasing global mean temperature change (IPCC, 2001). The EU translated the UNFCCC objective into an objective to limit the global mean temperature increase to 2°C compared to pre-industrial levels, indicating that above this level the "risks of dangerous and unpredictable climate change increase significantly and costs of adaptation escalate" (European Commission, 2007b; Lenton et al., 2008). In reality, even below 2°C the impacts on more vulnerable and exposed ecosystems and societies are expected to be significant (IPCC, 2007), and the target is primarily a political statement. An important issue is whether the target is perceived as credible or else political support is improbable. In that context, from a scientific perspective it must be shown that the 2°C target is technically feasible, economically viable and politically manageable.

Achieving the 2°C target is strongly related to the introduction of stringent mitigation policies on a global scale, in particular from the OECD countries as well as major emerging economies. A strong mandate arising from successful post-2012 climate regime negotiations in Copenhagen 2009 is therefore of the utmost importance to create the necessary momentum for the implementation of these mitigation policies. As for the European Union, the current global leader in mitigation and adaptation policies, the inability to implement far-reaching mitigation policies in its member states will inadvertently reduce attempts of major developing countries, e.g. China, India or Brazil, to invest heavily in a more sustainable energy future. The current goal to reduce EU-wide emissions by 20% and raise the level of renewable energy consumption to 20% until 2020 compared to 1990 levels (European Commission, 2008) is already being challenged by EU and national government legislation. Therefore it is important for the European Commission and the EU member states to learn as much as possible from past experience to be able to create the environment within which strong mitigation policies in Europe can be implemented in

* Contributed by Henry Neufeldt.

the future. This will not only give credit to Europe as the global leader in climate change policies but will also provide Europe's industries with the security to invest in green technologies and thus benefit the most from climate change.

Basic facts around the 2°C target

When referring to the 2°C stabilisation target, we refer to a global average temperature that is less than 2°C above pre-industrial levels (normally 1860). Considering that we are currently already nearly 0.8°C above that value and are committed to something in the order of another 0.6°C through past emissions that are not yet apparent due to considerable inertia of the global climate system, the temperature increase related to future emissions may not be higher than another 0.6°C over the course of this century.

The chance of reaching the 2^{o}C target falls with increasing greenhouse gas (GHG) concentrations in the atmosphere. The total concentration of GHGs can be expressed in terms of the radiative forcing (RF) of all gases as if it was caused by CO_2 alone (the so-called 'CO_2-equivalent concentration', CO_2e). According to Hare & Meinshausen (2006), there is about a 70% chance of achieving the target for a 400 ppm CO_2e, a 50% chance with 450 ppm CO_2e and a 25% chance with 500 ppm CO_2e. The current net RF of the atmospheric components is surrounded by high uncertainty (IPCC, 2007). However, the net average RF of the major components is similar to the RF of CO_2. Hence the CO_2 concentration (currently 386 ppm_v) is similar to the current CO_2e concentration.

This policy brief builds on results arising from the mitigation and policy research domains of the ADAM project[1] and a policy seminar held at CEPS on 11 February 2009.[2] It presents policy-relevant research that can feed into the ongoing policy process within the European Commission and at member state level. Section 1 explores the implications of the 2°C challenge for concentrations, emissions reduction and mitigation policies, taking into account the enormous uncertainties that play a role in these relationships. Section 2 shows which portfolios of mitigation options will most likely achieve the target and exposes the costs and technological challenges that await us in the different regions of the world. Section 3 describes the policies and measures that Europe will have to implement in all energy-relevant sectors and explores the costs and benefits of these policies. Section 4 reviews, *ex-post*, the performance of EU climate mitigation policies to date and tries to draw lessons that help us devise more effective and better policies for the future.

1. Implication of the 2°C target for mitigation policy*

Baseline scenarios show that, if current trends continue unchecked (no climate policy), the temperature increase relative to pre-industrial levels could be in the order 3.2-5.2°C in 2100 (uncertainty in emissions) or 2.7-6.7^{o}C, also accounting for uncertainty in climate sensitivity and the carbon cycle. In other words, the EU 2^{o}C target is not going to be met without explicit policies to constrain emissions. What concentration target is required critically depends on uncertainty in the climate sensitivity. In order to raise the likelihood of achieving the 2°C target above 50% stabilisation levels of greenhouse gas concentrations below 450 ppm CO_2e are required. Stabilising below 400 ppm CO_2e could further increase the likelihood to over 70% (Hare & Meinshausen, 2006). Even with stabilisation at 450 ppm CO_2e, the temperature increase could be in the order of 3.5°C if climate sensitivity is high (van Vuuren et al., 2008). A first conclusion is that, in addition to efforts to reduce anthropogenic greenhouse gas emissions, societies should also consider strategies for adapting to higher global temperatures (aim for 2^{o}C; be prepared for more). This also implies that adaptation and mitigation are often not trade-offs, but two connected sides of an effective climate policy.

For a given concentration target, emissions reductions are uncertain as well, as a result of timing of policies and uncertainty in the removal rate of greenhouse gases from the atmosphere. In any case, for very low greenhouse gas concentration targets, major emissions reductions are required already in the short-term. Overshoot scenarios represent an efficient way to achieve a high probability of reaching long-term temperature targets at relatively low costs (Den Elzen & Van Vuuren, 2007). On the basis of such scenarios, it is possible to show that emissions reductions in the order of 50% in 2050

[1] Adaptation and Mitigation Strategies: Supporting European Climate Policy (ADAM).

[2] The previous ADAM-CEPS Policy Briefs are based on three science policy seminars held at CEPS in Brussels: on 1 October 2007 in the context of the European Commission Green Paper on Adaptation: "Why we will need adaptation and how it can be implemented" (Aaheim & Aasen, 2008; Aaheim et al., 2008; McEvoy et al., 2008); on 4 April 2008 on "The future of European electricity: Choices before 2020" (Eskeland et al., 2008); and on 1 October 2008 on "Climate governance post-2012: Options for EU policy-making" (Biermann et al., 2008).

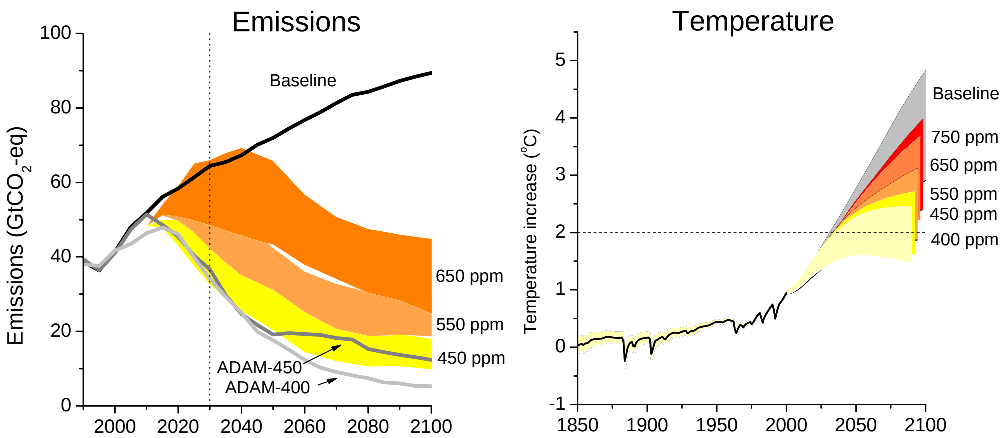
* Contributed by Detlef P. van Vuuren and Morna Isaac.

would be consistent with reaching a 2°C target with a probability of around 50%.

The implications of reaching such ambitious emissions profiles are challenging, even under the optimistic assumption of a world that cooperates in achieving global mitigation (which we present here). Excluding different world regions will either raise the costs or render the target unachievable. The IMAGE 2°C scenarios that aim for 400 and 450 ppm CO_2e concentration targets show that in both scenarios the energy system will be almost totally different from the "baseline" development. Important reduction measures may constitute material and energy efficiency, use of renewable energies and of carbon capture and storage (CCS), reducing non-CO_2 gases and increased use of bio-energy. For the 400 ppm CO_2e scenario, most probably negative emissions by the end of the century would be required – which can be achieved by combining use of bio-energy and CCS. It is also likely that climate policy will have major consequences for land use, given the role of bio-energy and carbon sequestration. As both the 400 and 450 ppm CO_2e emissions profiles show a peak in global emissions around 2020, emissions reductions in all major emitting countries, including large emerging economies, would be required by that time (see Figure 1). Increasing participation in an international mitigation regime thus represents the most important policy challenge for achieving low stabilization targets. This will require a clearer understanding of the required emissions reductions over time for different countries and sectors. Political strategies need to constitute an acceptable combination of long-term mitigation targets and the appropriate investment in R&D to reduce costs through more advanced technologies in the future.

Scenarios have started to explore the consequences of baseline emissions and ambitious targets in a more integrated way. Results show that for many possible impacts, adaptation policies even at 2°C will be just as important as mitigation policies. This is for instance the case for agriculture and rises in the sea level. Cost-benefit analysis as a tool can help in assessing the consequences of climate policy in a structured way – but will never provide a single answer as the results are dominated by uncertainty – and even more important subjective interpretations of risks and equity considerations (Hof et al., 2008; Barker et al., 2008).

Figure 1. Indication of emissions profiles and temperature outcomes of different stabilisation targets



Sources: ADAM-project and MAGICC calculations from Van Vuuren et al. (2008).

2. Achieving low stabilisation: Technologies, costs and risks*

In order to achieve political commitment to tackle the 2°C target, it needs to be shown that the goal is not only technically feasible but also economically viable if it is to be acceptable to stakeholders and decision-makers around the world. The previous section has shown that the 2°C target can be achieved with different emissions pathways at different probabilities. Here we explore the feasibility in terms of technologies and economic costs for three different CO_2 concentration pathways (550 ppm, 450 ppm, and 400 ppm CO_2e). To obtain a robust picture of mitigation costs and technological options, the results are based on a model comparison with five state-of-the-art energy-environment-economy models (Knopf et al., 2009).

* Contributed by Brigitte Knopf and Ottmar Edenhofer.

All models were able to achieve even the very low stabilisation scenario with existing technologies and at moderate costs. But in all mitigation scenarios the energy mix strongly depends on the model. This suggests that there is not just one way to achieve emissions reductions but that several alternatives exist: extension of renewables, use of CCS, increase of nuclear power, increase in biomass energy use and energy-efficiency improvements.

Achieving the 550 ppm CO_2e stabilisation scenario allows for high flexibility in the deployment of different technologies: one technology can be replaced with another without a significant increase of costs. When more ambitious targets are to be achieved (i.e. 400 ppm CO_2e), this flexibility is lost: without the CCS technology or without the extension of renewables due to climate policy, the required emissions reductions can no longer be achieved. Moreover, the biomass potential (i.e. the amount of energy that can be generated from biomass) considerably determines the costs of mitigation. The biomass potential also has an important influence on the energy mix such that a high amount of biomass energy may restrict other renewables, such as wind, solar and hydro, from entering the market (Edenhofer et al., 2009).[3]

The availability of CCS is of pivotal importance for achieving low stabilisation levels. The analysis shows that without CCS, the 400 ppm CO_2e target is not achievable. But even a low CCS potential of about 120 GtC could render the ambitious target attainable, albeit at rising costs (Edenhofer et al., 2009). However, as CCS has not been applied on a large scale so far, the future availability of this technology remains to be proven. This is a major uncertainty when devising possible future energy technologies.

[3] It is important to note that so far only the technical potential of the energy supply has been analysed in the model. Conflicts with other types of land use, in particular food production and biodiversity protection, as well as the question whether this potential can be sustainably harvested have so far not been investigated. Furthermore, zero emissions are attributed to bio-energy use, thus neglecting emissions from direct and indirect land-use change and the biomass production process itself (see e.g. Rao et al., 2008). Certain types of land-use change (e.g. converting wetlands or tropical forests) will lead to increased greenhouse gas emissions rather than emissions reductions. Neglecting these emissions will not only hide possible additional climate damage, but also yield an overoptimistic assessment of the economic potential of biomass in scenarios including carbon pricing.

In the baseline scenario, the increasing use of nuclear power is important. In the mitigation scenarios, however, the technology is not seen to play an important additional role, such that keeping nuclear power at its current level has nearly no effect on overall costs because nuclear power and fossil fuel power plants with CCS are considered as substitutes. However, nuclear power could become a more important option when the Fast Breeder technology is considered.

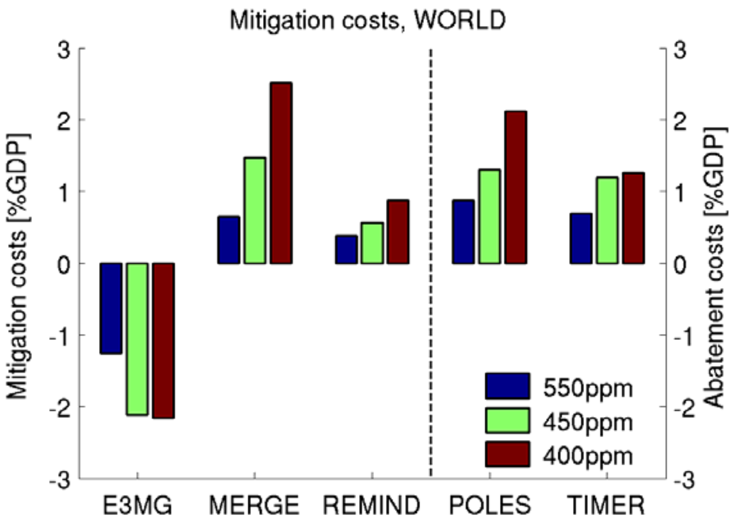
Overall, global mitigation costs, as aggregated GDP losses until 2100, are reported to be below 0.8% for the 550 ppm CO_2e scenario, and below 2.5% for the 400 ppm CO_2e scenario[4] (Figure 2). The yearly losses are moderate until 2040 but increase in four of the five models during the transition phase of the energy system and stabilise or even decline thereafter.

To investigate the regional distribution of the mitigation costs, a contraction and convergence scheme is applied that allocates emission permits to each region according to status quo emissions in 2000 and converges to equal per capita allowances in 2050. The regional distribution of the mitigation costs differs greatly between the models (Knopf et al., 2009), however, some consistent conclusions can be drawn. Costs for the three developed country categories, the EU27, the US and Japan cluster closely together and are lower then the global average. The United States consistently has the highest costs of the three. By contrast, differences between the developing country groups or countries tend to show much larger variations between models and depend substantially on the target. In contrast, the costs relative to the world average for the industrialised countries, Europe, the US and Japan, are nearly independent of the mitigation target.

With a stricter target, the costs for Russia decrease substantially in all models relative to the global average: Russia benefits from selling emissions permits as it can produce negative emissions due to its large biomass potential. And in one model Russia even reports gains due to mitigation.

[4] The E3MG model (Barker et al., 2008) reports overall gains for all stabilisation pathways, as it does not assume full employment of resources and imbalances in employment in the baseline. The climate policies partly solve the inefficiencies in the baseline.

Figure 2. Costs for implementing the 550ppm, 450ppm and the 400ppm CO_2e scenario



Note: For E3MG, MERGE and REMIND, the mitigation costs (gains for E3MG, respectively) are given as cumulated GDP losses until 2100 relative to baseline in percent of baseline GDP. POLES and TIMER report the increase of annual costs for mitigation (so-called abatement costs) relative to the baseline as a % of GDP (right axis, indicated by the vertical dotted bar).

Source: Edenhofer et al. (2009).

The analysis of the regional energy mix shows a more divergent picture than the global values. In most cases the variation of the energy mix is greater between the models than within any specific model. It follows that each model pursues a unique model-dependent strategy in most regions. Nevertheless, in some cases a robust strategy across all models can be identified: Russia, e.g. uses large amounts of biomass and India applies large amounts of nuclear energy compared to the world average in all models. The total energy use in Europe shows a consistent picture among the models with increasing energy use until 2050 and a slight decline thereafter. In India the total energy use rises by a factor of nearly ten in all models. For Russia, the US and China the projected trends depend very much on the model and the assumptions concerning the regional availability of low carbon energy carriers.

While the 2°C target's technical and economic feasibility has been shown, it remains to be demonstrated that it is politically manageable. For this it is necessary for policy-makers and citizens alike to believe that the target can be reached (psychological feasibility). Hence, regardless of the target, in the short-term quick action is needed. For the long-term decisions, the strategic development of technologies, technology transfer and capacity-building in developing countries is central to their involvement in a future climate regime.

3. Consequences for Europe[*]

The long-term objective of EU climate policy is to reduce EU GHG emissions by 60% to 80% until 2050 compared with 1990 (European Commission, 2007a). The largest single instrument to achieve this objective is certainly the EU emissions trading system, which was introduced in 2005. The EU ETS is expected to be improved for the next commitment period beginning in 2012 and it is assumed that it will be developed further to become part of a worldwide ETS between 2020 and 2030 such that CO_2 certificate prices increase over time reaching about €200/tCO_2 in 2050 and reflecting the scarcity of CO_2 carrying capacity of the globe.[5]

However, the EU ETS alone will not be sufficient to achieve -60% to -80% GHG emissions until 2050. In addition to the EU ETS, for each sector specific policies and measures must be introduced to overcome the inherent barriers and market imperfections. This Policy Brief considers policies for the following sectors: buildings; transport; industry and electric appliances and electric motor systems; energy conversion and renewables.[6]

[*] Contributed by Wolfgang Schade and Eberhard Jochem.

[5] Details of the models and their assumptions can be found in Jochem et al. (2009).

[6] Mitigation (and adaptation) policies in the electricity sector have been the topic of an earlier ADAM-CEPS policy seminar and are described in Eskeland et al. (2008).

Two main elements constitute the strategy to achieve a low-carbon society: improved energy efficiency and increased use of renewables. Improved energy efficiency enables a reduction in *final energy demand* of -50% in households, -5% in industry and -20% in transport for the period 2005 to 2050. In addition to these energy efficiency gains, fuel switch to no- or low-carbon fuels will reduce *CO_2 emissions* from 4.6 to about 1.6 Gt CO_2 in Europe, of which the energy conversion sector reduces its emissions by more than -80%, households by more than -60%, transport -40% and industry -25%. The shift towards renewable energies will be particularly significant for electricity generation, for which it is expected that 70% will come from renewables by 2050 (Schade et al., 2009).

The volume of the required investments to accomplish the transition towards a low-carbon economy over the period 2005 to 2050 is estimated to amount to more than €7 trillion. As buildings constitute the largest share of the total capital stock, about 70% of these investments would be directed towards improving energy efficiency in buildings. About 17% would be needed for the transition of the energy system into a largely renewables-based system.

The downside of these investments would be higher production costs. Temporarily higher energy costs are compensated by reduced energy demand due to the efficiency gains. In total the balance between the investment push and the cost increase is close to neutral. Moderate employment shifts are expected from service sectors to investment goods-producing sectors due to the large climate policy-induced investments.

Whilst the European Commission can enforce legislation for certain sectors and technologies (e.g. the buildings or eco design directive), selection of appropriate measures at the national level will often depend on specific policy traditions and public values and cultures, which differ between member states. Respecting these differences will allow for policy development at the appropriate levels and ensure best integration of all levels of society, not least the private sector, consumers and financial institutions.

For stakeholders from industry it is important that policies provide credible short-term (e.g. 2020) and long-term targets (until 2050). Short-term targets alone, without any longer-term perspective, could potentially lead to lock-in into unsustainable technologies. For instance a switch from coal to gas that is reasonable in the short-term could form a barrier for the long-term development of renewables. Therefore the cap on emissions is the most important political target to be pursued. On the other hand, looking at the long-term alone will not provide the necessary incentives for investing in technological change. Predictability from the side of policy-makers is key to allocating further investments to decarbonise the society.

Policies for buildings in the residential, service and industrial sectors

In buildings, European energy demand for heating and cooling can be reduced by almost 60% in 2050 relative to the year 2000. To achieve this, substantially reduced heat losses from new buildings as well as from the existing building stock are required:

- For new buildings, low-energy building codes have to be introduced within the next four to seven years and passive house standards (about 15 kWh per m^2 and year) need to be achieved by the mid-2020s, with some difference allowed for northern (earlier) and Mediterranean countries (later).
- Of the existing building stock, 80% to 90% will need to be retrofitted with energy-efficiency measures by 2050. For this, the yearly retrofitting rate has to rise by a factor of 1.7 to 2.5 compared to business-as-usual. Through improved standards for insulation and other options of passive heat protection, levels of energy efficiency can reach 80% or more compared to new buildings.
- Minimum renewable energy quotas for the remaining fuels required for heating to further reduce emissions (e.g. thermal solar systems in all European countries except the Nordic states; modern forms of wood use for countries north of the Alps).

These policy efforts can be achieved through regulations, monitoring and improved training of professionals.

Policies for transport

Until recently, transport was considered to be one of the sectors in which it would be very difficult to reduce GHG emissions. However, the ADAM project, building on national experience and new emerging policies on the European level, designed and analysed a set of policies that will enable the transport sector to reduce its emissions by 50% until 2050, thereby contributing significantly to European CO_2 reduction efforts.

A successful transport policy package has to implement both incentives and regulation. Different modes and means of transport should be considered separately as each transport activity disposes of specific potentials for GHG reductions. Most importantly, policies should be designed and implemented following a long-term strategic target. Only a long-term strategy will allow for the necessary investments and adaptations of the transport and spatial planning system to be made.

The strongest reduction of GHG emissions can be expected for urban transport, in particular passenger transport. The reason is the combination of both the availability of low-carbon technologies (e.g. fuel-efficient city cars, electric vehicles) and the availability of alternative transport options in urban areas (e.g. public transport, slow modes, car-sharing systems). To foster the shift to low-carbon technologies, the policy bundle includes GHG emissions limits of cars, taxation based on GHG emissions, efficiency labelling, city tolls and subsidies for market entry of new technologies. Such a package will also stimulate the renaissance of slow modes as well as tram systems in larger cities.

For freight transport, logistical improvements play the largest role to reduce GHG emissions. Other elements are incentives for efficiency improvements and modal-shift from road towards railways (e.g. road-user charges, railway capacity increase and interoperability), the inclusion of air transport and ship transport into the EU ETS and the increased usage of biofuels for heavy trucks and planes. Furthermore, a number of break-in-trends is expected until 2050, in particular the emergence of electric cars and electric light trucks.

Policies for industry, electric appliances and electric motor systems

Although industrial production in Europe is expected to double between 2005 and 2050, industrial energy demand will stagnate at the present level (after a peak between 2020 to 2030) due to extensive gains in material efficiency of energy-intensive basic products and materials and in energy efficiency, particularly in fuel use. Greenhouse gas emissions are reduced by 25 to 30% relative to present emissions due to drastic reductions of coal and heating oil use and increased shares of electricity and renewables (thermal solar, biogas from industrial organic wastes, heat pumps). This will be achieved through emissions certificates (affecting the large boilers and energy-intensive production plants), and a mixed basket of policies combining:

- mandatory minimum standards and labels for industrial cross-cutting technologies,
- energy-efficiency funds to promote energy management schemes and investment in energy-efficient technologies and in material efficiency,
- local learning networks of energy efficiency contributing to a major reduction of transaction costs and promoting the setting and monitoring of quantitative targets in industry,
- mandatory energy audits, benchmarking programmes, subsidised professional training, and energy managers in companies with annual energy costs above specified threshold levels,
- efficiencies of electric appliances and electric motor systems (e.g. compressors, ventilators, pumps, elevators, etc.) can be improved by 30% to 80% relative to present average performance. These potentials can be realised by adaptive technical standards e.g. minimum energy performance standards (MEPS), top runner schemes and labelling (e.g. 'high efficiency inside'),
- removal of tax exemptions (with revenues partly being used for promotion programmes) and finally
- R&D for breakthrough technologies such as applications of renewables in selected industrial sectors, new physico-chemical processes, or industrial CCS (e.g. cement industry), but also for improving material efficiencies and material substitution.

Policies for the energy conversion sector and renewable energy technologies

Europe is expected to develop a portfolio of new electric power technologies for generation and delivery. No major technological option is neglected for reducing total European greenhouse gas emissions to a level compatible with the Europe's climate objective of 2°C. By 2050, nuclear power generation will slightly reduce its share of total electricity generation to 20%, and only 10% of the European electricity production is provided by fossil technologies, whereas the large majority (70%) comes from renewables. These substantial structural changes will be achieved by policies such as:

- a continuation of the ETS where emission certificates are auctioned by the national governments,
- a decreasing feed-in tariff system for all European countries for electricity generated by renewables and co-generation before 2015,
- technology-specific support policies for renewables in combination with binding targets set at the European level during the next few decades to stimulate market penetration of renewables and to foster technological learning and generate economies of scale both significantly reducing the cost of renewables and
- further efforts in R&D for all options of renew-ables and efficiency technologies for all sectors.

4. Can the EU deliver its own targets?*

The EU in a global context

In 2006, total GHG emissions in the EU27, excluding net CO_2 removals from land-use, land use change and forestry (LULUCF), were 5.14 Gt CO_2e (EEA, 2008). The EU therefore currently accounts for about 10.5% of global greenhouse gas emissions.[7] Taking all historical GHG emissions, the EU25 had contributed about 18% to global mean surface temperature increases in 2005 (about 0.74°C since 1900, Dellink et al., 2008). This distinction is important because the EU has set two types of climate policy targets: those related to its own emissions and those related to the global mean temperature increase (the 2°C target). The first of these is, in principle, within the EU's own competence to determine; the second is mostly outside the EU's own competence, beyond its contribution to global emissions and to creating a broad and effective global climate regime. These emissions numbers address the obvious point that even radical reductions in EU emissions will have comparatively limited impacts on the longer-term goal of stabilising concentrations of GHGs in the atmosphere. And this relative contribution of EU emissions reductions to global emissions will continue to fall as emissions from UNFCCC non-Annex 1 countries (like China, Brazil, India and Nigeria) grow rapidly in the coming years.[8] Therefore, even if the EU meets its emissions targets, it may fail to meet its broader objective of ensuring a safe climate.

EU climate policy targets

The EU has over the past decade articulated a number of objectives for its climate policy, most recently at the European Council meeting in December 2008. The headline objective is the restriction of mean global surface temperature increases to no more than 2°C above pre-industrial levels over the long-run. Today this target is usually interpreted as requiring a stabilisation of GHG concentrations in the atmosphere. The 2°C objective remains aspirational, since noone alive today will be able to confirm whether the target is achieved or not. Getting onto a global emissions trajectory that leads to the necessary GHG concentration will require substantial emissions reductions by the EU and by other countries. Here, too, the EU has set specific targets, beginning in 1997, around the time the Kyoto Protocol was negotiated. Current EU emissions reductions targets and the groups of countries to which they apply are set out in Table 1. Beyond these high-level targets, there is a panoply of other targets of various kinds – targets for the market penetration of specific technologies (renewable, biofuels), energy efficiency targets, emissions targets for classes of product (vehicles) and so on – associated with EU energy and climate policy which are also intended to feed through to emissions reductions. An interesting question is whether these various targets are all consistent with the overarching emissions and temperature targets.

Table 1. Key EU greenhouse gas emissions reduction targets

Commitment	Coverage		Emissions Reduction Targets	Dates
	Member States	**Other**		
Kyoto Protocol	EU15		-8%	1990-2010 (average over period 2008-10)
EU Council 2008	EU27		-20% -30%*	1990-2020 1990-2020
		EU ETS	-21%	2005-20
		Non-ETS	-10%	2005-20

* If a new global climate agreement is negotiated.

* Contributed by Frans Berkhout.

7 Based on the Intergovernmental Panel on Climate Change (IPCC) estimate of global anthropogenic greenhouse gas emissions of 49.0 $GtCO_2$e in 2004 (IPCC, 2007).

8 Already in 2005, non-Annex 1 countries had contributed about 47% of the mean global temperature increase, compared to about 53% by Annex 1 countries (including the EU, the US and Japan).

EU climate and energy policy

European climate policy stretches back nearly 20 years and can be characterised has having become increasingly broad, complex, ambitious and Europeanised. Current EU climate action grew out of the European Climate Change Programme (ECCP) I and II (beginning in 2000), and the most recent statement of policy is the Climate and Energy Package agreed at the European Council and endorsed by the European Parliament in December 2008. Climate change has become a major policy issue for the EU, especially significant in the build-up to the 2009 UNFCCC Conference of the Parties (COP) in Copenhagen, where a new global climate agreement is due to be negotiated.

Central to European policy is a set of legally-binding targets by 2020: to cut GHG emissions by 20% (relative to 1990), to establish a 20% share for renewable energy and to improve energy efficiency by 20% (the so-called '20:20:20 objectives for 2020'). The January 2008 European Commission Communication (COM(2008) 30 final) articulates a number of principles for achieving these targets, including fairness, cost minimisation, looking over the longer term to 2050 and the need for a new global climate agreement. From amongst a wide range of climate policy instruments and strategies, the primary instruments for achieving EU climate targets are:

- the EU ETS covering some 50% of EU GHG emissions for which, under the revised system, targets will be set at the EU level from 2013 and permit auctioning gradually introduced by 2020;
- Common and Coordinated Policies and Measures (CCPMs) including a broad mix of traditional command and control mechanisms, market-based instruments, informational measures, funding for R&D and innovation, voluntary agreements and networking.

The most significant of these CCPMs are a renewable energy directive setting specific targets for EU member states, a biofuels directive setting targets for use of biofuels in transport, binding emissions standards for new passenger cars and a new directive on CCS. Most CCPMs are covered by a new 'effort sharing agreement', which sets out national emissions reductions targets for EU member states based on differences in GDP per capita, and associated with a legally-binding linear trajectory between 2013-20 with regular monitoring and evaluation. Beyond these European policies, implemented at member state level, most EU member states have nationally-specific portfolios of climate policies and measures, developed to ensure that their national targets are achieved, complementing and interacting with EU policies and measures.

EU emissions trends and projections

The European Environment Agency (EEA) acts as the main authoritative source of information on trends and projections for EU emissions. The latest report (October 2008) shows that emissions are falling in the EU and it paints a generally positive picture about the EU15 meeting its Kyoto target (-8% compared to 1990). But the EEA also projects that this will *not* be achieved with currently-implemented measures alone, which will generate only a projected -3.6% emissions cut in 2010. Only by counting additional measures,[9] Kyoto mechanisms (Clean Development Mechanism and Joint Implementation) and sinks (protecting or enhancing terrestrial carbon stocks on forests and land), together accounting for a staggering 7.7% emissions reduction, will the EU be able to meet its Kyoto target. If all these reductions are achieved, the EU15 are expected to over-achieve on their Kyoto target (-11.3% by 2010).[10] Of this, existing domestic and EU energy and other policies would account for 32% of expected reductions in 2010, an additional 29% will be achieved by additional measures still to be implemented before 2012, with the rest accounted for by CDM and sinks. It is clear from these figures that there is both still a long way to go in achieving the necessary emissions reductions and a heavy dependence on Kyoto mechanisms.

Climate policy effectiveness

All public policy seeks to influence behaviour – investment, innovation, consumption – to achieve some socially-desired outcome. If policy is very successful it becomes embedded in social and economic norms and behaviour. But it is also important to remember that policy is always acting in a broader economic and social context. This makes it hard to measure the impact of policy because the phenomenon that policy is seeking to influence – in this case GHG emissions – is also affected by many other factors. So, for instance, energy price changes can have a marked effect on energy use and therefore on their associated emissions. Some commentators have suggested that

[9] A wide range of measures are included under the category 'additional measures', including full implementation existing policies like the renewable directive, the energy efficiency in buildings directive and the co-generation directive (where progress has been slow since its introduction in 1997), as well as new measures, like a proposal to include aviation in the EU ETS, a revision of the fuel quality directive and new emissions limits for new cars.

[10] The accounting convention used here states that 2010 emissions will not be the emissions for the year, but the average over the commitment period (2008-12).

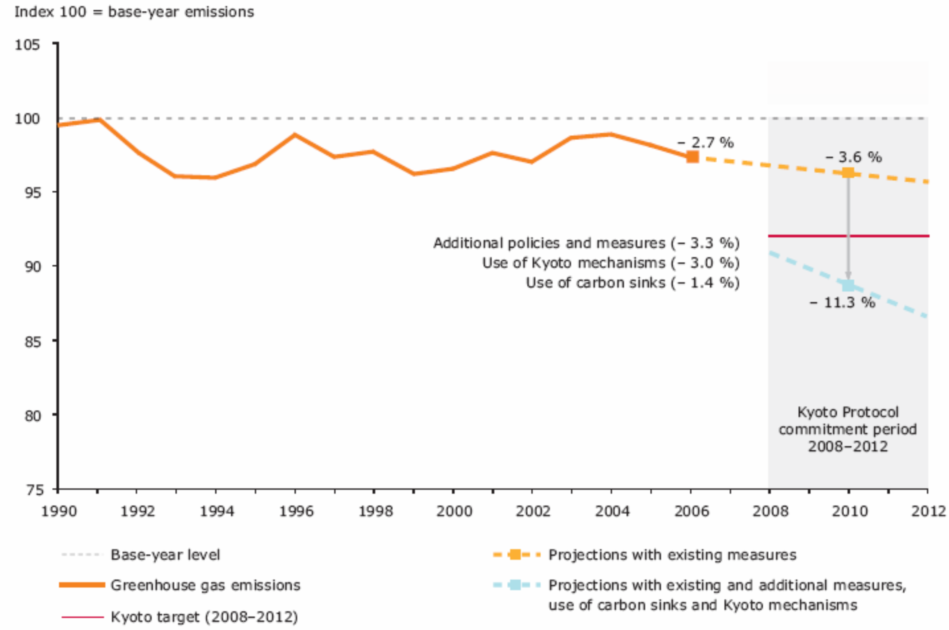
the global economic recession will also lead to a substantial, albeit possibly temporary, decline in emissions. Moreover, policies other than energy and climate policies may have a marked influence on GHG emissions. The well-known case of the 'dash for gas' in the UK, precipitated by the liberalisation of the electricity supply industry and the privatisation of the coal industry, is a textbook example of this.

A more specific reason why measuring *policy effectiveness* is difficult is our still incomplete knowledge about how policy signals affect the behaviour of economic actors, not only through prices, but through the relative incentives and penalties they generate, and the expectations they shape over the longer term. Policy analysts tend to argue that measuring the effectiveness of specific (or portfolios of) policies have proven difficult in the past, especially where policies are new or novel, like the EU ETS. While economic modellers need to make assumptions about how policies will influence the relative price of technologies, goods and services and how this, in turn, will affect supply and demand, such assumptions are treated more carefully by policy scientists. A degree of caution is therefore required in making projections for the future. Even looking back can be difficult. In total EU15 greenhouse gas emissions have fallen by about 0.15 $GtCO_2e$ since 1990. We have no baseline for emissions from that year, so we do not know what emissions might have been (the counter-factual); nor do we have an analysis of the contribution of EU and national climate policy to achieving these reductions. In short, quantifying the effectiveness of policies remains as much an art as a science, looking both forwards and backwards.

This is reflected in the climate policy evaluation studies that have been reviewed in a meta-analysis in the ADAM project (Haug et al., forthcoming). Amongst about 250 policy evaluation studies reviewed, we found very few 'tonnes per policy' studies, i.e. evaluations that were able to make projections for the emissions reductions that might be expected to arise as a result of implementing the policy. Having said this, the impact of the EU ETS, the renewable directive and the rest of the CCPMs is expected to grow in future. Certainly for the EU ETS, for which specific EU caps will be set from 2013, compliance (and non-compliance) will be more directly measurable.

But we should also remember market developments that may have nothing to do with climate policy: high energy prices, investment in greener infrastructures, increasing competitiveness of renewable energy technologies (RETs) as world markets expand, growing concern about energy security (Russia, Asia) and so on that are all likely to have a positive impact on emissions reductions over the coming years. Indeed, we may argue that these effects are likely to have a much greater impact on emissions pathways than policies by themselves. Policies have a role in facilitating innovation, diffusion and behaviour change, but they are just one side of the equation. In the context of the overall objective of a safe climate, the main political contribution by the EU to emissions reductions is likely to be helping to achieve a global deal at Copenhagen.

Figure 3. EU15 greenhouse gas emissions and projections for the Kyoto commitment period 2008-12



Note: The full effect of the EU Emissions Trading Scheme is not reflected in all member states' projections.
Source: EEA (2008), based on EU member states' greenhouse gas inventories and projections.

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