CEPS Policy brief
No. 164 • July 2008

CENTRE FOR EUROPEAN POLICY STUDIES

The Future of European Electricity
Choices before 2020

Contributors

Gunnar Eskeland
Centre for International Climate and Environmental Research Oslo (CICERO), Norway

Eberhard Jochem
Fraunhofer Institute for Systems and Innovation Research, Germany, and Centre for Energy Policy and Economics (CEPE), ETH Switzerland

Henry Neufeldt
Tyndall Centre for Climate Change Research, University of East Anglia, United Kingdom

Thure Traber
German Institute for Economic Research (DIW), Germany

Nathan Rive
Centre for International Climate and Environmental Research Oslo (CICERO), Norway

Arno Behrens
Centre for European Policy Studies (CEPS), Belgium

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/).

Executive Summary

The electricity sector plays a central role in the European Union's efforts to achieve greenhouse gas (GHG) reductions of at least 20% by 2020 compared to 1990 levels. While the electricity sector is currently responsible for about one-third of Europe's total energy-related GHG emissions, there are large potentials for reducing emissions. Mitigation strategies will need to focus on more efficient electricity use, but also on improved conversion rates and new technologies such as renewables and carbon capture and storage (CCS). Apart from mitigation of climate change, the sector will also have to adapt to climate change. Global warming will have a significant impact on the ability to generate electricity and to deliver it without interruption. This ADAM-CEPS Policy Brief focuses on four issues relevant to the nexus between climate change and the electricity sector.

The paper first elaborates on the *impacts of climate change on the European electricity sector and on related adaptation needs.* Southern countries will most likely be faced with less demand for heating but substantially increased demand for air conditioning. They may also experience losses in hydropower and problems with cooling of thermal power plants. Northern countries will equally experience less demand for heating and may gain potential for electricity production from hydropower. At the same time, they may have to adapt to more storms and heavy precipitation. In both regions, electricity supply disruptions due to storms, floods and heat waves may increase the need for more decentralised electricity generation in order to avoid negative impacts on electricity users.

The next section focuses on *policy options* to facilitate the transition of the electricity sector towards a well-adapted, carbon-lean electricity system. A stable and predictable policy framework is a necessary precondition for investment decisions by the private sector. However, policy instruments need to be assessed according to their effects on wealth distribution, choice of technology and time horizon. Similarly, affected groups (e.g. producers, investors, industries, households) need to be taken into account to enhance the political feasibility of policy interventions. Many EU member states are likely to opt for combinations of policy instruments in order to overcome various sectoral or technology-specific barriers and to promote non-fossil options with substantial innovative and cost-reduction potentials.

An assessment of *technologies and technological change* shows that the electricity sector could contribute more than its proportional share to the EU GHG reduction target, if the most cost-effective options are addressed. These include a more efficient use and production of electricity, more co-generation, continuing substitution towards natural gas, more nuclear energy and renewables as well as realising the potentials of carbon capture and storage (CCS) after 2020.

Finally, the paper analyses *European choices in a global context*. Stringent climate change policies in Europe may have the potential to guide and accelerate the world's technological path towards sustainability. We suggest reducing the risk of 'carbon leakage' by shielding energy-intensive industries from competitive pressures, e.g. by introducing border tax adjustments. However, we also highlight the benefits of international trade, which will allow efficient and low- (or zero) carbon solutions to be produced cost effectively in countries with low labour cost and to be diffused quickly on world markets.

Introduction

In spring 2007, the European Union committed itself to greenhouse gas (GHG) emissions reductions of 20% by 2020 compared to 1990, and to reductions of 30% conditional on a global climate change agreement for the period beyond 2012. In addition, the EU agreed to increase the share of renewable energies in total energy consumption to 20% by 2020.[1] Through these targets, the EU aims to establish itself as a global climate champion in the attempt to limit average global temperature increases to 2° C above pre-industrial levels.[2]

Europe's electricity sector is central to climate change mitigation strategies, due to:

- its role in greenhouse gas emissions, amounting to about one-third of total energy-related GHG emissions;
- its potential for emissions reductions, indirectly through more efficient electricity use and more efficient use of electricity-intensive materials, and directly through improved conversion efficiencies, substitution of fossil fuels and CCS;
- its potential as an emissions-lean energy carrier, for example in the transport sector, which is currently responsible for about one-fourth of European energy-related GHG emissions;
- its central role in energy security, linked to the use of natural gas; and
- its links to other political issues, such as deregulation, competitiveness of electricity-intensive basic products, nuclear energy, and consumer welfare.

[1] See European Council (2007).

[2] Ibid.

One research stream within the ADAM project[3] focuses on the implications of mitigation and adaptation strategies for the electricity sector. The project analyses measures that could reconcile economic growth and development objectives with low GHG emissions, assessing costs and their implications for the European and global economy. Equally important, it focuses on how costly policy errors can be avoided.

Apart from mitigation of climate change, the electricity sector will also need to adapt to global warming. A warmer world requires less heating and more cooling. It also changes river flows and the frequency of extreme weather events, as well as the ability to generate electricity and to deliver it without disruptions. The ADAM project therefore also explores the links and feedbacks between adaptation and mitigation.

This third ADAM-CEPS Policy Brief[4] elaborates on these issues from a research perspective, but in a policy-relevant way. Section 1 describes the impacts of a warming world on the electricity system with regard to electricity demand and supply, and elaborates on the necessary adaptation strategies. Section 2 analyses policy instruments in support of the necessary transition, and explores biases regarding political feasibility. Section 3 analyses technologies and technological change, both for short-term emissions reductions until 2020 and with a longer-term view on a low-carbon electricity system in Europe. Finally, section 4 deals with opportunities and challenges of different policies for the European electricity sector in a global context.

1. Climate change impacts and adaptation in the European electricity sector

Adaptation to climate change will be required on the energy supply side (electricity production, transmission and distribution) as well as on the demand side. The intensity of required adaptation will depend on future GHG emissions and will be different across member states depending on their geographical location, present climate and future changes. Countries near the Atlantic or the North and Baltic seas will most probably have to adapt less to temperature increases but may have to adapt more to storms and heavy precipitation. Countries in the Mediterranean area and those with more continental climates will need to adapt more to temperature increases and related increases in electricity demand.

Impacts of and adaptation to climate change in electricity generation in Europe are difficult to estimate beyond 2020, because the system is likely to change substantially due to a shift towards a low-carbon economy and possibly also to more decentralised electricity generation. Until 2020, climate change impacts on the electricity system are rather small and uncertain (e.g. impacts of heat waves and low river flows in summer on thermal power plants will become important after 2020; wind damage is uncertain; electricity plants are usually not built in flood-risk areas; and the sea-level rise will be negligible in the lifetime of existing electricity plants). Blackouts/brownouts, whilst extremely costly for the economy, are more likely to be related to insufficient planning and infrastructure, particularly transmission lines – and less to climate change.

1.1 Impacts and adaptation in electricity conversion plants

Rising temperatures of the atmosphere and rivers will result in lower efficiencies of thermal power plants. This is mainly due to higher power demand for pumps to maintain desired condensing temperatures and also due to changes from wet to dry cooling towers. The adaptation of electricity generation will also affect electricity generated with renewable energy sources.

- Rising precipitation in countries north of the Alps and Portugal, as well as melting glaciers in the Alps will increase run-off water and increase the potential for *hydro electricity generation*. With expected additional precipitation of at least 40 mm per year, this will particularly be the case in Ireland, the United Kingdom, the Netherlands, Belgium, the Nordic and the Baltic states. In some countries, however, more frequent floods may result in minor hydro-electricity production cuts. In Mediterranean countries, hydropower generation is likely to suffer from reduced precipitation, particularly in the winter season due to changing climate patterns. Such reductions are expected in some member states that have already experienced inadequate water supply in some years (Cyprus, Malta, Greece, Southern Italy, Spain, Portugal, Bulgaria and Romania).

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[3] 'Adaptation and Mitigation Strategies: Supporting European Climate Policy' (ADAM), funded by the European Commission.

[4] The first ADAM-CEPS Policy Brief (Aaheim & Aasen, 2008) explored the economics of adaptation. The second ADAM-CEPS Policy Brief (see Aaheim et al., 2008), which drew upon discussions at an ADAM seminar, dealt with adaptation to climate change in the context of the European Commission's Green Paper on Adaptation.

- Higher temperatures and atmospheric CO_2 concentrations in moderate climates (north of the Alps) may benefit the growth of *biomass*. This may favour electricity generation from agricultural crops, manure and wood chips.
- Efficiency of *photovoltaic plants* could slightly be reduced due to higher temperatures, particularly during heat waves.
- Increasing average wind velocities improve the electricity output of *wind converters*. However, the extent of increasing wind velocities is still unknown, and higher frequencies of heavy storms may negatively affect total annual wind power generation.
- Brownouts and blackouts due to storms, floods and heat waves may lead to more decentralised electricity generation in order to avoid the impacts of interruptions on supply for certain electricity users. However, there are almost no empirical studies on this issue.

1.2 Impacts and adaptation in electricity transmission

Damage to electricity transmission lines has been observed during all heavy winter storms in the last 15 years. Examples include:

- the icy winter storm in 2005, which revealed that the steel pillars of the transmission lines of RWE in Germany were aging faster than expected. RWE will have to re-enforce 28,000 pillars of its transmission lines with an estimated investment of €500 million to adapt the system to heavy storms;
- the storm 'Emma' in late February 2008, which interrupted transmission and distribution lines leading to outages in several European countries.

Climate change is also likely to result in some electricity transmission losses due to higher average temperatures. Heat waves may considerably increase resistance of power lines as increased air conditioning coincides with higher transmission demand and low generating capacity (due to reduced cooling capacities of thermal power plants).

It is unclear how much retrofitting of the European transmission line network will be needed during the next decade and how it may influence transmission and distribution. As changes in frequency, force and regional distribution of heavy storms are likely to be poorly forecasted, surprises cannot be excluded. These uncertainties, stemming from a lack of knowledge in natural sciences regarding extreme events, will become more important in the case of very long re-investment cycles of large thermal power plants and high voltage transmission lines.

Uncertainties regarding the impacts of climate change, and extreme events in particular, may be addressed by adhering to the precautionary principle, which favours policies that support efficient and low-emitting technologies, behaviours and life styles. The stringency of (and expectations about) future climate policy will depend on the magnitude of real future climate change impacts, and on how costly adaptation will prove to be.

Finally, European policy responses will also depend on mitigation efforts of large global emitters (USA, China, India, Japan, etc.). Their climate change policy will in part set the stage for more or less need for adaptation in Europe. In addition, it will have a large influence on technological developments and the market for new technologies. Uncertainty regarding mitigation in high-emitting regions must result in efforts of foreign policy and for international cooperation and technology policy, including publicly funded RD&D. Openness for technical and entrepreneurial innovations in areas of zero or low-emitting technologies is important, keeping in mind their emissions reduction potential, their cost reduction potential and their expected acceptance in Europe.

The transition towards a zero or low-carbon electricity sector will require the exploitation of profitable potentials for efficient electricity use, of foreign policy and international cooperation and of innovation policy. The interdependence of various policy fields calls for close cooperation between the European Commission, EU member states and industry, including utilities which will have to revise their business concepts from merely supplying electricity towards supplying least-cost energy solutions to their customers.

1.3 Impacts and adaptation in electricity demand and final energy sectors

In most European countries, the amount of energy required for heating greatly exceeds the energy used for space cooling. However, cooled floor area is steadily increasing due to higher internal loads, the spread of glass facades, and rising standards of comfort and per capita income. Events like the extraordinarily hot August of 2003 are accelerating this trend. Over the long term, rising mean annual temperatures (e.g. 1.3° C during the 20th century in Switzerland) are increasing the specific energy demand for space cooling. Aebischer et al. (2007) report an increasing incidence of thermal discomfort resulting from overheating of buildings during summer, both due to building retrofits and climate change.

For much of Europe, increases in electricity demand for cooling will be outweighed by reductions in the need for heating energy. However, electricity required for cooling is far more carbon-intensive than energy used for heating (e.g. gas, oil). Depending on the final energy mix for heating and cooling and the primary energy mix of the electricity supply in member states, net CO_2 emissions could thus even increase.

Preliminary modelling results suggest a decrease in heating demand of 11% in the Nordic and Baltic countries, a decrease of 12-16% in the other countries to the north of the Alps and a 16-33% decrease in Mediterranean countries by the year 2050 for a business-as-usual scenario.[5] Econometric analyses for several European countries and different climatic conditions conclude that there is an influence of growing incomes on higher demand for heating and cooling.

Electricity demand will also be influenced by changes in technology, including by how cooling is generated (e.g. by district or waste heat and absorption techniques), and by changing the construction of buildings. Electricity demand is expected to decrease slightly in Nordic and Baltic countries, particularly where electricity makes up a substantial part of heating energy (e.g. Norway or Sweden). In terms of heating expenses, climate change will thus yield greater benefits than costs in northern Europe. The opposite will be true for southern Europe. These regional differences may require transnational compensation systems to balance inequitable effects.

Box 1. Case Study of Switzerland

A case study of the ADAM project estimates Swiss electricity demand for cooling and air-conditioning to more than double by 2035 under the business-as-usual scenario. 60% of the projected increase can be attributed to an expansion of partially or fully air conditioned spaces in buildings. The remaining 40% of the increase result from higher specific requirements of the space that is already air-conditioned.

Climate change is estimated to raise total electricity demand of buildings in Switzerland by 5-10% (up to 15% in specific cases). The impact in Mediterranean countries is likely to be higher. Data for these countries will be available later in 2008.

Depending on the magnitude of climate change in the next decades, there will be some substantial effects on the energy/electricity system. These will include a reduction in demand for heating energy in all countries in winter and additional electricity demand for air-conditioning and cooling in summer. A possible shift towards electricity in the European car sector can lead to a surge in electricity demand and a major shift in transportation technology and 'fuelling' infrastructures. Compared to such a transformation, the expected rise in electricity demand for cooling, water pumping and desalinisation can be considered small. The coincidence of high cooling demand, increased water demand (e.g. for agriculture) and reduced plant efficiency during heat waves in summer could require additional peak power supply. These problems could, however, be overcome by better long-distance transmission connectivity, smart grids and electricity storage facilities.

2. Policy instruments: Enabling and shaping the transition

Political feasibility is essential for climate policy instruments[6] to be successful. Policy-makers thus need to take into consideration how various stakeholders are affected by different measures in terms of costs and incentives, changing boundary conditions and technical innovations. Rising global prices of fossil fuels, emissions cap-and-trade systems with increasingly strict caps, and specified feed-in-tariffs for renewables are likely to increase electricity prices, although efficiencies of thermal power plants and cost reductions of renewables compensate for much of these policy-induced price increases. While most electricity consumers will be able to cope with price increases by more efficient use of electricity, a few producers of electricity-intensive basic products will need specific attention (see section 4.2).

The electricity sector case study of the ADAM project emphasises three dimensions of climate policy instruments (see Table 1):

i) *Polluter pays principle*: the effect of climate policies on the transfer of rent (tax vs. quota, price vs. non-price);

ii) *Technology neutrality*: the effect of climate policies on the choice of technology or fuel, i.e. a differentiation between neutral and specific instruments (quota system alone vs. supplemented by feed in tariffs, standards etc.); and

[5] The business-as-usual scenario assumes that global average temperature will rise by 4° C compared to pre-industrial levels (Van Vuuren et al., 2007).

[6] For example, emissions trading, subsidies, feed-in tariffs, R&D support, technical standards, labelling, professional training, etc.

iii) *Research and development* (R&D): time horizon of climate policies, i.e. quick emission reductions or emphasis on R&D for long-term technological change.

In the EU, tradable permits (in the context of the EU emissions trading system, EU ETS) are always found in combination with support for energy efficiency and renewables. Support measures often include cross subsidies, such as green certificates and feed-in tariffs. This combination of instruments may be justified by the combination of climate change-related objectives (polluter pays principle) with innovation and industrial policy objectives (first-mover advantage in global markets). In addition, R&D policies are implemented across Europe, but at modest levels. An analysis of current mitigation policies shows that: i) polluters are not fully charged for their emissions, i.e. emissions prices are relatively low compared to estimated external costs to society, ii) the system is not technology neutral and may fail to support some options, and iii) long-term R&D is insufficient due to low expected emissions prices. Short-term R&D for renewables is generally well supported via market-based instruments, such as feed-in tariffs and green certificates. R&D support for efficiency solutions, however, is far less pronounced. Table 1 summarises these findings.

As suggested by public choice theory, groups with concentrated interests are better at influencing policy in Europe than poorly organised groups with widely dispersed interests. This is well reflected in the different lobbying powers of electricity suppliers (e.g. nuclear, renewables) and end-users (e.g. focusing more on efficiency). In addition, the interests of future generations – those most affected by climate change – are only weakly represented by some NGOs.

Table 1. Assessment of European climate policy instruments

	Dimensions of climate change mitigation policy instruments		
	Full polluter pays principle	**Technology neutrality**	**R&D**
#1. EU ETS	Yes and No. Not fully realised with freely distributed quotas.	Yes, for the sectors included.	No. Expected future emissions prices often too low.
#2. Cross subsidies of RES-E	No. Tax part often fails to raise prices.	No. Support is typically technology specific.	Cross subsidies assist in dissemination, but not far-reaching R&D.
#3. Energy efficiency support	Energy efficiency support often circumvents polluter pays principle.	Standards, labels and energy efficiency support are often technology specific.	Energy efficiency typically acts in the short term, not on long term R&D.
#4. R&D support	Yes for intellectual property rights. No for R&D support in public budgets.	R&D support is typically technology specific.	Yes. Tends to overcome barriers for the development of climate friendly technologies. Efficiency is a big challenge.
Policy mix	The sum of these four types of instruments typically leaves emissions prices too low to allow for a full implementation of the polluter pays principle.	Some technologies are supported, others not.	Long-term R&D often suffers: expected prices are too low, R&D support too low.

Source: Eskeland & Linnerud (forthcoming).

The following characteristics of the electricity sector need to be considered for choosing the analytical framework:

i. The electricity sector predominantly relies on *long-lived assets*, with high fixed (and sunk) costs. Examples on the supply side include power plants based on coal, nuclear or hydro as well as transmission lines and distribution grids. On the demand side, examples include long-lasting production plants and machinery (e.g. electric steel, primary aluminium, copper, cement mills, paper machines) and equipment such as pumps, compressor or ventilation systems.

ii. Coal and lignite thermal power plants are heavy polluters in terms of greenhouse gas emissions, while renewables and nuclear are relatively clean. Thus, producers of the same output may very differently be affected by policy instruments.

iii. Greenhouse gas emissions reductions are costly in electricity generation, requiring investment in new capacity, typically in renewables, nuclear or carbon capture and storage (CCS). On the other hand, reductions on the demand side are often highly profitable, but undiscovered by investors and obstructed by various barriers.

iv. With limited trade across Europe's external borders and a fairly inelastic demand, European policy can greatly influence the user price of electricity (i.e. electricity tariffs) in Europe, but with little influence on the efficient use of electricity.

As a result of these characteristics, full implementation of the polluter pays principle would induce intensive search for optimal solutions in electricity generation. However, it would also place a burden on electricity-intensive industries and reduce asset values unevenly. In addition, it would not be a very forceful incentive to exploit profitable potentials of efficient electricity use by most end-users.

Both member states and the EU, therefore, reject the implementation of full payment for external damages (i.e. the polluter pays principle), and are opting instead for combinations of policy instruments in order to overcome obstacles on the demand side and to promote non-fossil options with substantial innovative and cost-reduction potentials on the supply side. Such instruments include quotas, renewables support and the alleviation of barriers to the efficient use of electricity in final energy sectors. In brief, a combination of policy instruments can initiate a transition while imposing a smaller burden on firms and consumers, albeit at the cost of technology neutrality.

It is likely that the ETS together with renewables support schemes will succeed both in creating pressures for emissions reductions from existing polluters and in assisting the introduction of currently known low-carbon technologies in electricity supply. These support mechanisms allow for more efficient electricity generation and low-emitting technologies to be introduced without higher prices for emissions and electricity. The stimulation of long-term R&D, however, is dependent on new ideas for technical innovations (e.g. electricity production in North Africa and transmission to Europe, thermo-electrical solutions) and on sufficiently high (expected) emissions and electricity prices. If these prices are too low, other means of support for energy technology R&D should be taken into consideration (e.g. public support).

3. Technologies and technological change

When dealing with the implementation of cost-effective options for emissions reductions by 2020, major questions for Europe revolve around three sets of questions:

- How much electricity will be required in Europe by 2020 and beyond? How much additional electricity demand can be expected due to information and communications technologies, automation, or electric cars?
- What level of emissions reductions will be achievable through the deployment of available and (almost) market-ready technologies? Such technology options include efficiency measures in use and generation of electricity, intensified use of renewables, nuclear energy or natural gas as primary energy sources, etc.
- What level of emissions reductions could be achieved by new technologies yet to be developed, and by when? Future technologies may include fuel cells, thermoelectric applications, and carbon capture and storage, etc.

The EU's target of reducing greenhouse gas emissions by at least 20% by 2020 can be met at moderate costs, particularly by more efficient energy use in all final energy sectors. According to its share in EU GHG emissions, the electricity sector would be responsible for contributing 40% to total EU emissions reductions.[7] However, due to comparatively low abatement costs, the electricity generation is likely to contribute more than its proportional share to EU27 emissions reductions. Low-cost mitigation options in electricity generation are mainly based on investments in new and highly efficient plants, fuel switching to natural gas and selected renewables in favourable conditions. In almost all sectors, profitable potentials of electricity use are most important, but often neglected due to a lack of knowledge and information or hindered by various barriers and market imperfections.

Technological change induced by innovation, high prices for fossil fuels and political measures to control GHG emissions could lead to entirely different energy and electricity systems and generation structures. Uncertainty about future electricity demand and climate variability may also

[7] Results are based on two models: GRACE-EL (general equilibrium model) and EMILIE (energy market model). We assume an annual GDP growth of about 2% in Europe until 2030. It is also assumed that electricity demand in a business-as-usual scenario is growing at a rate of 1% annually, reflecting a partial decoupling of primary energy demand from economic growth.

induce new generating capacities with shorter life times. Retrofitting of existing thermal power plants at their present sites and capacities to adapt to climate change could become less standard than in the past.

3.1 The scope for technological change in the medium term

Focusing on available technologies (see above) is justified due to their importance for reducing energy electricity demand and related emissions. However, too much emphasis on these measures may limit large-scale technological change, including the development of yet unknown or currently very costly power production options, such as fuel cells or thermoelectric solutions. There is a tension between support that is directed towards existing technologies and support that favours the potential of the unknown. R&D support will be severely challenged to get this balance right. It should not focus too much on near-term gains, but also on more basic research laying the foundation for far-reaching technological change.

Dealing with technological change thus raises various questions on how to facilitate the deployment of new technological options in the long run:

- Do existing policy instruments over-emphasise existing responses (such as improvements of fossil thermal power plants), thus limiting more far-reaching technological change (including certain renewables)?
- Are price assumptions and the availability of natural gas critical for technological change (e.g. with respect to renewables, nuclear power plants or coal-based plants with CCS)?
- Does the relative or absolute decline of energy-intensive industries limit the scope of technological change (i.e. new surplus capacities may be detrimental to efficient electricity use or expansion of renewables)?

Furthermore, the effects of policies that combine cap-and-trade instruments (like the EU ETS) with renewables support on price expectations for electricity and emissions and thus on investments in far-reaching technological change need to be analysed. ADAM research shows that a moderate tightening of the EU ETS, which tends to accelerate obsolescence and replacement of assets in the power sector until 2010, does not change the preferred fossil fuel carrier but rather the choice of more or less efficient generating technology. Equally important is the role of natural gas. If Europe chooses to (or is forced to) limit the expansion of gas use (e.g. for energy security reasons), this will raise the costs of emissions reductions and of electricity in the intermediate term, but it will also stimulate innovative technologies in the end-use sectors.

The role of policy in inducing far-reaching technological change is undisputed. At the same time, a lack of coherent strategies may also impede the introduction of low-carbon solutions. The risks of too narrow policy solutions may be illustrated by the following example: Cooling may be achieved by means of conventional technologies (i.e. air conditioning by compressors) or by means of other options that are much less energy intensive, such as: passive/non-mechanical ventilation, overnight cooling, design, spatial planning, etc. However, compared to a scenario with electricity-powered cooling systems – associated with strong technology fix and largely autonomous responses of private agents – the other options require much more planned adaptation strategies such as building standards, fiscal incentives and integrated multi-purpose landscape planning.

In this context, the need for a coherent, stable and predictable policy framework needs to be stressed. While there is little doubt about the ability of industry and customers to cope with climate change in the medium and long-term, this can only be achieved with clearly stated and credible challenges.

3.2 Carbon capture and storage as an intermediate illustration

Perhaps mid-way between currently known and far-reaching technological change is carbon capture and storage (CCS), whose development is dependent on GHG emissions reduction targets in the EU and on the price of emissions. With early regulation on the EU level, CCS is expected to have some first minor impacts by 2020. IEA (International Energy Agency) technology perspectives and own calculations illustrate that hard coal with CCS can be competitive in Europe at emissions prices beyond €15-20 per tonne of CO_2 and power prices beyond 4-4.5 eurocents per kWh. At higher emission prices, natural gas with CCS becomes competitive. Thus, under stringent emissions reduction targets, CCS is very likely to be relevant even for gas-fired electricity generating thermal plants.

These results reflect the technological options until 2020-30. Alternative assumptions, such as tighter emission caps combined with less availability of natural gas (and/or higher gas prices), may prove more favourable to technological change, including CCS. However, CCS should be carefully assessed regarding carbon leakage, risk management and public acceptance.

3.3 Long-term technological developments

Public expenditures on research and development of energy technology, including on electricity, are relatively low and have been falling by about half during the last 30 years. An expansion of public support to R&D could play a role in accelerating efficiency gains of traditional and new generation technologies and renewable energies. It could also help to create more efficient solutions in end uses of electricity. Public funds for R&D will be especially important if emissions and electricity prices are low. Too low prices deter private investments in technological developments needed to combat climate change.

Especially those technologies that are presently immature may realise an increase in efficiency and a decrease in costs (e.g. fuel cells, thermoelectric applications, several renewables, smart grids). For this reason, the technology choices by 2020 may have important consequences for the development of technologies that are state of the art in the long term.

The enormous variety of mitigation solutions of electricity demand and generation (including imports from North Africa via high voltage, constant current power lines) offer a large potential for reducing electricity-related GHG emissions, possibly at a scale and with a complexity greater than in other energy-using sectors. The options should be carefully observed and promoted; CCS should be searched regarding risk management and public acceptance.

4. European choices in a global context

A common concern about stringent emissions reduction targets is that they could lead to a re-allocation of fuel and electricity-intensive industries to countries where climate legislation is less stringent. Such a development would speed up structural change and could lead to additional unemployment in Europe. Also, it would be counterproductive to climate change mitigation efforts, as emissions reductions by countries with a strict climate policy could be (more than) offset by increases in other countries. This effect is called ‘carbon leakage’.

However, the ‘carbon leakage’ argument may not be as strong because many electricity-intensive industries have already experienced substantial growth in countries not bound by emissions constraints in the Kyoto Protocol (e.g. primary aluminium, copper, pulp). Similarly, favourable domestic primary energy sources (e.g. hydro power in Canada or Iceland, coal-based power in Australia, natural gas in Qatar) will continue to play an important role, often unrelated to emissions policies. In addition, some of the electricity-intensive basic products are either too bulky and inexpensive to be shipped over great distances (e.g. cement) or for other reasons their value chains depend less on electricity prices and more on close location to customers, reliability of quality and services, and properties of the final products.

4.1 Europe's impact on the world

Stringent mitigation targets in Europe have the potential to bring about new efficient solutions in electricity use in all sectors of the economy, such as new solutions for co- and tri-generation, highly efficient thermal power plants, new technologies using renewable energies, and reduced costs of those new technologies through learning and scale effects. This effect of guiding the technological pathways may be exemplified by the cases summarised below that not only reflect manufacturing and global networking of companies, but also transfer of knowledge and skills.

- Large power plants are constructed by a few global players only. Strict European CO_2 targets for fossil-fuelled thermal power plants will affect research activities in Europe and thus also the products of these global players (General Electric, for example, has built a large research centre in Munich, in the last few years). As these companies compete worldwide, they will certainly resort to the most up-to-date technologies, including, for example, CCS, if the European Commission made CCS obligatory by 2020.
- Similar processes of technology advancements and transfer can be observed by smaller companies in the areas of energy efficiency or renewable energies. Many European wind technology manufacturers, for example, have founded joint ventures in Asian countries, as have manufacturers of control techniques, power electronics or efficient motor systems.
- There are many (and an increasing number of) large production companies worldwide that have introduced company-wide technological standards in order to reduce transaction cost. Examples include: oil companies such as BP or Shell, car producers such as Volkswagen or Fiat, chemical companies such as BASF and consumer goods industries such as Procter & Gamble. Where European production sites are in the lead regarding energy efficiency and low carbon emissions, they will influence all sites of

a company worldwide and thus the performance of the competing companies as well.

- Many talented students in engineering, natural sciences and business economics coming from Asia or Latin America get their education in European universities and early work experience in European employment. In the last few years, many European universities started master programmes in technical or economic higher education. Young Chinese or Indian students from these programmes will advance quickly and influence standards and practices in buildings and machinery. If Europe chooses a stringent climate policy, this will have an impact on the research and the content of courses in European universities, and hence on students from emerging countries.

In summary, the medium- to long-term impact of a stringent climate change policy in Europe may have the potential to guide and accelerate the world's technological path into a sustainable direction of more efficient electricity use and generation. This process will partly be realised by global players, human capacity-building in Europe and financial incentives such as CDM and JI.

4.2 Dealing with global competition

An ambitious European climate policy should strike the right balance, pushing industry and technology to make progress that enhances productivity and competitiveness alongside emissions reductions.

Raising the pressure to mitigate is likely to lead to a certain amount of carbon leakage. In particular electricity- and emission-intensive basic products and industries (e.g. primary aluminium, copper) may migrate out of Europe. While this lowers emissions in Europe (but probably not globally), it reduces the industries' willingness to invest in technological change. At the same time, emissions prices in Europe will be lower than they would otherwise be. It is thus important to deal with the issue of carbon leakage and to introduce some special treatment for European industry in electricity-intensive sectors.

Analysis done in the ADAM project indicates that it may be sensible to use some policy instruments to shield energy-intensive industries from competitive pressures (e.g. by means of border tax adjustments). Such limited protection of a few electricity-intensive products will significantly reduce carbon leakage and will raise the potential for technological progress by increasing emissions costs and electricity prices. The emissions reduction targets set for 2020 will not be jeopardised, even though their achievement will be slightly more costly.

On the other hand, international trade can also benefit global efforts to combat climate change as it allows for efficient and low- (or zero) carbon solutions to be produced cost effectively in countries with low labour costs and to diffuse quickly on world markets. In recent years, European know-how has increasingly been used to produce investment goods in Asia to reduce the costs of those technologies. One example is small hydro-turbines produced in Indonesia. However, the competitive advantage of low labour costs may not yet have been realised to its full potential in terms of some investment goods, such as energy-efficient solutions or electricity generation from renewable energy sources.

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