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Global and Regional Energy Challenges to 2050 and Beyond: Experiences from Assessing Energy Pathways for Europe

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Abstract: This article provides a discussion about the global and regional energy challenges to 2050 and beyond. It concludes that the political debate on future solutions and challenges for the energy system is most often focused on which types of technologies to choose from. Yet considering the deep emission cuts required, it seems clear that all available technologies and measures must be applied over the coming decades. The main challenge is that there is too much fossil fuel (especially coal) in a climate change context. As a consequence, successful implementation of carbon capture and storage (CCS) technologies is important to meet climate targets. Failure to implement CCS will require that the global community agree to almost immediately start phasing out the use of fossil fuels. However, such an agreement, which would require pricing the natural capital and ecosystems in an entirely different way than today, seems unlikely.

Keywords: CCS (carbon capture and storage), climate debate, energy challenges, fossil fuels, GHG emissions

1 Climate modeling, such as reported by the Intergovernmental Panel on Climate Change (IPCC), suggests that reductions of 50-85% in global emissions of CO2 (relative to the emission levels in 2000) are required to enable the stabilization of atmospheric levels of greenhouse gases (GHGs) at 440-490 ppm (~350-400 ppm CO2), corresponding to a global temperature increase in equilibrium of 2.0ºC to 2.4ºC (IPCC, 2007). It is urgent to make these cuts in emissions. *The emission levels should peak no later than 2015 with 50% to 70% reductions in GHG emissions required to limit the global temperature increase to 2ºC.* For this target to be met with >66% probability, further reductions are required after 2050 (Fee *et al.* 2010).

2 A recently issued report by the World Bank ("4ºC Turn Down the Heat", 2012) stresses the urgency in changing course by pointing that the world is now on a 4ºC warming trajectory if current trends continue. It is obvious that achieving the 2ºC target represents a tremendous challenge from the technical and political points of view. The global GHG emissions continue to increase mainly due to the abundant resources of fossil fuels, the long turnover times for the capital stock of the energy infrastructures, the long lead times for the development and scaling up of low-carbon technologies and the increase in GDP and its associated increase in energy use. The latter is related to an economic system which fails to price natural capital and eco-systems services (*e.g.* Arrow *et al.* 2004, Mäler, Aniyar and Jansson 2008, Daily *et al.* 2009). The world must urgently address the challenge of substantially reducing GHG emissions. Reduction in GHGs, especially carbon dioxide (CO2), must be carried out in a way to be accepted by society at large, which in the current economic system means in a manner that maintains security of supply, competitiveness of economies and maintaining social as well as economic sustainability. It is fair to assume that this means that to reach the required cuts in emissions, the developed parts of the world must reduce emissions more than the global average emissions.

3 Meeting the challenge of drastic cuts in GHG emissions constitutes a challenge with respect to technical, social, political and economic issues. An obvious problem is that

around 85% of all commercial energy consumed comes from fossil sources and reserves, and resources of these are very large and, if used, will result in CO_2 emissions which exceed any carbon budget that fulfils proposed climate targets (Kjärstad and Johnsson, 2012). The technologies and measures available to reach the above mentioned target are to use less energy, to shift fuel and technology or to capture and store CO_2.

4 Historically, economic growth (increased wealth) has resulted in increased use of energy and it has proven difficult to decouple growth from increased energy use (Ayres and Warr, 2005, Cleveland, Kaufmann and Stern, 2000, and references therein) and from increased emissions of carbon dioxide (and other GHGs). So far, there has been a strong dependency on fossil fuels for energy. Fossil fuels are highly rich in energy since they are a result of several millions of years of accumulating organic matter, which society now takes out as energy over a very short period. Within the coming decades, society cannot be expected to use less energy but use the amount of energy it finds most economic, given available information and prevailing market conditions. There is also an increase in population, but affluence and increased wealth using the current developed world lifestyle should be a greater threat to climate changed mitigation than population increase in itself. This is double since for poor regions an increase in wealth is a prerequisite for reducing population increase, especially with respect to that increased wealth for the poor resulting in access to education and birth control.

5 Another option to reduce the energy use is to employ different technology, such as replacing an old inefficient power plant with a new one with higher efficiency. Yet, this may only result in increased competitiveness and what is referred to as rebound effect, i.e. more units of energy sold. The concept of rebound effect was first described by Jevons (1865) and is sometimes called the "Jevons paradox." Jevons found that in spite of significant increases in the efficiency of steam engines, requiring less coal for a certain work output, steam engines were more widely used resulting in an increase of coal consumption. The concept of rebound effect (Saunders, 1992, Berkhout, Muskens, and Velthuijsen, 2000) is complex and has been under debate during recent decades since it has important bearings on environmentally driven energy efficiency policies. It can result in both direct rebound effects (such as observed by Jevons) as well as indirect effects where money saved from increased efficiency in a certain sector (e.g. home heating systems or buying a smaller, cheaper and more fuel efficient car) is spent in another energy consuming (and GHG emitting) sector. It seems that energy-efficiency policies need to include a policy which also influences how the money saved is spent. Lifestyle changes have also proven difficult with respect to "downsizing" the energy use. With increased wealth (including rebound effect) we tend to spend our additional money on carbon intensive activities, such as with low fare airline traveling or long distance charter trips rather than on low carbon alternatives (See Roy and Pal (2009) for an overview of this issue). The issue of lifestyle changes is connected to the concept of rebound effect.

6 Fuel shifting has been applied widely, especially in the stationary energy sector. Notably, Europe and North America have seen a significant shift from coal to natural gas electricity generation (e.g. Kjärstad and Johnsson, 2007). This has lowered the carbon intensity of electricity generation (increased thermal efficiency and less carbon intensive fuel). Yet, as indicated above, this has also made electricity production more competitive implying a rebound effect and at least for Europe, increased dependency on foreign natural gas production (reduced Security of Supply) as opposed to using domestic coal (especially lignite) resources and renewable fuels. The shift to biomass has indeed reduced emissions but the overall effect is still limited and for some types of biomass, the climate benefit is not always obvious (considering direct and indirect land use change, LUC and ILUC). Most bioenergy systems can deliver large greenhouse gas savings, if they replace high emissive fossil-based energy and that the bioenergy production emissions, including emissions due to land use change, are kept low (Berndes, Bird and Cowie, 2010a).

7 In the 1970s and 1980s, there was an increased use of nuclear power which resulted in lower CO_2 emissions compared to if the corresponding electricity (base load) would have been produced from fossil fuels (such as coal). Subsequently, nuclear power has lost public acceptability in many regions and the high upfront costs make it a risky investment on a deregulated market (as opposed to the nuclear programs in the 1970s for which the investment risks were more or less taken by national governments). In recent years, Europe has shown a move back to nuclear power with discussions and decisions on lifetime extensions and upgrading of existing plants. This trend has recently been moderated as a result of the 2011 events in Fukushima, Japan, following the earthquake.

8 At present, there are significant initiatives on increasing the deployment of renewable energy, but renewable technologies (especially wind power, solar PV, solar thermal and biomass) still only account for a small share of the energy mix in most countries. In cases where renewables account for a significant share of the energy mix, it is often in the form of "old" renewable such as large scale hydropower for which further

deployment is limited. Even still, many regions have seen a strong growth in renewable energy over the last decade, notably for wind and solar power. This is mainly due to subsidies, like feed in tariffs, and these subsidies have pushed the technology development and created "green" job opportunities.

9 Capturing and storing carbon can be done by so-called Land Use Change and Forestation (LUCF), and by capturing carbon dioxide from large point sources with storage in deep underground formations, referred to as Carbon Capture and Storage (CCS). LUCF is not straightforward and the world has rather seen significant deforestation, especially in developing regions (e.g. Asia and South America), but there are more attempts to find sustainable forest industries and certification systems of biomass (Berndes *et al.* 2010a).

10 CCS involves capturing of CO2 from flue gases of large centralized emission sources, such as power plants and other industrial processes (See Johnsson (2011) for an overview of CCS technologies). The captured flue gas is then transported to a storage location deep underground. If successfully implemented, CCS might also enhance the security of supply by allowing continued use of domestic fuel resources, such as lignite and coal. Yet, it will likely take at least a decade for CCS to reach a commercial state and will only occur provided that there is a high enough cost to emit CO2. Successful application of CCS will make it more likely that fossil (mostly coal) dependent regions will accept a global climate change mitigation agreement. Failure to implement CCS, on the other hand, would require the global community to almost immediately phase out the use of fossil fuel and leave the reserves and resources in the ground (*cf.* Johnsson, Kjärstad and Odenberger, 2012). This seems more unlikely than reaching an agreement on global climate change mitigation.

11 The conclusions summarized in this article are from the project "Pathways to Sustainable European Energy Systems" (hereafter referred to as "the Pathway project"). The Pathway project has applied the above options to investigate routes for the European energy system from present up to 2050. Focus has been on the stationary energy system with links to the transportation system. The results are reported elsewhere (Pathways, 2011a and references therein). The present article provides a brief summary in terms of challenges for society, and begins with an introduction about the conditions for the study and the methodology used.

Assessment of the Energy System: Two Important Conditions

12 The work performed in the Pathway project rests on two conditions when evaluating pathways to transforming the energy system. First, the need to include the existing energy system in the analysis and secondly, the abundance of fossil fuels, including the importance of understanding the global fossil fuel markets. Both these conditions may sound obvious, but are often not stressed in analysis in literature dealing with transforming the energy system to meet climate change. Two pathways were investigated in the project, named "Market" and "Policy." These were chosen to illustrate where the main responsibility rests to bring about the required changes in the energy system. The Policy pathway corresponds to a future where targeted policy measures (e.g. on energy efficiency and renewables) are successfully implemented whereas the Market pathway is a future that leaves the transformation more to the market with a pricing on CO2 emissions as the only policy.

13 An important condition when transforming the energy system is that there is already a system in place, i.e. the present energy infrastructure. The energy infrastructure consists of components that typically have a long life time. Once investments have been made in a power plant, transmission network, a natural gas pipeline or in a paper factory it will be costly to shorten the expected lifetime. Typically such systems have a technical lifetime of at least 25 years, but often up to 40 years. When assessing different ways to transform the energy system it is not only important to study the role of new technologies and measures, but also to identify technologies that fit into the existing energy system. Until the year 2050, successful application of what is here referred to as bridging technologies will be of great importance for transforming the system. Bridging technologies are dependent on the existing energy system. The term is used merely to stress that all technologies and measures we have at hand and can expect to have over the coming decades must fit into the existing energy system or be heavily dependent on the present system for good performance. This includes co-firing biomass in existing power plants, building new district heating systems, retrofitting the existing building stock and applying carbon capture and storage technologies as well as enforcement of the electricity network to accommodate renewables (such as wind power). Handled properly, bridging technologies can facilitate a cost effective transformation of the energy system without lock-in effects. In Asia and other economies for which the development is stronger than in Europe, the energy infrastructure is obviously younger and the problem is mainly that most of the newly built infrastructure is still of a conventional type, such as buildings with inefficient heating and cooling systems or conventional fossil fuelled power plants of moderate efficiency and without CO2 capture.

14 Figure 1 summarizes the development from the existing system to a more sustainable system over bridging technologies. The figure also stresses that the analysis to investigate possible pathways to a more sustainable system must be carried out in an iterative way. The picture should be seen as dynamic in that new possibilities and barriers evolve with time. For example, when the Pathway project was originally formulated in 2004, the concept of electrification of the transportation sector was not really an issue widely discussed as it is now.

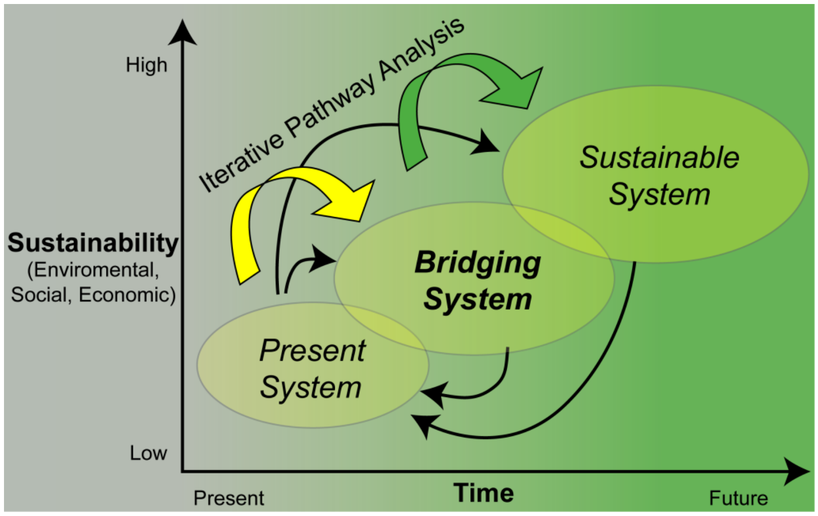


Figure 1. Conceptual presentation of the transition from a non-sustainable energy system to a sustainable energy system

15 Figure 1 implies that a future energy system is larger than the present one. This is only possible when it comes to the use of renewable technologies and not for the use of finite resources such as coal, oil and gas. Yet, the use of fossil fuels continues to increase and as also indicated above, imposes a tremendous challenge for mankind if society should limit global warming to 2°C. There is both a need to reduce the use of fossil fuels or apply CCS technologies as well as to decouple economic growth from the use of energy or at least from the use of fossil fuels. Thus, CCS technologies can serve as a bridging technology allowing continued use of fossil fuels without emissions of CO2.

16 The world is running out of oil, but in a climate perspective, not fast enough and in addition, oil is not the main issue. Instead, there are large resources of coal and substantial natural gas resources and other hydrocarbons such as tar sands, shale gas and shale oil (Kjärstad and Johnsson, 2012). An important part of the work in the Pathways project has been to map and assess the global fuel infrastructure of oil, coal and gas since these markets are truly global (despite the project's European focus). The mapping was considered necessary since there are different views on how fast we are running out of fossil fuels. In addition, over the four decades until 2050, the existing and planned fossil fuel infrastructure will greatly influence the possibility to transform the energy system. In fact, there is substantial new fossil fuel infrastructure being planned and under construction (Kjärstad and Johnsson, 2012). This development is in contradiction to near term climate targets, and it seems the knowledge and awareness of this development is often low. Thus, facts on the possibilities for development of the fossil fuel markets are required. Existing and planned fossil fuel projects are power plants, natural gas pipelines, gasification and re-gasification terminals, new coal mines as well as enhanced oil recovery in existing fields.

Methodology

17 The analysis of the European energy system carried out in the Pathways project rests on an techno-economic analysis of the energy system, mapping of the European energy infrastructure (establishment of databases), and assessment of technologies and methods for transforming the energy system. In addition, the project also applied non-technical methods to analyze the energy system in various perspectives, including the function of law and issues about renewable energy, path dependency in a social science perspective and business management for corporate sustainable development.

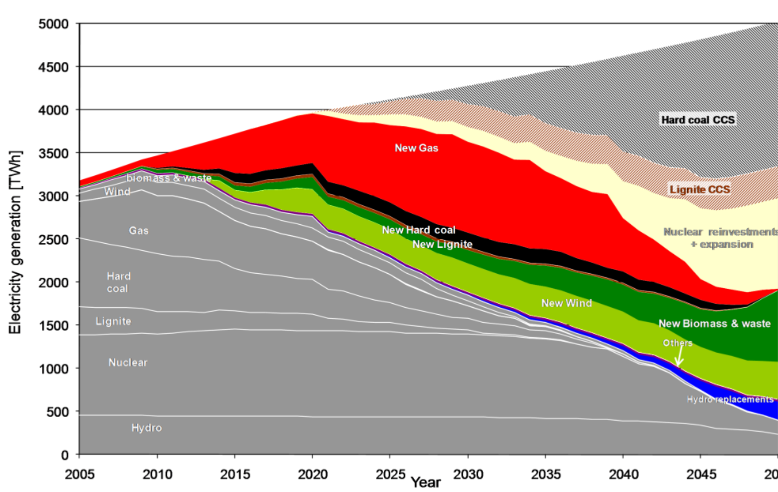
18 A number of so called techno-economic models were applied in the project and several of them developed specifically for the project (Pathways, 2011b). An important input has been the above mentioned description of the existing energy system, i.e. that the turnover in capital stock is taken into account in the modeling and analysis. In addition

to serving as input to the modeling, the mapping of the energy infrastructure has provided a thorough understanding for the European energy system and the conditions for new technologies. There are a number of technologies for which infrastructural conditions are highly important. Carbon capture and storage depends on the possibility to link CO2 sources with storage sites in an effective way, through an efficient transportation system. Wind power is similar, but the issue is to find new sites and with large scale wind power integration investments in transmission capacity or energy storage becomes of importance. The main results from the project are summarized below, while details on the methodologies and the results are given elsewhere (Pathways, 2011a, b).

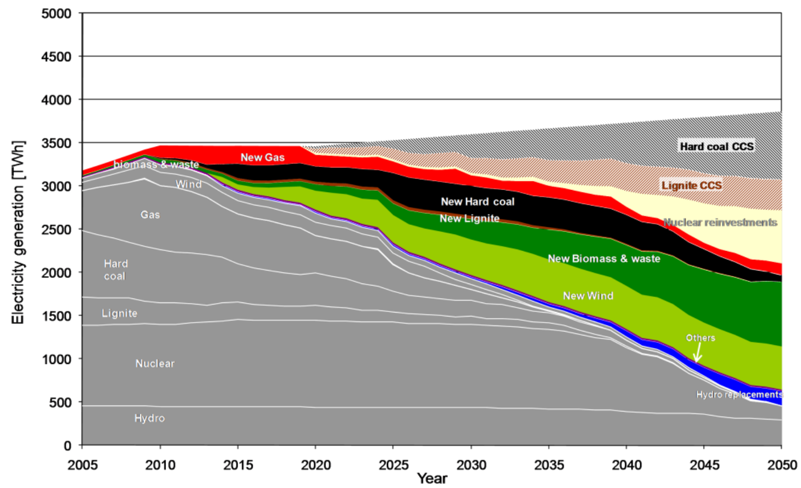
Results

19 From the energy systems analysis, it can be concluded that there are several possible pathways towards a more sustainable European energy system. Although extensive changes in the energy system are required to follow the pathways, the technologies and measures are generally already available. Consequently, the major challenge for transformation of the energy system is a political one, even though significant technological developments are certainly needed. The project has analyzed two pathways. The first is the Policy Pathway which takes its departure from the EU Energy and Climate Package (EC, 2008) and has a strong focus on targeted policies that promote energy efficiency and energy from renewable sources. The second is the Market Pathway that leaves more of the responsibility for transforming the energy system to market forces. In the latter pathway, the cost of emitting CO2 (and other GHGs) is the principal policy measure. The pathways represent examples of different strategies for Europe to meet the challenges of climate change and other sustainability goals rather than predictions of the future.

20 It is possible to make deep cuts in emissions until 2050 while maintaining the security of supply. However, from the mapping of the energy infrastructure and modeling results it seems rather obvious to the author of this article that this will require that all available technologies and measures are used. If society chooses to reject certain technologies and mitigation measures, there is a high risk that the necessary transition will either not take place or will progress too slowly. All commercially and near commercially technologies and measures are associated with problems and barriers (at least to different groups in society), but, more importantly, also offer possibilities. Society needs all of these to transform the energy system, but conditions and use will depend on regional conditions and there is no “silver bullet” technology/measure. As concluded from the study, there are many possibilities and the cost to apply the technologies/measures available should not be prohibitive for society and there should be great possibilities to challenge climate change while maintaining security of supply and competitiveness. The stationary energy system (electricity and heat) offers the largest possibilities to start the transition of the energy system. Figure 2 compares the two pathways (“Market” and “Policy”) for the European electricity system (EU27+Norway) as obtained from one of the models developed within the project (See Odenberger and Johnsson, 2010, 2011 for details). Using a mix of technologies and energy savings, it is possible to reduce emissions from the European stationary energy system *with 85% to the year 2050 (relative to 1990) at a cost which should not be prohibitive for society*. The cost typically increases from some 20 €/ton CO2 up to some 150 €/ton CO2 at the end of the period. Yet, in the end of the period there is only little CO2 left in the system, i.e. although 150 €/ton may seem like a high cost there is only a small amount of CO2 traded in the economy.



2a.



2b.

Figure 2. Electricity generation in EU-27 and Norway as obtained from the modeling ("Others" include PV, wave, small-scale hydro and tidal power). a. Market scenario, b. Policy scenario. The model minimizes the total systems cost given assumptions such as cost for the different technologies applied and a cap on CO2 emissions (which gives the cost for emitting CO2). The grey areas represent the existing plants.

21 Several of the key options for transforming the energy system constitute what can be termed "bridging technologies." Bridging technologies take advantage of the existing energy infrastructure and facilitate the development of new energy technologies. Important bridging technologies include: co-firing of biomass in existing power plants, using incineration and industrial waste heat in district heating systems, applying process integration in industries, the retrofitting of the existing building stock, and the application of carbon capture and storage (CCS). Although entirely new and more "sustainable" technologies (e.g., hydrogen-based technologies, solar cell technologies and nuclear fusion) will undoubtedly be developed, these technologies are unlikely to play major roles in the four decades leading up to the year 2050. That is the year when GHG emissions must have been reduced by 50-80% on a global scale, implying reduction to almost near zero emissions in the developed world.

22 A prerequisite for achieving a market that drives the energy system towards following one of the two pathways studied in the project (or any other pathway that results in the same level of emissions reduction) is that there must be a cost associated with emitting GHGs, most importantly, CO2. This cost could be in the form of a tax or a charge in an emission trading scheme. So far, the transition of the energy system (most notable the introduction of renewable technologies) has been due to targeted support schemes, including feed in tariffs for power generated by renewable fuels (wind power, solar PV and biomass). Such subsidies are important to establish technology development, but technology specific subsidies are not sustainable for achieving large scale diffusion of renewable technologies while maintaining technology development driven by competition between technologies. It is not clear to what extent this is also the opinion among politicians who may believe that subsidies will push technology development so that it becomes competitive even without a cost to emit CO2.

23 Reaching the ambitious climate targets in the two pathways shown in Figure 2 requires efficient use of the available resources, including better use of primary energy in existing systems. The electricity generation and district heating systems have the potential to facilitate efficient use of primary energy while reducing CO2 emissions.

24 As indicated above, an important condition for transforming the energy system is that there is already a system in place, i.e., the present energy infrastructure (such as the existing power plants in Figure 2) with associated actors and institutional framework. This comprises a large capital stock with a long turnover time. Furthermore, there are legal and social structures as well as valuable know-how attached to the technologies that currently predominate, all of which offer possibilities for rapid implementation of bridging technologies. However, they also limit the possibilities for large-scale introduction of entirely new systems. It is important to find ways to use the existing infrastructure to initiate the transformation on a large scale and to create the optimal conditions for new technologies. As an example biomass co-firing can establish biomass supply systems with the conversion system (co-firing unit) less sensitive for disruptions in biomass supply (*cf.* Berndes et al. 2010b).

25 Although the bridging technologies take advantage of the existing energy

infrastructure, this infrastructure also needs to be developed as a new support infrastructure and be established with the corresponding institutional framework. The implementation of CCS and increased use of bioenergy require an extensive transport infrastructure, e.g., CO_2 transportation and storage networks and biomass handling facilities. The production of second-generation biofuels requires substantial changes in the agricultural and forestry sectors. Large investments will have to be made to strengthen, expand, and upgrade the electricity networks so as to accommodate increased levels of wind power and other forms of intermittent electricity generation. Expansion of district heating networks will be a challenge in terms of new investments, public support, and planning. Synergies can be created if the transition of the energy systems is co-ordinated with the transformation of other sectors, such as industry, transport, waste, and agriculture.

26 A sustainable energy and climate policy needs not only technical advances, but also a legal system that supports the implementation of policies. This situation does not currently exist in the EU. In many cases, there are clashes between EU or national energy policies and other interests, e.g., with respect to impact on the local environment, and these interests are often supported by legal restrictions. In other instances, the technologies are too new to be covered by existing legislation (Pathways, 2011a: 101-106). Even if the cost barrier for a technology is removed, barriers for implementation may emerge in the design of the legal and administrative systems required for that technology. It is important to develop legal systems that support the implementation of the policies required to transform the energy system.

27 Reversal of the current situation and moving towards sustainability are complex processes that require fundamental changes across society with the electricity, industry, transport, and waste management sectors as well as a broad range of institutional framework. Though the required structural changes imply great challenges for society, these changes also represent opportunities for synergies. Seizing these opportunities will be cost-efficient and will contribute to maintaining, and perhaps even strengthening Europe's competitiveness on the global market. Companies that are active in the stationary energy sector are already preparing for the requirements of sustainable development and are intensifying their efforts to integrate sustainable practices into their business models. By applying a strategic perspective to the environment, companies can develop new business opportunities and contribute to sustainable development within their sphere of activities (Pathways (2011a: 291-298); Schaad (2012) and references therein).

28 From a climate change perspective, there is far too much fossil fuel. The world may be running out of conventional oil, but from a climate perspective the Pathways project shows that this is not happening fast enough (Pathways 2011a: 2015-220, Kjärstad and Johnsson, 2012). Moreover, the availability of oil is not the major issue. Rather, there exist large resources of coal, natural gas, and other reservoirs of hydrocarbons, such as tar sands and oil shale. These large resources are constantly being developed, which means that it is of great importance that a price is attached to CO_2 emissions and other GHGs so as to stimulate the development of renewable technologies, energy efficiency measures, and technologies that allow the use of fossil fuels without CO_2 emissions. The threat from the abundant resources of fossil fuels makes it crucial to develop CCS technologies (Johnsson, 2011). If CCS is not applied it will probably be very difficult to get fossil-fuelled regions and countries to comply with stringent GHG reduction targets and reach a global agreement on emission reductions. It will also be difficult for the European Union to reach its 2050 climate goals without successful implementation of CCS.

29 Cost-effective implementation of energy efficiency improvements should include all parts of the energy system from supply to end-use. The estimations made in the Pathway project are based on showing that cost-effectiveness (in the long run) in the European energy system will be attained with approximately 30-50% energy conversion efficiency measures and 50-70% end-use measures (Pathways 2011a). Most of these energy efficiency improvement measures will, in addition to increasing energy efficiency, reduce GHG emissions and lead to the increased use of renewable energy sources in the EU countries. These synergies will make the measures more cost-effective.

30 Biomass is the only renewable primary energy source that inherently generates carbon-based fuels and is the basis for much of present-day energy technology (*cf.* Pathways 2011a: 227-232). This makes biomass very suitable for use in heat and power production as well as in the transport sector. Promotion of bioenergy use that exploits existing energy infrastructures in order to reduce risk and reach lower costs is proposed as an attractive near term strategy.

31 The public and political debate on future solutions and challenges for the energy system are mostly focused on which types of technologies and systems to choose from. When considering the deep emission cuts required over the next four decades to 2050, it seems rather clear that *all* available technologies and measures must be applied. Even if only considering the stationary sector, reduced energy use (savings

and energy efficiency measures), fuel shift including increased use of renewables as well as application of CCS are required if the development of these should be within limits which can be handled. Obstacles are, for instance, finding sites for wind power and CO2 storage which will gain acceptance by the public.

32 The responsibility for the transformation of energy systems must be at all levels, spanning from global to local. Although the two pathways analyzed in this project differ with respect to who in society is assumed to take the major share of the responsibility for transforming the energy system to follow the Pathways, they also require governance at the international, national, and local levels.

Conclusions

33 This article discussed results obtained from the project "Pathways to Sustainable European Energy Systems" (Pathways 2011a). It concludes that the public and political debate on future solutions and challenges is mostly focused on which types of technologies and systems to choose from, but it seems that *all* available technologies and measures must be used. Consequently, the main challenge is to get a clear policy measure in place, most notably a cost to emit CO2 and other greenhouse gases.

34 Six main conclusions can be drawn from the results discussed in this article. *First*, the main challenge is that there is too much fossil fuels (especially coal) in the climate change context. Fossil fuel markets are continuously being developed outside the context of climate change mitigation. Although the abundance of fossil fuels may seem obvious, proponents for changing course towards an energy system built on renewables often put forward the argument of that society is running out of fossil fuels. *Secondly*, the present energy infrastructure limits the transition of the energy system, but also imposes possibilities to quickly initiate the transformation using bridging technologies, such as co-firing of biomass in coal fired power plants and on the longer term application of Carbon Capture and Storage (CCS) technologies. *Thirdly*, large scale introduction of renewable based technologies and energy savings are required, but so far such transition has been governed by technology specific policy measures (subsidies) rather than from a cost of emitting CO2. *Fourthly*, due to the abundant fossil fuel resources, successful implementation of CCS technologies seems to be a key factor if to meet climate targets. This will facilitate fossil fuel dependent economies to agree on binding climate targets. The successful application of CCS may moderate geopolitical risks related to regional differences in the possibilities and thereby willingness to comply with large emission cuts. In Europe, application of CCS will enhance security of supply by fuel diversification from continued use of coal, especially domestic lignite. *Fifthly*, failure to implement CCS will require that the global community, including Europe, agree to almost immediately start phasing out the use of fossil fuels. Such an agreement seems rather unlikely, especially considering the abundant coal reserves in developing economies such as China and India and on-going project on expanding coal, oil and gas infrastructures. And *lastly*, the development and implementation of renewables, energy efficiency measures, CCS, and other climate mitigation technologies should be governed by clear and long term policy instrument related to pricing of CO2 emissions rather than targeted support schemes.

[PDF]

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