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Topic 9

A New EU Energy Technology Policy towards 2050: Which Way to Go?

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Executive Summary

Challenges for policy makers are huge if the EU climate policy goal of reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050 shall be reached. There is no doubt that a new energy technology policy design for the post-2020 period is needed, not only because the current policy framework is running out in 2020, but also because of increasing global competitive pressure in the low-carbon technology sectors. Moreover, as market actors are calling for new, transparent and lasting policy commitments *now*, the policy will likely be negotiated in times of financial crisis and institutional frictions in the EU, of which no one can predict its duration. To contribute to this debate and assist DG ENER in preparing a new Communication on 'Energy Technologies in a future European Energy Policy', this THINK report develops and discusses possible paths for a renewed EU energy technology policy towards 2050.

Section 2 demonstrates that there is a *need for public support* to correct for market failures originating from the environmental- and innovation externalities, to account for capital market imperfections and to fully exploit international trade opportunities in clean technologies. There further is a *need for EU involvement* to coordinate market failure corrections between Member States and to bundle national forces. Last, there is a *need to re-think current policies* to correct for limitations of existing policy measures, to give a clear and stable vision for post-2020, and, at the same time, to reinforce European competitiveness in low-carbon technology sectors on the global market and take into account the changed context.

Section 3 illustrates the possible pathways for a new EU energy technology policy and discusses the role of the SET Plan in these possible futures. The first path implies that 2020 policies would be improved and extended to 2030 and 2050. From this reference case, we can depart in two major ways. Path 2 builds on a *strong carbon price signal* and will mainly involve technology-neutral support to innovation. In this path, after having delivered its initial push, the SET Plan as an instrument to prioritize among technologies and projects ceases by 2020. It will rather function in a 'light' version as a platform for open access information exchange and stakeholder coordination and cooperation. In contrast, an alternative policy path 3 departs from a *weak carbon price signal* and technology targets. Directed technology push will play a major role to enforce these targets. In this path, an advanced SET Plan would also provide the basis for the determination of an optimal portfolio of low-carbon technologies across sectors, as well as for the optimal allocation of public (especially European) funds.

No policy path is clearly superior to another. Our evaluation of these policies shows that whereas price signals are, in theory, the most cost-efficient way to achieve climate goals, in practice the signaling effect of carbon prices might not be strong enough. Policymakers face considerable difficulties to implement 'high-enough' prices and to include all GHG emissions into the scheme. Technology targets and directed push, on the other hand, have a relatively larger potential to enhance green growth and to give (even if biased in magnitude) strong signals to investors. Moreover, technology targets could account for different national technology push programs and adjust the burden of decarbonization among Member States. In times of economic crisis and institutional frictions, these burden sharing and cooperation mechanisms can increase the robustness and implementability of technology support.

Section 4 discusses implications for a revised EU energy technology policy. Best practice for technology push will depend on the overall energy policy context. This context is uncertain, with uncertainty originating from two sources: First, the role of the SET Plan will depend on the context of carbon pricing. Second, in a bigger perspective, two major concerns adding further uncertainties appear. *Shifts in paradigm of EU energy policy* away from decarbonization and in favor of competitiveness might weaken carbon pricing mechanisms, calling for an even stronger technology support. Similarly, a shift in favor of supply security requires a stronger push for decarbonization technologies to achieve balanced energy portfolios, as well as a strong push for enabling technologies such as networks to guarantee properly working energy systems. *Technological revolutions*, such as a possible global shale gas revolution, could result in the "rational" price of carbon falling extremely low.

This reasoning calls for a *renewed post-2020 SET Plan* that frames the context for future technology push and gives credible signals for investors regarding the magnitude and direction of push policies. A renewed SET Plan should allow for all possible future policy paths. It should be more focused and provide the basis for planning and prioritization among decarbonization technologies. In the first step and similar to the current model, stakeholders from individual sectors could work together within Industrial Initiatives to identify technological progress and future research needs. In a second step, priority technologies that (a) are key to achieve 2050 objectives, and/or (b) can help to support green growth within the Union should be identified based on a *comprehensive approach across sectors*. Such targets have to be determined by carefully analyzing growth potentials of European manufacturers and the degree of competition they face from foreign clean technology producers. Selected technology targets and EU funding of innovation should then be in line with the SET Plan prioritization.

A prioritization of low-carbon energy technologies entails high risks of picking wrong winners, especially because future energy market developments such as the evolution of shale gas may entirely change the benefits and market value of different supply technologies. In this vein, for mature technologies close to the market, pushing consumption-oriented technologies dominates pushing production-oriented technologies in terms of both feasibility and robustness. First, it is politically feasible: Opposing to a push for production technologies that often would benefit certain Member States in which major suppliers are located, energy efficiency enhancing measures benefit all industries independent of geographic location and create jobs throughout all Member States. Second, such push is robust with respect to future energy market developments: Consuming less is a no-regret policy and minimizes system interdependences of a directed push.

The creation of options for technology breakthroughs has to be a main pillar in any future SET Plan. While strategies for technologies close to the market rely on shorter-run benefits like green growth stimuli up to 2020 or 2030, such push strategies have to be accompanied by long-run funding commitments for a wide range of immature technologies that might be successfully deployable after 2030 and towards 2050. Because this stage of innovation involves basic research and very early R&D, i.e. projects that entail a low chance of success but a sufficiently high pay-off if successful, the argument for a *broad* technology funding becomes important. Over time and as the probability of success increases, funds should become more concentrated.

Moreover, we present other *no-regret measures* that hold for any future technology policy. Policies should enable an attractive and stable business environment, there is a need to remove barriers to behavioral change, and the limited public money needs to be spent wisely. **Section 5** concludes.

1. Introduction

The present EU energy technology policy needs to be revisited. Market actors and the European public demand new, transparent and lasting policy commitments, not only because the current technology policy framework is running out in 2020, but also because of increasing global competitive pressure in the low-carbon technology sectors. In light of the prevalent financial and EU debt crisis, some Member States recently also abandoned several expensive energy regulations, mostly those pushing clean energy technologies. A clear policy path that takes account of these new developments for the post-2020 period is still in its infancies. Our analysis builds on recent policy initiatives, including the EU Energy Roadmap, the EU renewable energy strategy and energy efficiency legislation. To contribute to the debate and assist DG ENER in preparing a new Communication on 'Energy Technologies in a future European Energy Policy', this THINK report develops and discusses possible paths for a renewed EU energy technology policy towards 2050.

Energy technology policy comprises all measures that aim at promoting a selected set of energy technologies from early research to market deployment. Such a promotion typically leads to many overlaps with other policy areas. As different technologies show different environmental impacts, energy technology policy also relates to environmental policy. When selected technologies and projects are then supported at the basic research stage, technology policy intersects with science and innovation policy. And when certain technology sectors are promoted on the world market, technology policy influences industrial or even trade policy. In this report, we focus on energy technology policy in a narrow sense, in which policymakers can choose what technologies to promote, by what means, to which extent and for which period of time. Overlaps with other policy areas are referred to whenever needed.

The relation between technology and environmental policy, however, deserves special mentioning. The overarching EU climate policy goal is to reduce greenhouse gas (GHG) emissions to 80-95% below 1990 levels by 2050. This goal also defines European energy technology policy towards 2050: Given that a certain level of GHG emissions in non-energy sectors (such as agriculture) is not avoidable, the electricity sector has to be decarbonized by an ever higher degree. Besides, an electrification of other sectors such as transportation or heating and cooling – even though pace and extent are uncertain – will result in an increased role of electricity in final energy consumption.

There are doubts that the mix of currently implemented policy measures can deliver cost-efficient decarbonization. With the exception of the EU ETS, most policy schemes – as for instance various means to support renewable energy sources (RES) or existing financial support to innovation – are implemented at national levels. The Strategic Energy Technology (SET) Plan, generally perceived as the "technology pillar" of the EU energy and climate policy, offers a first instrument and attempt to explicitly target a common EU energy technology policy. However, it expires by 2020. Limitations regarding existing policies' efficiency and effectiveness are costly, as the scope of energy technology policy is large. The 2011 Capacities Map published by the JRC reveals that around EUR 3bn are spent annually on non-nuclear low-carbon energy R&D. About 70% is funded by the private sector. The major part of public funding is provided by Member States and only about 20% by the EU, or 7% of the total EUR 3bn spent annually – which equals less than EUR 160mn per year (see Appendix 2).

Whereas energy technology paths to 2020 are roughly known, they are basically unknown for the post-2030 horizon. Several studies illustrate possible technology paths for decarbonization towards 2050. Most prominently, the EU Energy Roadmap proposes a variety of decarbonization scenarios and concludes, in line with other roadmaps (ECF, 2010; Greenpeace, 2010; Eurelectric, 2011; IEA, 2012), that 2050 is technologically feasible. A wide set of technologies can contribute to decarbonization, including consumption-oriented measures increasing energy efficiency and decreasing overall consumption; and production-oriented technologies, comprising low-carbon generation (RES, nuclear) and decarbonized fossil fuels (CCS). All 2050 roadmaps have one element in common: significant improvements in energy efficiency and grids play a crucial role. Hence, on the supply side, three key variables remain, the shares of RES, CCS and nuclear.

Uncertainty in choosing viable decarbonization technologies, however, does not only stem from EU-internal factors. Also technology development outside the EU, or the global financial crisis, influence the success of European decarbonization efforts. Whatever way taken, it is of greatest importance to achieve decarbonization in a cost-efficient way, to foster European competitiveness in R&D and manufacturing of low-carbon technologies, and to ensure growth at a time when governments are forced to curtail public spending. Successful innovation on the world market will help to decrease costs to reach 2050 objectives and make technologies needed to do so a good business case, creating employment and growth.

The remainder of this report is structured as follows. Section 2 first introduces economic rationales for policy intervention and EU involvement in energy technology policy, before discussing the need to re-think currently implemented policies. Section 3 illustrates possible future policy paths for a new EU energy technology policy, discusses the role of the SET Plan and evaluates policy designs under each path within a multi-criteria approach. Using the findings of this evaluation, we discuss implications for a renewed, post-2020 SET Plan in Section 4. We derive technology-specific recommendations based on a policy evaluation, but also based on a discussion on what happens if assumptions, as for instance regarding future technological developments, are relaxed. Moreover, we present other no-regret measures that hold for any future technology policy. Section 5 concludes.

2. Do we need a (new) (EU) energy technology policy?

In this section, we first discuss why there is a need for any policy intervention in the area of energy technology development and deployment. Second, we justify the need for such policy intervention going beyond the national level. The final section then deals with the need to re-think currently implemented policies.

2.1 Why an energy technology policy?

There are at least four kinds of reasons for policy intervention, including (i) the environmental externality, (ii) innovation externalities, (iii) capital market imperfections, and (iv) increasing global competition in green-tech sectors. Policy intervention, hence, can be motivated by market failures on the one hand (as for (i), (ii), and (iii)) or by strategic industry and trade policy issues (as for (iv)) on the other.

The environmental externality

The emission of greenhouse gases involves a negative externality. Emitters cause climate change and, thus, impose costs not only on themselves but on the whole population and future generations. The reduction of emissions, consequently, is a global public good and unless such reduction is adequately rewarded, or the damaging emissions properly charged, the incentive to develop and deploy low-carbon technologies will be too low. From a global perspective, a common, comprehensive, global carbon price would be the economically efficient instrument, inducing emission reductions wherever they are cheapest and minimizing abatement costs across all sectors (Stern, 2006). For a discussion of the relative merits of different carbon pricing schemes see Grubb/Newbery (2007) or Goulder/Parry (2008). But, in the absence of such internalization of environmental externalities, further policy intervention, in matters of energy technology for example, is needed.

Innovation externalities

Most low-carbon technologies are not yet competitive or even not technically proven. All fundamental and a part of applied knowledge gained from research activities is a public good – without a very restrictive access regime, innovating firms cannot fully appropriate the returns from their RD&D activities due to existing social, market and/or network spillover effects.[1] A similar appropriability problem also can arise for technology deployment with later adopters benefitting from knowledge gains and production cost decreases achieved by early adopters. Furthermore, there is a tension between the need to encourage private sector RD&D, which companies argue requires strong enforcement of intellectual property rights, with the public desire to make the resulting discoveries as widely available as possible so that they can be deployed at large scale.

Without further public support, the level and timing of private investments in the development of new clean energy technologies will be socially suboptimal (see also Acemoglu et al., 2010). Companies tend to focus on innovations leading to more rapid or more secure pay-offs, even though an optimal innovation portfolio, from a societal point of view, might also include innovation projects that yield positive cash-flows only in the longer-run or with a lower profitability. While the potential market for green technologies is huge, the margins to be earned, even with an adequate carbon price, will likely be modest, as energy prices are limited by existing well-developed fossil options. Consequently, public support in the energy field will be far more important than for other sectors, where products do not face close substitutes. There are valid economic reasons for a technology policy that addresses the full spectrum from basic research and development to demonstration and early deployment.

Capital market imperfections

In a perfect capital market, financial resources would be allocated to their most profitable uses. The accuracy of this allocation will depend on two factors, the availability of information, and the ability to interpret this information properly (Peneder, 2008). Real world settings, however, face problems of adverse selection (the innovator has better information about expected net benefits of a project than the investor who might

1 Marginal social returns can be significantly higher than marginal private return to the innovator. Jaffe (1996) gives an excellent account of various market and technological spillovers arising from private innovation activities. Martin and Scott (2000) and Foxon (2003) discuss market failures of low-carbon innovation.

finance it) and moral hazard (the innovator may change his behavior after the financing decision has been taken, e.g. increase the risk profile of the project).

Innovations in clean energy technologies often pair very high capital requirements with substantial economic, technical and regulatory uncertainties – a situation that hampers access to finance. Moreover, many investors are constrained in (equity as well as debt) capital, not only due to the limited availability of funds as a result of the financial crisis, but also since certain actors face difficulties to raise *available* funds. There is evidence that especially small and new firms suffer from higher cost of capital than their larger, incumbent competitors (Hyytinen/Toivanen, 2005). Transaction cost can be very (and actually too) high relative to the required financing volume. And also the timing of returns can be an issue. From an investor perspective it might take too long until any benefits can be monetized given also uncertainty regarding future adaptations of policy frameworks. This is further reinforced by the phenomenon that the private sector often tends to use a too high discount rate when evaluating R&D projects (Cohen/Noll, 1991). Hence, there are again good economic reasons for policy intervention to reduce uncertainties, relax credit constraints and remove investment and financing barriers.

Increasing global competition

The challenge Europe is facing today is "to remain at the forefront of the booming international market for energy technology" (EC, 2010, p. 15), at a time when Member States curtail public spendings. If decarbonization has no alternative but real potential gains from decreasing energy production- and supply costs only occur in the longer-run, growth effects stemming from the competitive production and profitable trade of low-carbon technologies on the world market are key to enhance growth in the shorter- to medium-term. Regarding *wind energy*, for instance, top-European turbine manufacturers such as Vestas, Siemens, or Gamesa saw a continuous reduction in their global market share. But it is predominantly European manufacturers that are active in the offshore wind market today, and there could be an argument to use this advantage of being a pioneer, and to benefit (i) from domestic technology adoption as well as (ii) from exporting the technology to non-European markets. Similarly, for *solar PV* China has become the 'manufacturer of the world'. Manufacturing of cells and modules is a labor-intensive process, and the performance and quality of Chinese products is comparable to European ones. But European firms still have a strong position in solar PV manufacturing *equipment* – high-tech products that are sold to Asian countries, too.

2.2 Why an EU energy technology policy?

Policy intervention can be governed by the EU, jointly coordinated among countries, or by individual Member States who seek to intervene mainly on their home market. The challenges we face, i.e. those accompanying the transition to a low-carbon, high-reliability power system at acceptable social costs, are clearly European, and to rely only on individual Member State action is likely to lead to a sub-optimal outcome. From an institutional perspective, there are shared competences between Member States and the EU regarding the achievement of the European environmental and energy policy goals (Art. 192 and 194, Treaty of the Functioning of the EU) as well as related to actions that ensure the conditions necessary for the competitiveness of the European industry (Art. 173). It is thus necessary to investigate whether there are substantial economic benefits to be gained from a renewed EU involvement, but at the same time to set those benefits into relation with the costs of pooling public regulatory power at this highest political level.

Benefits from EU intervention can be expected from the coordination of national policies The currently implemented bottom-up approach with 20-20-20 targets being specified in EU Directives that have to be implemented into national laws resulted in a wide set of national policy designs. Moreover, technology push initiated at the EU level can avoid an unnecessary duplication of national or regional initiatives which is especially relevant for technologies in the 'valley of death', where substantial investments are required for commercial-scale demonstration and early deployment but projects are not yet viable in the short-term. Furthermore, most of the Member States simply are too small to implement certain instruments or to compete on a global scale with economies such as the US or China; and when joint action is taken, technology-, but also industry- and trade policies are more credible towards world market competitors, while also being more credible for attracting foreign investment. A common EU funding scheme can also avoid that Member States would only fund technologies that are produced within their own borders and free-ride on third countries to push other technologies. European co-funding can leverage additional national and private funds (EC, 2011d; JRC, 2011; Liljelund et al., 2011). And also for overcoming the financial crisis and relaxing funding constraints, the EU has to play its role, as the financial crisis clearly is a European problem asking for European solutions.

Following the principle of subsidiarity, EU action, however, shall only be taken when it is more effective than actions at national, regional, or local level. Potential drawbacks of EU involvement might be the disregard of national specificities, the reduction of institutional competition between alternative policy approaches, and the loss of decentralized 'willingness to do more'. Considering the above arguments in favor of EU intervention, it becomes clear that they outweigh their costs for some policy areas where strong coordination is needed (such as the EU ETS). However, at the same time when EU regulations become themselves complex and alien to national habits, also transaction costs increase and might outweigh the benefits of EU intervention. Nonetheless, the above arguments indicate that no energy technology policy can work properly without a certain type or degree of EU governance.

2.3 Why a new EU energy technology policy?

In what follows, we discuss the need to re-think current policies. We consider limitations of the existing instruments that aim at correcting i) the environmental and ii) innovation externalities; and illustrate drawbacks of the current policy in reacting to iii) capital market imperfections, the EU financial crisis and institutional frictions, and iv) to increasing global competition.

Limitations of existing policies addressing the environmental externality

One major instrument to address the environmental externality is carbon pricing. An **EU-wide cap and trade system** was introduced in 2003. The 2009 climate and energy policy package strengthened legislation and extends the coverage of the EU ETS substantially.[2] However, the EU ETS does not yet

2 Directive 2009/29/EC considers a single EU-wide cap on emission allowances from 2013 on, the stepwise replacement of a free allocation by auctioning, and

deliver an adequate price signal (see e.g. Ellerman et al., 2010; Schmidt et al., 2012; Martin et al., 2012). Prices are neither at a sufficiently high level nor reliable, but instead are argued to be too low and far from being predictable in the long-term. As a consequence, the UK Government in 2011 unilaterally introduced a price floor of GBP 16/ton – following a linear path up to GBP 30/ton in 2020. But the EU ETS is still a new instrument. Stern (2006) argues that the first two decades of its implementation will "be a period of transition" before "carbon pricing is universal and automatically factored into decision making" (p. xix).

Regarding **non-ETS sectors**, carbon emission reduction targets have been centrally set within the Effort Sharing Agreement (EC, 2009). The decision on policy instruments to implement has been left to the Member States, though carbon taxes are expected to play a major role. The proposal of a new Energy Taxation Directive provides a framework for the adoption of a tax comprising both an energy-and a GHG emissions component. Minimum carbon tax levels of EUR 20/t CO2 are proposed for several energy products. Apart from this, a few European countries have already imposed specific taxes on the CO2 content of energy products. Finland and Sweden, for instance, introduced a special tax in the 1990s. After a long debate in 2009, Ireland introduced a carbon tax as a component of a general package of fiscal consolidation. Thus, there is wide heterogeneity among national policies; some Member States even have certain fossil fuel subsidies in place due to various political reasons and national implicit tax rates on energy vary substantially (Pazienza et al., 2011).

an enlarged list of activities and GHGs covered. Decision 2010/634/EU sets the total EU-wide amount of allowances at 2,039mn for 2013. The cap will decrease by 1.74% per year, with this factor scheduled to be reviewed by 2020.

Besides carbon pricing, Directive 2009/28/EC on the **promotion of renewable energy sources (RES)** sets binding national targets for the share of RES in gross final energy consumption by 2020. Member States have full autonomy in developing their national action plans and in the choice of policy measures. Implemented support instruments include (a) feed-in tariff (FIT) schemes which guarantee a certain price for a specific period of time or predetermined amount of production; (b) feed-in premiums (FIP) guaranteeing a certain add-on to the market price; or (c) quota obligations with tradable green certificates (TGC), a quantity-based instrument where either producers or suppliers of energy are obliged to have a specific share of RES in their portfolio. Besides, tenders may be used in combination with the above instruments, such as tenders for a fixed FIT where potential investors bid the required support level.

Several studies assess the performance of alternative policy instruments (e.g. Jacobsson et al., 2009 or Ragwitz et al., 2011 and references therein). Ecofys et al. (2011) provide a detailed overview on implemented RES support policies in Europe (see also Appendix 3). Price-control schemes with guaranteed access to the grid seem to be a prominent tool (Fouquet, 2013). Furthermore, countries typically have implemented a whole set of instruments, differentiating among technology types and installation sizes and being adapted regularly. A complete re-orientation of policy schemes, as happened in Italy where in 2002 a TGC scheme has substituted a FIT policy, is rather an exception than the rule.[3] In this vein, Kitzing et al. (2012) find indications for a bottom-up convergence of policy choice. Indeed, the Commission expressed lately that "a greater convergence of national support schemes to facilitate trade and move towards a

3 In 2005, a FIT scheme for solar electricity called "conto energia" was launched again in Italy and had been revised several times until the 5th conto energia in 2012.

more pan-European approach to development of renewable energy sources must be pursued" (EC, 2011b, p. 11).[4] In any case, Directive 2009/28/EC has been designed to ensure the achievement of the 2020 RES target. However, this may not in itself promote the necessary long-term investments to also achieve 2050 decarbonization objectives.

Regarding **energy efficiency**, the third column of the EU energy and climate policy package, the Parliament gave a green light to the new Energy Efficiency Directive in September 2012. Member States did agree on an indicative target of 20% energy savings and to several binding measures.[5] Besides, other relevant pieces of legislation imposing various standards and obligations include Directive 2010/31/EC on the energy performance of buildings, the Energy Labelling Directive 2010/30/EC and Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products.

Limitations of existing policies addressing innovation externalities

The EU's **Strategic Energy Technology (SET) Plan** has been adopted in 2008 as the so called 'technology pillar' of the EU energy and climate policy that aims at accelerating the development and deployment of low-carbon technologies. Its implementation started with the establishment of the *European Industrial Initiatives* (EIIs) which bring together industry, the research community, Member States and the Commission. Within these Initiatives, strategic objectives have been formulated based on *Technology Roadmaps* that identify priority actions for the decade from 2010 to 2020. More specific *Implementation Plans*, containing more detailed descriptions of proposed RD&D activities, as well as suggestions about potential funding sources, are developed regularly for three-year periods.

The SET Plan has been a successful initiative with respect to (i) information exchange by providing a common platform for industry, academia, Member States, and the EC; (ii) more coordinated planning by identifying priorities and action plans within EIIs and European Technology Platforms; and (iii) the joining of forces between private and public sectors and research community as well as between different Member States and/or stakeholders, within for instance the European Energy Research Alliance. Now, this instrument has to proof to be helpful also in successfully *implementing* formulated research and innovation plans.

However, the SET Plan in its current formulation – with the objective to "support the *achievement of 2020 goals*" has a limited time horizon. In addition, it is based on a *within-sector* approach regarding planning and priority setting. Hence, this current policy does not necessarily support an optimal (cost-efficient) portfolio of low-carbon technologies, i.e. decarbonization at least cost.

4 Evaluating responses to a public consultation on the implications of non-harmonized RES support schemes, CEER (2012) presents opinions on that issue as well. Proponents of harmonized support schemes argue that harmonization would avoid distortions in competition and instead create a level-playing field allocating RES production to areas "with best available and most cost-efficient resources and grid connection" (p. 14) whereas other stakeholders point on the key advantage of a decentralized approach of allowing individual Member States to tailor support schemes to their specific conditions.

5 These include the fact that energy companies are requested to reduce their energy sales to industry and residential sector by at least 1.5% p.a.; a 3% renovation rate for public buildings and an obligation to develop national roadmaps on how to make the entire buildings sector more energy efficient by 2050.

Furthermore, a sustainable energy technology policy will need to react to the new context given the EU and financial crises and increasing global competition in green-tech markets.

Technology push in the form of **direct support to innovation** can involve a whole set of financing instruments. Such instruments are indeed policy instruments (Olmos et al., 2011). In addition to their function of closing the gap between the cost of innovation and funds private parties are willing to contribute, they (i) might be able to target specific technologies (e.g. public loans/guarantees, public equity, subsidies in the form of technology prizes); (ii) show a certain flexibility in (re-) directing funds to alternative innovation projects (e.g. lower for public loans than for subsidies in the form of benefits related to RD&D investments); and (iii) typically are better suited to support certain types of innovating entities.

As illustrated in the 'Carvalho Report' (European Parliament, 2010), the EU Framework Programmes have been powerful mechanisms for catalyzing RD&D and accelerating the development, demonstration and deployment of low-carbon technologies, and to implement the SET Plan. Nevertheless, many stakeholders criticize that FP7 is, "despite the improvements made in relation to FP6, still characterized by excessive bureaucracy […] and undue delays" (p. 4). The report moreover complains about a lack of global orientation and recommends a further internationalization for the future through active cooperation with non-European countries. Current practice also shows that subsidies in the form of grants and contracts – the most attractive form of support from the innovators' perspective, but also the

Box 1: EU funding to energy RD&D and innovation

Annual EU budgets are prepared in the context of multi-annual financial frameworks. The next period will begin in 2014 and intensive discussions on spending priorities are ongoing.

Research funding is organized through *Framework Programmes*. For the current FP7, the total budget increased substantially to EUR 50bn compared to 18bn for FP6, with certain sums dedicated to energy (2.35bn), environment (1.89bn) and Euratom (2.7bn). These numbers represent a clear increase over past budgets, but in relative terms the share of energy did continuously decrease over time. *Horizon 2020* will be the new EU funding program for research and innovation running from 2014 to 2020 with a total budget of EUR 80bn. It will combine all existing research and innovation funding through FPs and the innovation-related activities of the Competitiveness and Innovation Framework Programme and the European Institute of Innovation and Technology.

The *Intelligent Energy Europe* facility, launched in 2003 and running until 2013, aims at promoting energy efficiency and RES with a total budget of EUR 727mn during its second phase covering 2007-2013. The major part of the fund is made available through annual calls. Moreover, EUR 9bn are distributed as part of *cohesion policy*. The *European Investment Bank* and the European Bank for Reconstruction and Development provide low-interest loans.

The *European Energy Programme for Recovery* is a short-term measure that was set up in 2009 as a response to the financial crisis. With a budget of EUR 4bn it aims at co-financing projects in the areas of gas and electricity infrastructure (2.3bn), offshore wind (565mn) and CCS (1bn), which without such additional EU funding likely would be delayed, downsized or even cancelled. Funds that had not been used by 31.12.2010 have been transferred into the *European Energy Efficiency Fund* (EUR 125mn complemented by 75mn from the EIB, 60mn from Cassa Depositi e Prestiti and 5mn from Deutsche Bank) that offers different types of debt and equity instruments.

A new source of EU funds has been the *NER300*. Within the EU ETS, 300mn emission allowances are set aside in the New Entrants' Reserve. The instrument is managed jointly by the EC, the EIB and Member States. Projects developers apply to the Member State in which the project would be situated. Each Member State selects a set of projects from the applications and passes it to the EIB, where proposals then are evaluated and selected.

most expensive one for the public sector – are, by far, the preferred policy instruments to fund clean energy innovation of any type.[6]

Limitations of existing policies addressing the EU financial crisis and market liquidity

The **EU and financial crises** has severe consequences on the ability to mobilize private (both company internal and external) and especially public funds. As a consequence of the recent developments in credit markets and regulatory measures that have been implemented accordingly,[7] it has become increasingly difficult to access long-term financing, especially for projects with a high investment volume, as is the case for many energy innovation and demonstration projects. In addition, the current period of austerity has imposed tight fiscal constraints on national budgets and forces governments to re-think fiscal policies. They are reconsidering what their countries can afford in terms of low-carbon energy technology support. Different countries, such as Greece, France or the UK, have cut RES subsidies substantially (Gilder Cooke, 2012).

The crisis has affected all Member States, but not all in the same way and to the same extent, which exposes the EU to the danger of braking into new informal zones. Less affected countries, mostly in northern Europe, have entirely different starting position for decarbonization policies than more affected Member States, mostly in southern Europe. Germany or the Netherlands, for instance, could keep employment relatively stable whereas other countries like Spain saw increases in unemployment rates by about 15 percentage points (EC, 2011c). Hence, on the one hand, there are a few countries, such as Germany or the Netherlands, which can benefit from relatively low financing cost, public funding opportunities and a quite high consumer willingness to pay for energy policy. On the other hand, there are many countries that suffer from extremely high financing cost, highly limited public funds, and consumers not willing, or able, to afford low-carbon technology support. As will be discussed later in-depth, this obviously will have an impact on the feasibility of any centralized energy technology policy at EU level.

A first policy response to these challenges has been the European Energy Programme for Recovery (EEPR), a EUR 4bn program that was set up in 2009 to boost Europe's economic recovery by "stimulating economic activity and promoting growth and job creation" (EC, 2012b, p. 2; see Box 1). However, given the complexity and magnitude of the crises, much more action is needed to keep low-carbon RD&D and innovation on track towards 2020 and 2050.

Limitations of existing policies addressing increased global competition

Europe must not be regarded in isolation. Third countries built strong competitive positions in RD&D and manufacturing of different low-carbon

6 Even though there is an increasing interest from (private and public) venture capital investors in green technologies, their role will probably remain a minor one also in the future (Lester/Hart, 2012). Venture capital funds typically do not exceed a few hundred million EUR, and an individual project investment does not exceed about EUR 10mn which is quite low for energy (especially demonstration) projects. Besides, equity investors tend to exit after a period of about 10 years and a market with exit options is an important precondition.

7 *Basel III* as a global regulatory standard on bank capital adequacy, stress testing and market liquidity strengthens capital requirements and introduces new regulatory requirements on liquidity and leverage. *EU Directive 2009/138/EC* codifies and harmonizes EU insurance regulation and amongst others sets standards regarding the amount of capital that insurance companies must hold to reduce the risk of insolvency.

technologies and European players suffer from substantially reduced market shares in e.g. the solar PV or onshore wind turbine sectors. As also highlighted in the most recent Competitiveness Report (EC, 2011c), global competition has become much tougher and the need to remain competitive on the world market has become more important. For Europe to be a beneficiary in the low-carbon market, rather than just a consumer of technologies developed elsewhere, there is no alternative to putting innovation at the heart of its growth strategy.

At one extreme of an industrial policy stands the proactive state, on the other extreme, authorities that minimize public intervention but build on competition and free trade. Changing conditions on the world market for clean technologies might provide further justifications for policy measures that strengthen the power of European players in order to keep a competitive advantage, build industrial leadership and attract foreign capital. There are different arguments backing government intervention under certain circumstances. For instance, the presence of increasing returns to scale and imperfect competition in a sector can provide a rationale for supporting the domestic industry to raise national welfare (Krugman, 1987).

Europe strongly values open markets and free competition. In the recent past, however, some voices call for actions supporting European players in keeping pace with its international competitors. In a recent Communication (EC, 2012), six "Key Enabling Technologies" (KETs, e.g. advanced materials or advanced manufacturing technologies) have been identified which is a first step towards explicitly focusing and prioritizing specific industrial sectors. These KETs have been recognized as cross-cutting technologies, feeding into many different industrial value chains and enabling a wide range of product applications, including those related to the transition towards a low-carbon economy. However, the need for trade and industry policy intervention in the energy sector and at European level has to be discussed with care and in recognition of current trade legislations.

2.4 Main findings

There is a *need for public support* to correct for market failures originating from the environmental- and innovation externalities, to account for capital market imperfections and to fully exploit international trade opportunities in clean technologies. There further is a *need for EU involvement* to coordinate market failure corrections between Member States and to bundle national forces. And there is a *need to re-think current policies* to correct for limitations of existing policy measures, to give a clear and stable vision for the post-2020 period, and at the same time to reinforce European competitiveness in low-carbon technology sectors on the global market and take into account the changed context.

Hence, there are three challenges for any future EU technology policy: (i) to rule out limitations in existing policies and provide a framework for the post-2020 period, (ii) to enhance green growth, and (iii) to be robust with respect to EU financial crises and institutional frictions. These challenges constitute efficiency criteria for our following policy evaluation:

- **Climate-effectiveness**: Does the policy deliver decarbonization by 2050?

- **Green growth**: Does the policy enable green growth? Does it respond to fierce global competition in green-tech markets?

- **Robustness to EU financial crises and institutional difficulties:** Is the policy robust with respect to EU financial crises and institutional frictions? Will the policy be robust to financing gaps and/or to a future potential lack of governance resulting from institutional frictions on the way towards 2050?

Since all benefits that increase the effectiveness of future policies come at certain costs, and in addition, differ regarding potential difficulties related to their implementation, we further add:

- **Cost-efficiency**: Does the policy achieve climate and growth goals at lowest costs?

- **Implementability:** Is the policy politically and institutionally feasible? Which barriers to implementation are expected?

In what follows we discuss the role of the SET Plan and its corresponding technology push within different possible EU energy policy paths. We rely on the five criteria above to evaluate each of these settings.

3. Possible paths for a new EU energy technology policy

To capture the broad spectrum of policy options, this section develops and discusses opposing paths for a future EU energy technology policy that can pave the way towards 2050.

3.1 Possible policy paths

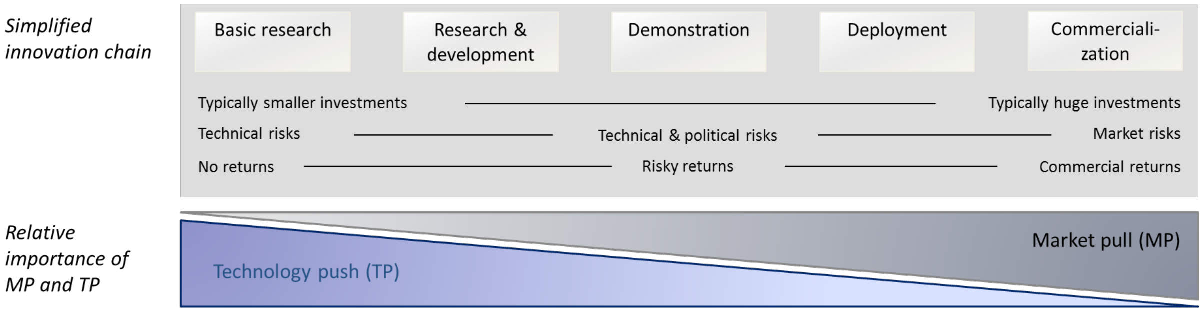
3.1.1 Policy instruments

Two broad classes of instruments can be used to accelerate innovation, demonstration and deployment of low-carbon technologies. First, *market pull* instruments mainly address the positive externalities of clean energy production and shall incentivize deployment of and innovation in low-carbon technologies. A general distinction can be made among instruments building on price signals (such as carbon pricing) and instruments incentivizing via the definition of binding quantitative targets (such as the national targets for RES shares in gross final energy consumption by 2020). Second, *technology push* mainly targets the correction of positive externalities related to spillover effects during the innovation process. Besides monetary transfers, technology push might also shift financial risks from entrepreneurs to public authorities by guaranteeing financial support in case research for innovation does not turn out to be successful or scalable for market implementation. Again, a distinction among two classes of instruments can be made. Push can either be directed (such as EEPR funds dedicated to support offshore wind and CCS demonstration projects) or, in contrast, can involve technology-neutral support to innovation.

Innovation in the 2050 context does not merely focus on entirely new inventions. Instead, it also entails applied research to improve existing technologies, to manufacture next generation non-fossil energy production and to advance efficient network- and consumption technologies (Rametsteiner/Weiss, 2006). Figure 1 depicts a simplified illustration of the innovation chain and characterizes each step in terms of its investment needs and types of risks and returns. Whereas technical risks are dominant in the very early stages of the innovation chain and innovators' main concern is the financing of the research activities; political and commercial risks become more and more relevant as technologies evolve along the chain.

There is a consensus in energy technology policy literature that market pull alone does not lead to

Figure 1: Simplified innovation chain and relative importance of technology push and market pull



Source: Own depiction

the desired outcomes (Horbach, 2007; Nemet, 2009; Jones/Glachant, 2010). A well-designed policy instead involves pull such as a carbon price to deal with the environmental externality, and, at the same time, technology push to deal with the knowledge and spillover externalities. The relative importance of market pull to technology push decreases as one moves from technologies close to market competitiveness towards highly immature ones (Grubb, 2004). Especially the central stages of the value chain, commercial-scale demonstration and early deployment, involve substantial investment needs accompanied by still non-negligible risks. This "valley of death", where the key challenge is the transition from publicly co-financed to private operations, is discussed in-depth elsewhere (e.g. Murphy/Edwards, 2003).

Each of the above instruments can theoretically be implemented in a decentralized way, with Member States designing national action plans and introducing a set of related policy measures. An example is the current practice regarding renewable support policies, where it is the responsibility of national governments to achieve RES targets for 2020, who then support an individual mix of low-carbon technologies by implementing measures like feed-in tariffs or a scheme of tradable green (or white) certificates and by providing support to technology development in the form of research grants, tax incentives, etc. In contrast, policy action can also be coordinated at a cross-national level with the EU taking an active role (e.g. the EU ETS, cross-national planning and priority setting as within the Industrial Initiatives of the SET Plan, or EU research funds).

Hence, policy paths consist of three elements:

(1) Market pull instruments framing the context for technology push by a) creating markets via strong price signals and/or b) providing signals through quantitative targets;

(2) Technology push instruments: a) directed technology push and/or b) technology-neutral support to innovation;

(3) Governance of these instruments: a) decentralized national action and/or b) centralized, cross-national action with EU involvement.

In the following, we introduce three possible future pathways for an EU energy technology policy. From a reference case, we can depart in two major ways: in line with options for a post-2020 RES policy outlined in a recent Communication on renewable energy (EC, 2012d), it can either be prices or quantitative targets that give the key signals to innovate and invest in clean technologies.[8] Starting from this distinction and different paths of market pull framing the context for energy technology policies, for each case the respective role of the SET Plan and optimal technology push are discussed.

3.1.2 Policy path 1: Reference case

The first policy path determines a reference case and implies that 2020 policies would be improved and extended to 2030 and 2050. This option is based on a mix of incentives coming from carbon pricing and quantitative target setting. As in the current 2020 policy, with both the EU ETS and EU-wide targets for RES and improvements in energy efficiency, along with national energy policies to meet corresponding national targets, a wide set of market pull instruments prevails. For similar reasons as today (interactions between policies, ETS and subsidies annihilating each other), the carbon price will only provide a relatively weak investment and innovation signal.

The SET Plan would be further developed and expanded, resulting in at least as much as the current nine Industrial Initiatives that can provide the basis for information exchange and research prioritization. Therefore, SET Plan support will continue to be of a rather broad nature and not be unanimously focused on and aligned with more specific technology targets. Besides Industrial Initiatives, Technology Platforms and EERA, also competitive technology- and research funds, similar to past and current Framework Programmes, will be continuously relied upon. Both, technology-specific push but also competitive funds, coming from EU and national sources, are prevailing as technology push instruments.

Hence, the governance of instruments remains, just as in the 2020 policy, mixed with elements managed at national and cross-national levels and continues a policy of multiple means and actors. The EU will by design have to govern and coordinate the ETS. However, with targets and national action plans coexisting, Member State action will play a major role in shaping the energy mix. Notably, there are centralized means such as EU-level funding programs, cross-national research alliances and Industrial Initiatives, as well as decentralized instruments regarding non-ETS carbon pricing, RES support policies, or e.g. national support to innovation.

3.1.3 Policy path 2: Strong carbon price and focus on price signals

Starting point for the second policy path is a strong carbon price signal. Here we assume perfectly adjusted ETS and according non-ETS prices that mirror in a single, adequate and reliable carbon price covering most, if not all, GHG emissions. Such a carbon price would then be the major driver of innovation in clean technologies and for decarbonization. Sectoral targets cease after 2020, and from then on, the market will react to the carbon price alone. Additional national support schemes might co-exist; however, the strong carbon price will decrease the necessity of ambitious individual Member State actions.

Technology push plays a rather accommodating role to lift promising technologies from R&D to commercialization and preliminarily would rely on

8 This basic distinction between price and quantity signals was first studied by Weitzman (1974), who stresses that differences between them can only be due to asymmetric information between firms and their governing regulatory entities, and that in many cases indeed a mix of both can be applied.

technology-neutral financial support to innovation, and, thus, on competition for funds among different technologies and innovation projects. While the carbon price enhances decarbonization technologies that are discovered by the market, promising projects at the early stages of such technology developments can obtain additional public funding. Such funding will be granted only until market incentives take over at later stages. After having delivered its initial push, the SET Plan as an instrument to *prioritize* among technologies and projects ceases by 2020. It will rather function in a 'light' version as a *platform* for open access information exchange (on e.g. the status quo of technologies, costs, experience with pilots, etc.) and stakeholder coordination and cooperation. Hence, it will preliminary become a tool that (i) can help potential innovators and investors to take the right decisions and (ii) can help to mobilize private funds (e.g. banks or pension funds can judge better into which kinds of projects to invest).

The governance of instruments will have to be predominantly centralized and administered by the EU since the key instrument in this path would be a strong, EU-wide carbon price. Technology push could potentially be administered and funded by both the EU and Member States with centralized funding programs and individual national funding schemes co-existing. For this policy, there is also a possibility for the EU to generate its own source of income which could be made available to implement such funding methods: parts of the income generated through the auctioning of allowances could be collected centrally and be redistributed for coordinated RD&D support.

Table 1: Summary of policy paths

	Policy path 1: **Reference**	Policy path 2: **Strong carbon price**	Policy path 3: **Weak carbon price**
Market pull (MP) Key signal through price or quantitative target?	Hybrid	Strong carbon price	Sectoral targets
Technology push (TP) Directed or technology-neutral?	Hybrid	Predominantly technology-neutral TP	Predominantly directed TP
Governance of MP and TP instruments Centralized or decentralized?	Hybrid	Predominantly centralized	Predominantly decentralized

SET Plan	**BAU**	**Light**	**Advanced**
Open access information platform	x	x	x
Stakeholder coordination and cooperation platform	x	x	x (going also beyond European borders)
Planning and priority setting *(more informal, i.e. not legally binding)*	x (within sectors)		x (across sectors)
Basis for allocation of public funds *(esp. EU funds)*	(x)		x
Basis for target setting *(formal, i.e. legally binding)*			x

Source:: Own depiction

3.1.4 Policy path 3: Weak carbon price and sectoral targets

Starting point for the third policy path is the presence of a very weak carbon price signal. Incentives for innovation and technology deployment here will mainly originate from quantitative sectoral targets – with sectors being understood as specific low-carbon technologies – that provide stable signals to industry, consumers and finance sectors as to what technologies will be prioritized on. In the updated business-as-usual scenario of policy path 1, those targets were less focused and, in line with the 2020 SET Plan, did support almost the full range of technologies. In this policy path 3, the technology push will be specific to the most promising technologies, be it consumption- or production oriented. These targets would be long-term objectives and can, depending on the degree of their exact specification, aim at intermediate steps in 2030 and 2040, or directly at the 2050 horizon. The strong and binding EU-level and corresponding national targets will be jointly agreed upon by the Member States at the EU level, taking into account also region-specific technological potentials and cost. Their implementation then will occur under individual governments' responsibility. National action plans provide Member States with a degree of freedom for their own national implementation.

Major technology push will come from an extended SET Plan, which focusses on more narrowly selected technologies. This 'advanced' SET Plan would attempt to find a future proof technology portfolio by using a *cross-sector* approach that provides clear signals to investors but leaves national authorities with sufficient leeway in implementation. The SET Plan, thus, will not only serve as a platform for information exchange and stakeholder coordination and cooperation, but also provide the basis for planning and priority (as well as target) setting and the determination of an optimal portfolio of low-carbon technologies, as well as for the allocation of public (especially European) funds. Technology-specific, directed financial support will be a key element in the concept of this policy design. Competitive funds for clean technologies might co-exist, but will play a minor role.

The governance of policy instruments, hence, will be predominantly decentralized. While the EU has to play a role in administering the ETS and moderating Member States' decisions on sectoral targets, the implementation of this policy mainly relies on decentralized national action. There is the possibility of aligning national implementation: national action plans and support schemes could be harmonized throughout Member States and be aligned to the defined sectoral targets.

3.1.5 Main findings

The presented policy paths indicate the wide range of potential policy frameworks. The role of the SET Plan will differ depending on the future policy path. For path 2, a light SET Plan will function as a platform for open access information exchange and stakeholder coordination and cooperation. Hence, it will preliminary become a tool that supports innovators' and investors' decision making and that can help to mobilize private funds. In contrast, for path 3, an advanced SET Plan would also be a tool to determine an optimal portfolio of low-carbon technologies and research activities across sectors, and, thus, provide the basis for planning and priority (as well as target) setting and for an optimal allocation of public funds. Table 1 summarizes the key drivers and governance of instruments as well as the role of the SET Plan in the three possible future directions of an EU energy technology policy.

3.2 Evaluation of policies

The following multi-criteria evaluation is used to elicit trade-offs among alternative policies. We do not use our findings to globally rank policies, since the absence of an objective procedure for weighting competing criteria restricts the possibilities for a scientifically robust ranking. But identifying trade-offs will allow us to provide feasible and individually tailored real world policies that base on different elements of each policy path. In Section 4.4 we also present *no-regret measures* (e.g. related to the mobilization of funds or the optimal design of public support to innovation) that are relevant for any energy technology policy and, therefore, not part of the multi-criteria analysis.

3.2.1 Climate effectiveness

If all GHG emissions are included into a cap-and-trade scheme, as would be the case in a very strict version of policy path 2, the decarbonization target would be reached by definition. Climate effectiveness will be less predictable for a scheme where part of the emissions are not included into the trading mechanism but are subject to a carbon price in the form of an emission tax. For such price-based instruments, the aggregate emission reduction quantity will be a response of market players to the tax and, hence, can only be estimated ex-ante. Climate efficiency will also be less predictable for policies 1 and 3, which, besides a relatively weak carbon pricing scheme build on complementary target setting. The ETS here covers only a small subset of emissions. Policy makers cannot be sure which exact amount of abatement will be induced and a certain under- (or even over-) achievement of the emission reduction target may occur.

Hence, with respect to climate effectiveness, policy path 2 seems to be slightly preferable to paths 1 and 3. However, with such a long time horizon, predictions about the exact outcome in 2050 are hardly possible and the problem will rather lie in achieving cost-efficient abatement, which is discussed below. It has to be noted, though, that different simulation exercises provide strong arguments for early action and that "tackling climate change is the pro-growth strategy" (Stern, 2006, p. ii). An alternative strand of literature (see e.g. Nordhaus, 2000), assumes that technologies mitigating climate change evolve spontaneously and argues that for high enough discount rates waiting might be optimal. However, Aghion et al. (2009b) or Kempfert and Schumacher (2005) illustrate that to employ cost-efficient clean technologies in the future, policymakers have to stimulate green innovation *today*. Energy technology policies should not only aim at achieving the 2050 target in the long-term, but aim at an ambitious emission reduction path as of now.

3.2.2 Green growth

Global competition has become much tougher and as discussed above, an EU energy technology policy should ideally reinforce European competitiveness in low-carbon technology sectors and foster green growth. Besides some very first attempts to identify Key Enabling Technologies, policy path 1 does not present explicit remedies addressing these challenges. National initiatives in general also will not be sufficient because most of the Member States are too small to compete on a global scale with economies such as the US or China.

For the second policy path, departing from strong price signals, it would be the industry that should discover promising areas of innovation and public intervention would only be initiated when technologies are already relatively close to the market. On the one hand, there are good arguments to build on market signals and private sector decisions. On the other hand, one could argue that there might be the risk that public support for innovation, that at the same time could foster green growth, might come too late. Being too late also implies missing out potential first mover advantages in globalized markets.

In contrast, policy 3 allows public authorities to 'pick winners' already in very early stages of the innovation chain, and governments or the EU can explicitly target those technologies where one can build (or keep) industrial leadership. Forces could be joined for instance at regional levels and EU-level support to innovation could be optimally applied. However, this strategy faces several risks. First, '*wrong winning technologies*' might be targeted. There is a "widespread concern about the potential for policy makers to efficiently direct technological change in a welfare improving manner" (Johnstone/Hascic, 2010). Such winner-picking also might discourage potential innovators to explore new least-cost innovation. A second risk concerns potential *institutional lock-in* in the allocation of funds. Once projects for a certain technology are funded, it is hard to instantly change technology priorities, and such an unstable design would also shy away future investors. Lastly, policy 3 features the risk of a *political lock-in*. Once technologies are chosen, funded and there are rents to distribute, interested stakeholders might make it impossible in the political processes to shift funding to other technologies.

Despite these risks inherent to policy 3, the strong reliance on technology push nevertheless offers a huge potential to stimulate green growth. Technology push can also be used to push innovation and growth *within* the EU, and even in selected Member States or regions. Under the EU ETS, in contrast, European consumers incentivize innovation on the world market by also making it more profitable to invest in green technologies outside the EU and then to sell products to companies operating under the emission trading scheme.

3.2.3 Robustness to EU financial crises and institutional difficulties

An energy technology policy towards 2050 inherently bases on long-term targets. Therefore, such a policy should be robust to scarce financing caused by current (and possible future) financial crises and be consistent with future developments of the EU institutional system.

A first relevant aspect here is the ability of policy options to mobilize funds. The current situation does not create sufficient certainty for investors. As the current crisis shows, and Gilder/Cooke (2012) discuss, several highly indebted countries stop supporting RES. Investors might shy away from these countries for a considerable future time. Stakeholders furthermore argue that the (current) EU ETS price is far too low and volatile to yield stable investment signals. Policy path 3 with strong technology targets and strong accommodating technology push, in contrast, can not only provide stable investment signals, but can also be used within a stimulus package in times of crisis. The decentralized governance moreover allows for tailored national solutions, which can react to differing national needs, e.g. countries can choose their abatement channels and shift abatement costs across sectors. A policy building on price signals is inferior to path 3 since technology targets provide clearer signals to investors, especially during financial crises where capital is scarce.

Second, one has to ask how the governance of these instruments can be deterred by potential EU institutional difficulties, such as the current debt crisis, that leaves different Member States with different potentials in sticking to committed long-run climate goals. The impact will depend on the (future) degree of heterogeneity among Member States. A higher degree of heterogeneity will speak in favor of decentralized solutions and hence for policy paths 1 and 3 for similar reasons as discussed above. For instance, the burden sharing related to strong performance standards in energy efficiency or for the achievement of technology targets in path 3 would allow for adjusting the burden of decarbonization among Member States, and thus seems to be the most robust to EU institutional frictions and financial crises.

3.2.4 Cost-efficiency

Given the fixed target of decarbonization, cost-efficiency implies cost minimization. Abatement costs will be minimized by using the various abatement channels available. These channels include switching to cleaner inputs (e.g. fuel switching), installing abatement capital (e.g. cleaner production technology, or installing energy efficient appliances), or reducing the overall scale of production or respectively consumption. Obviously, abatement costs differ across firms, households and sectors, and hence, it cannot be cost-efficient if all actors simply had to abate the same emission levels, say x% of their historical emissions. Instead, one common price on emissions minimizes abatement costs, as was already pointed out by Baumol and Oates (1971). This directly illustrates cost advantages for policy path 2.[9]

Whether policy path 3 is preferred over the reference case will depend upon the exact specification of technology priorities. For both options one may doubt whether policy makers possess the required information to define targets that imply that the costs of such technology mixes are just in line with the benefits of abatement. At the same time, technology mandates do not engage all abatement channels but likely will miss out promising, cost-efficient abatement opportunities.

3.2.5 Implementability

Implementability and subsidiarity compatibility of policies also need to be considered, taking into consideration the legal and institutional context. For the reference case, this is given. There are shared responsibilities between the EU and Member States fully in line with the shared competences as defined in the Treaty of the Functioning of the EU (TFEU). Centrally coordinated instruments complement national action as already established. Various stakeholders have the opportunity to use platforms such as the Industrial Initiatives to cooperate, and the within-sector approach of planning and priority setting of the current type of SET Plan avoids that individual sectors feel disadvantaged. Moreover, past success in bringing stakeholders together, being pioneer in certain technological areas or having built a competitive advantage, support arguments in favor of such a policy.

In contrast, policy path 2 can face substantial difficulties related to its implementation. Europe cannot be treated as an isolated system but is part of increasingly globalized markets. A strong carbon price will be reflected in higher energy prices. Firms outside the EU competing in the same markets, but not being subject to (any or similarly high) carbon prices

9 As Goulder/Parry (2008) emphasize, with high monitoring costs associated to emission pricing, its benefits disappear, what also can reduce trading levels and increase abatement costs (Stavins, 1995). The inability to perfectly monitor policy implementation might also explain suspected over-allocation of permits during the initial phase of the EU ETS, as studied in Ellerman/Buchner (2008).

would benefit from their price systems not reflecting the full cost of environmental damage. This puts European products at a competitive disadvantage, at least in the short-run. Obviously, some sectors would be more affected than others, as will be the case for different EU Member States depending on their product specializations and competitive advantages.[10] Especially countries being specialized in carbon-intensive products most likely will oppose a global strong carbon pricing scheme and will advocate exemptions for certain sectors or the free allocation of emission allowances to certain user groups, a scenario that is even more relevant with the current EU and financial crises raising the question whether such a policy would be affordable for all Member States. Hence, the incentives of policy makers might not be aligned with the optimal policy design from the society's perspectives, and this policy path would suffer from severe difficulties (a) to implement 'high-enough', adequate carbon price and (b) to include all GHG emissions into the scheme.

For policy path 3, there are certain barriers for implementation, as well. The definition of EU-level sectoral targets implies the determination of a kind of optimal portfolio of technologies for the mid- and longer-term horizon and respectively prioritization among sectors and research areas based on an advanced SET Plan. But such an optimal portfolio only can be determined under quite strong assumptions (all relevant information need to be available, functioning cross-sector and cross-country coordination) and one might question whether it is "possible to have a common definition for the whole of the EU, given the different structures of the national economies" (Ranci, 2012, p. 115). Furthermore, sectors are to some extent competing with each other and there probably will be strong opposition from those sectors that are afraid of losing relevance. Moreover, the implementation of this policy would involve difficulties to agree on sectoral targets (e.g. different Member States might favor different technologies) and to agree on a burden sharing among Member States. It also has to be considered that regular (re-)negotiations would be necessary to adapt (EU-level and national) targets and research priorities. Member States also are typically reluctant to give too much power to the EU. According to Art. 194 of the TFEU, decisions regarding the energy mix of a country are a national issue and the definition of sectoral targets will cause problems related to the subsidiarity problem (see Box 2).

A further aspect related to the feasibility and implementability of a policy relates to **distributional impacts**. Varying impacts of alternative policy instruments on different stakeholders or Member States can have important implications for considerations of fairness as well as for political opposition. On the *producer side*, as already mentioned above, European players might suffer from weakened positions on the global market if they are subject to strong carbon prices that are absent in other economies, and certain Member States would be more affected than others depending on the product specializations of their economies. However, the decision about whether to allocate emission allowances based on grandfathering or auctioning can have a significant effect on distributional burdens. With a free allocation, political feasibility is improved, whereas auctioning has the advantage that revenues could be used to finance reductions in existing, distortionary taxes (revenue recycling effect), or to provide RD&D funding. On the *consumer side*, the EU ETS and other market pull schemes such as feed-in-tariffs set prices that are common to all (industrial) consumers, and are (to a large extent) passed to

10 See Ellerman et al. (2010) for evidence on the past impact of the EU ETS on the competitiveness of different industries. See Delgado (2007) for a discussion on the impact of the EU ETS on different economies.

Box 2: Can the EU intervene on national energy mixes?

According to **Art. 194 (2)** of the Treaty of the Functioning of the EU, being part of the Energy Title, EU-level policy measures deemed necessary to achieve energy policy objectives such as the establishment of an internal market or supply security shall "not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply".

At the same time, **Art. 192 (2)(c)**, being part of the Environment Title, establishes that environmental policy measures "significantly affecting a Member State's choice between different energy sources and the general structure of its energy supply" can be adopted. In this case, however, unanimity of the Council – which actually allows every Member State to veto such decisions – and a consultation of the Parliament are required.

A centrally coordinated policy measure such as harmonized national targets for energy efficiency improvements or sectoral targets as introduced in policy option 3 would obviously affect Member States' choices of energy sources and structure of energy supply. Therefore, it only could be adopted under the **environmental legal basis** (referring to Art. 192) but would not be justified under the energy market provisions (as specified in Art. 194).

end-users. Such common prices will likely hit lower income groups hardest. In contrast, technology push for prioritized sectors will to a large extent be tax-financed, and policy path 3 leaves more room to include social aspects into energy technology policy – within one Member State but also across countries.

3.2.6 Main findings

The multi-criteria evaluation of the possible policy paths for an EU energy technology policy illustrates that a prioritization of policies is not straightforward. No single policy is clearly superior to the others. Different options perform best under different evaluation criteria. With respect to the EU Energy Roadmap, policy path 2 probably could pave the way towards a *diversified technology portfolio*, whereas path 3 probably seems to be more suited for scenarios that need a stronger technology push, such as the *high RES* or *high energy efficiency* cases.

Different trade-offs arise regarding the choice of policies and instruments. Policy path 2 would allow for cost-efficient abatement given a perfect market setting but might be difficult to implement. Policy path 3 might be well suited to enhance green growth and can provide remedies to EU financial crises and institutional frictions, but suffers from weak carbon price signals and diluted technology targets. Besides the difficulty of evaluating impacts along one single criterion – various aspects and complexities have to be considered – alternative criteria can be weighted differently by different policy makers. Hence, any real world policy will likely involve a mix of elements of each of the above polar cases.

4. EU technology push in an uncertain policy context

Best practice for technology push will depend on the overall energy policy context. This context is uncertain, with uncertainty originating from two sources: First, as already discussed, there are many possible future policy paths and the fact that no policy path is clearly superior illustrates that the EU policy might change over the course of achieving decarbonization by 2050. Second, and not discussed so far, uncertainties can arise from changes in key objectives of EU energy policy. In this regard, section 4.1 is dedicated to the future policy context resulting from the unknown

Table 2: Summary of the evaluation of policy paths

Criterion	Evaluation
Climate-effectiveness	We assume that the decarbonization objective **can be reached under all policies**.
Green growth	**Path 3 is the most robust** option with sectoral targets providing stable investment signals. The ability to account for different national technology push programs and to adjust the burden of decarbonization among Member States is only given in this policy path. In contrast, *path 1* has a lower ability to enhance green growth and *path 2* has growth potentials only in the longer-run, due to the high carbon price, that, however, also attracts non-EU made abatement products.
Robustness to EU financial crises and institutional difficulties	**Path 3 is the most robust** option with sectoral targets providing stable investment signals on the one hand, and the ability to account for different national technology push programs and adjust the burden of decarbonization among Member States in times of crisis on the other. In contrast, *path 1* does not present adequate remedies, yet. *Path 2* is not robust to financial crises or institutional frictions, too, due to the lack of the ability to account for Member State heterogeneity.
Cost-efficiency	**Path 2 is the most cost-efficient solution.** Abatement costs across all sectors and abatement channels are minimized when implementing one common emission price. In contrast, *paths 1 and 3* suffer from weak carbon price signals and diluted technology targets.
Implementability	**Path 1 is most easy to implement**, as implementation efforts are low and subsidiarity compatibility is given. In contrast, *path 2* is not fully feasible as the implementation of a scheme with one unique and high enough carbon price covering all GHG emissions would pose sever political difficulties. For *path 3*, implementation barriers mainly relate to achieving an agreement on sectoral targets and the related burden sharing among Member States.

development of carbon pricing. Section 4.2 elaborates on possible future developments that are not yet recognized in the EU Energy Roadmap. Section 4.3 then concludes on a robust push strategy and also presents additional "no-regret measures" that are relevant for any future EU energy technology policy.

4.1 Uncertain carbon prices

The **policy context** for a renewed post-2020 SET Plan and corresponding technology push is defined by market pull regimes, and here foremost by the EU ETS. Today, it can be heavily doubted that based on the current scheme and the currently determined emission cap, carbon prices in the magnitude of those reported in different EU Energy Roadmap scenarios and those needed in policy path 2 can be implemented.[11] Though, design improvements have the potential to make the EU ETS a stronger policy instrument. The future ETS design should aim at including the highest possible base under the scheme and broaden the impact of the common carbon price, while also aligning non-ETS carbon prices. The carbon price signal could also be stabilized through advanced banking and borrowing means which help to moderate price fluctuations (Ellerman/Joskow, 2008).

11 Carbon prices in the underlying simulation exercises are determined such that 2050 targets are reached, assuming equal prices/values for ETS and non-ETS sectors. These prices range between 234 and 310 EUR/t.

Given the current absence of a strong enough carbon price, together with the necessity to stimulate the innovation machine *now*, the need for a renewed SET Plan with a higher signaling effect in terms of what technologies to push becomes apparent. Coming back to the discussion on the policy paths, with a highly volatile emission price, and a potentially asymmetric impact on different income classes and different income countries, the benefits of an ETS diminish, even though from a theoretical cost-efficiency point of view, a cap-and-trade carbon pricing scheme dominates policy alternatives such as technology targets. When re-thinking where to depart from current 2020 policies, it becomes clear that high carbon prices are promising for efficient decarbonization, but likely will not be entirely feasible for the foreseeable future. In such a policy context, the SET Plan and corresponding technology push gain in importance.

4.2 Departures from the EU Energy Roadmap

It what has been discussed so far, we assumed that the 2050 decarbonization target is the central objective and that any EU energy technology policy aims at achieving the reduction of GHG emissions by 80-95%. We further assumed that even though there is uncertainty regarding the exact technology paths and system architecture, the possible menu of technologies is essentially known (including low-carbon generation, the decarbonization of fossil fuels and demand-side measures), and as the different existing roadmaps indicate, this decarbonization is technically feasible.

In what follows, we soften these assumptions and add further uncertainties to the picture. On the one hand, *technological revolutions* could substantially alter the set of available technologies contributing to decarbonization, what would have an impact on carbon prices and incentives to invest in innovation and deployment of other low-carbon technologies. On the other hand, *shifts in paradigms* to alternative policy objectives could outrank decarbonization. Hence, there are not only substantial uncertainties regarding viable decarbonization technologies within the context of the EU Energy Roadmap, but there are also possible futures that are not yet recognized in 2050 roadmaps.

4.2.1 Technological revolution

The EU Energy Roadmap scenarios build on a menu of essentially known technologies.[12] However, 2050 is 38 years from now. Thinking 40 years ago, there had not been the oil crises yet, European energy markets had national structures and electricity generation from RES was close to zero. In 2050, the energy system probably will be extremely different than it is today and the optimal portfolio of decarbonization technologies has a very long time horizon, not only looking ahead to the 2050 target, but technological lock-ins will persist even beyond. It is not only this very long-term nature of the problem; also recent developments such as the Fukushima accident influenced possible future scenarios. For instance, a '2050 bridge role' was still given to nuclear in the first version of the German energy strategy in late 2010, whereas the country announced a nuclear phase out until 2022 one year later. Another example is the increasing interest in US unconventional gas resources. Whereas the IEA in its

12 The SET Plan distinguishes among different degrees of maturity with Group 1 being close to market competitiveness with an expected mass market deployment in the short- to medium-term; Group 2 comprising emerging technologies expected to become cost competitive between 2020 and 2035; and Group 3 consisting of new technologies that are still immature today and expected to become competitive only after 2035.

World Energy Outlook 2007 (when the 20-20-20 strategy was adopted by the European Council) predicted a moderate growth for US gas production and did not mention shale gas at all, the World Energy Outlook 2011 is talking about a possible "golden age of gas".

One important aspect is that any energy technology policy should allow for the creation of options and technological breakthroughs. Innovation activities here typically involve basic research, novel ideas without the possibility to conduct cost-benefit analyses yet, or even fields of research that have not previously been seen as relevant to energy. Electro-fuels are a possible example: several research groups in the US work, in cooperation with the Department of Energy, on engineering an organism that converts electricity and CO2 into liquid fuels. The success of such a 3rd generation biofuel technology could revolutionize the transport sector. Another example is nuclear fusion which might become a source of reliable, low-carbon electricity generation not producing long-lived radioactive waste products. Such very basic R&D requires special support. The highly risky nature of the projects and long time horizon until any (if any) benefits can be reaped make public co-funding essential. However, as discussed below, any institutional or political lock-in of funding should be avoided to allow for an efficient use of limited public funds.

Another important aspect involves possible shocks that might eliminate technology options (e.g. Fukushima accident) or add new means of decarbonization. One such latter situation could be a (more global) **shale gas revolution** that may severely shake up our today's EU energy strategy: The production of shale gas, an unconventional gas resource, rose from less than 1% of domestic gas production in the US in 2000 to over 20% in 2010. EIA forecasts expect a continuous rise up to more than 45% by 2035 (Stevens, 2012). This recent development transformed the gas market into a buyers' market with Henry Hub spot prices falling from ~8-10$/MBTU to current levels quite below 4 $/MBTU. Optimistic voices see a huge potential for shale gas worldwide providing abundant supplies of cheap gas.[13]

Assuming that the US will become a large-scale exporter of cheap gas and that it is possible to replicate the American experience in other parts of the world, what are implications for investments in decarbonization and the EU energy technology policy? The availability of cheap gas on the market would allow for a certain degree of decarbonization at low cost (or even net benefits) via e.g. substituting coal by gas in the power sector, or oil by gas in transportation. If such business cases evolve, one could imagine that the EU, for instance, could see a phase-out of Polish coal and German lignite with the help of Polish shale gas. Hence, the 'rational' price of carbon might well fall extremely low under the push of shale gas as a 'market-based' decarbonization technology.

Nevertheless, natural gas is still a fossil fuel emitting CO2 during combustion processes and the 2050 decarbonization objective cannot be reached with shifting to gas alone. Shale gas may not only substi-

13 Indeed, there appear to be very large quantities of technically recoverable resources. China, for instance, is pushing strongly the development of its potential. However, uncertainty about both volumes and costs persists. US companies currently produce from very large and shallow plays, whereas resources in other areas tend to be smaller and located in greater depths, increasing exploration and production costs. There is also a general tendency to correct estimates on available volumes downward: in early 2012, Poland reduced its potential by 85% – from 5300bcm to below 800bcm. Furthermore, shale gas is produced based on horizontal drilling and hydraulic fracturing which involves the injection of chemicals. Severe environmental concerns have created strong local oppositions, and France or Bulgaria have already banned shale gas operations. Such other negative externalities should be part of any cost-benefit analysis.

tute for dirty coal but also for expensive RES, and the lack of a carbon price signal will inhibit investments into the development and deployment of alternative low-carbon technologies. Hence, some explicit push for other decarbonization technologies (zero-carbon generation, or CCS) will be crucial if the 2050 objective shall be achieved.

In summary, 2050 is a very long-term horizon and technological revolutions can have important, unpredictable impacts on the available set of and relative cost of decarbonization technologies. Also the role for electricity in decarbonization might be different than expected. Current thinking assumes that the decarbonization of this sector will be key and that electricity will play an increasing role in primary energy consumption. But this might change with e.g. a certain level of decarbonization in the transportation sector being achieved by shifting to gas-fuelled cars instead of electrification. This shows that there are some risks with focusing only on today's SET Plan technologies if there might be futures that are not at all recognized in the current Roadmap.

4.2.2 Paradigm shifts in EU energy policy

In 2009, the European Council agreed on the economy-wide GHG abatement objective of 80-95% below 1990 levels by 2050. Consequently, decarbonization has become one central theme on the political agenda. But energy policy builds on *three* fundamental pillars: sustainability, as well as competitiveness and supply security. We assumed so far that Europe aims at achieving this environmental target in any case. Assuming now that alternative policy objectives could outrank decarbonization, would this lead us to a different optimal technology portfolio?

First, **competitiveness** could rank particularly high. Among the different policy objectives, there are both positive and negative interactions. One the one hand, there is a broad consensus that open and competitive markets and adequate infrastructure investments are conducive to supply security and decarbonization (see e.g. Glachant et al., 2010). On the other hand, however, any unilateral climate policy (be it national or EU-wide) imposing substantial asymmetric cost on the regulated agents bears the risks of being detrimental for economic growth and ineffective in reducing GHG emissions: such policies increase the industry's cost at least in the short-run, which raises concerns from an economic point of view (loss in competitiveness), but also from an environmental perspective (carbon leakage).

There is considerable debate about the extent of carbon leakage and policy measures mitigating this phenomenon (e.g. Clò, 2010; Caron, 2012; Antimiani et al., 2012). One possible solution involves the free allocation of emission allowances to ETS sectors that would be subject to the risk of carbon leakage.[14] Alternatively, several forms of border adjustments (e.g. import tariffs) could be applied if it can be ensured that such instruments are consistent with WTO rules and are not abused for protectionist reasons.[15] Nevertheless, there are also considerations about positive interactions between decarbonization and economic growth. Fankhauser et al. (2008) argue that "growth theory has long identified technical change and innovation as major source of economic growth" (p.

14 Within the EU ETS, a progressive transition from grandfathering to auctioning is foreseen for energy-intensive manufacturing installations (80% free allocation in 2013, decreasing annually to 30% in 2020 and full auctioning in 2027).

15 See also Ahner (2009) for an in-depth discussion of the conformity of anticipated trade measures in EU climate change legislation with the international obligations of the Community under the WTO.

426) and that long-term dynamic innovation effects induced by climate policies will bring about a net job creation. However, a shift in the European policy focus towards prioritizing competitiveness would certainly not improve conditions for successful implementation of decarbonization policies.

Second, **supply security** might receive higher priority on the political agenda. At first sight, there seems to be a certain conflict with the achievement of environmental objectives, in particular CO2 mitigation, since these restrictions may limit options of energy supply. But climate policies can induce a broader use of low-carbon technologies, and thus also have a positive impact on diversification. Studying the UK electricity system, Grubb et al. (2006) find that the introduction of an emission target of 60% will lead to a substantial increase in diversity of sources of generation (mainly driven by a declining dominance of gas in the fuel mix), whereas, in contrast, in the absence of any emission target, diversity decreases. Similar results can be expected for coal-based systems where the transition towards gas-fired generation to reduce emissions would increase diversity, too.

Diversity of generation and supply sources, however, is not necessarily a requirement for the *national level* in a European market. The Nordic countries, with Denmark relying strongly on wind energy and Norway on hydro power, are a good example. In 2014, Skagerrak 4, the fourth interconnector, jointly built by Statnett and Energinet.dk, will become operational. Interconnection capacities and a functioning common market ensure security of supply and facilitate RES production from the locally available resources.

What are the implications of such shifts in paradigm? Would it require different strategies for an EU energy technology policy? Considerations regarding the competitiveness of European industry would probably weaken the EU ETS with exemptions from the scheme or the free allocation of emission allowances for certain sectors, or even an upward correction of the emission cap. Hence, to achieve the transition to a low-carbon economy, a well-designed energy technology policy will gain in importance. Similarly, from a supply security perspective, a balanced portfolio ensuring a well-diversified supply mix calls for stronger (also directed) push policies. Market integration is a fundamental precondition for allowing for decarbonization while ensuring secure supplies. Furthermore, supporting consumption-oriented measures – namely improvements in energy efficiency and reductions in consumption – will be a strategic move in any case. They will not only contribute to decarbonization, but also decrease the cost of market players, and thus increase their competitiveness, and reduce risks related to supply security.

4.3 Recommendations for the future EU energy technology policy

Several implications for the future EU energy technology policy arise. While some directly concern the specifications of the SET Plan and the magnitude and direction of its accompanying technology push, others are of general nature and offer no-regret options.

4.3.1 A renewed SET Plan and its corresponding technology push

A **renewed post-2020 SET Plan** should allow for all possible future policy paths and not exclude the possibility to act within a certain future context. It should be more focused than the current SET Plan and provide the basis for planning and prioritization among decarbonization technologies. Similar to the current model, stakeholders from individual sectors could work together within Industrial Initiatives to identify technological progress and future research needs. In a second step, priority technologies – i.e. those (a) being key to achieve 2050, and/or (b) helping to support green growth within the Union – should be identified based on a *comprehensive approach across sectors*.[16] Selected technology targets and EU funding of innovation should then be in line with the SET Plan prioritization. Key performance indicators, similar to those already specified in today's sectoral Technology Roadmaps, shall be used as a tool for monitoring and reviewing the progress of technology development, demonstration and deployment and, hence, become an essential element contributing to funding decisions.

There are several reasons that justify **some directed technology push**, instead of building fully on technology-neutral support to innovation. First, *certain low-carbon technologies are key to achieve the transition to a low-carbon economy* and there are reasonable concerns that without such support they will not be developed and deployed at the necessary scale and/or on time. This could for instance be the case for CCS. All scenarios of the EU Energy Roadmap contain a substantial part of electricity generation using this technology (between 10% in the 'high RES' and 33% in the 'Reference' case in 2050, see also Appendix 1) with CCS being viable from 2030 on. Other roadmaps present very similar numbers and assume commercial-scale deployment already for 2020 or 2025. Hence, if the timely deployment of CCS is a necessary precondition to achieve climate objectives, further support to innovation and especially demonstration projects is justified. However, as discussed elsewhere in-depth (e.g. Hirschhausen et al., 2010), CCS can only thrive, if at the same time financial, political and regulatory risks are reduced.[17]

Second, European technology push can have its justification as a *means to respond to fierce global competition in green-tech markets and to help to keep wealth within the Union*. Whereas the burden to finance market pull measures always is with consumers and tax payers but benefits can be reaped by both domestic innovators and producers, but also market entrants from outside the EU, directed technology push can be designed such that it favors domestic players. Explicitly targeting specific technologies also allows policy makers to accelerate technology development and support industrial leadership. This strategy is promising especially for high-tech segments or parts of the value chain that cannot be outsourced to low-cost competitors. It has to be noted, that strategic industry- and trade policy measures might be possible 'regret measures' (see Box 2).

Despite these advantages for a coordinated and centralized European technology push, the overall policy design should still rely to a large extent on bottom-up participation. Especially technology projects with 'normal risk and return profiles' are well suited to be supported by individual Member States, leaving high-risk support for the EU. While a bottom-up approach is certainly needed for national action plans and national funding, also the push coming

16 The current "business as usual" SET Plan does not include such a base for target setting across technology sectors in favor or against certain technologies. Hence, especially if carbon prices remain at relatively low levels, the current SET Plan is not able to deliver the basis for the then required strong target setting and corresponding technology push.

17 Similar arguments also hold for other low-carbon technologies, such as certain RES or forms of electricity storage. Stronger push policies here would become even more relevant if the large-scale deployment of CCS turns out to be infeasible and/or if more Member states decide a nuclear phase-out. Besides, also for different energy efficiency measures many studies show that there is a substantial economic potential of cost-efficient abatement, but that (especially non-economic) barriers hinder the realization of the full potential.

Box 3: 'Regret measure' industry and trade policy?

A strong technology policy will intersect with industry- and trade policy. Industry policy can either rely on competitive forces to enable (green) growth, or might compromise on competition within the EU in favor of *EU champions* that compete globally, as for instance done in the EU air transport sector with AIRBUS. This long lasting debate just became topical once more with the recent EU Communication on industrial policy (EC, 2012c).

Trade policy measures may either explicitly support home technologies on the world market (via subsidies), or protect them from foreign competition on the home market (via import quotas or tariffs). If the EU was the first mover, the rationale is to shift profits from foreign to domestic firms. Early literature on strategic trade policy (Spencer/Brander, 1983; Krugman, 1987) finds that, if an industry is characterized by increasing returns to scale, subsidizing home firms that then can commit to an increased future output, threatens the foreign firm. The foreign firm will decrease its output to not lower market prices. Subsidies given to the home firm are outweighed by the profits shifted from the foreign to the home firm. Whenever the EU would have to react to such measures undertaken by other countries, the rationale is to sanction the first mover.

The global market for clean technology is huge in volume. According to Roland Berger and WWF (2012), in 2011, the market volume grew by 10% to about EUR 198bn. Furthermore, markets are relatively new and often not perfectly competitive. Hence, it is tempting for governments to engage in trade policy to push domestic firms. Current trade disputes related to clean technologies, however, illustrate the complexity of trade policy. Most prominently, China is heavily supporting its solar PV industry, leading to anti-dumping counter measures by the US. The US sets anti-dumping duties between 18 and 250% on imported solar PV cells coming from China. Likewise, but on a smaller scale, Argentina is currently filing a case at the WTO, arguing that Spain was banning imports of biodiesel from Argentina by obliging consumers to buy biodiesel produced in Spain to fulfill EU targets on renewable energy.

Such policy measures also bear considerable risk. Besides provoking counter measures as in the China-US solar dispute, subsidizing home technologies on the world market might lead to falling prices and vanishing industry profits. Within the above example, China's aggressive policy led to a drastic fall of the world price of solar panels and hence the effectiveness of this policy in shifting profits can be doubted. China's manufacturing capacity grew so much that an enormous oversupply was created. Falling prices resulted in enormous difficulties for manufacturers and state-owned banks, which invested in these manufacturers with about $ 18bn of low-interest loans.

Therefore, the strong reliance on competitive forces as outlined in several Directives should be maintained. Major rationales for introducing industry- and trade policy instruments should relate to environmental or innovation externalities. All interventions going beyond this will effectively result in industry and trade policies that imply strong market interventions which are not justified on the grounds of market failures. If such measures are opted for, they can be pursued under all policy paths, but best in path 3 with a technology push that is stronger than initial market failures imply, and thereby can result in a first mover advantage on the world market.

from the European level will be bargained beforehand. Political considerations, such as who are beneficiaries of support, will aggravate the planning and priority setting for technologies when constructing the SET Plan and the agreements on where funding is derived from.

These barriers become even larger since Member States are inhomogenous in their technology base and ability to finance. As discussed above, there are countries that benefit from relatively low financing cost and a high consumer willingness to pay for energy policy, whereas others suffer from rather limited private and public willingness and ability to pay for low-carbon innovation. In addition, low-carbon technology bases range from strong low-carbon industry positions for e.g. wind energy in Germany or Denmark, or nuclear in France, to countries that do not have any of those or similar technology advantages yet. These differences hamper agreements on a unified approach for technology support.[18] Therefore, designing an energy technology policy top-down is difficult to sustain, which points out the need for decentralized solutions co-existing to European funding and support schemes. Decentralized solutions further include possibilities to adapt burden sharing to national conditions and needs.

4.3.2 Technology-specific recommendations

Without detailed cost- and technology data at hand, disaggregated technology-specific recommendations as to what technologies and research activities to push are not possible. However, from our analysis we can draw several conclusions that will generally hold. Technology support should predominantly be given to consumption-oriented and enabling technologies as well as to basic research that still allows for future technology breakthroughs. While supporting energy efficiency enhancing technologies can show effects already in the very short-term and up to 2050 and beyond, funding a wide range of basic R&D leaves the possibility for entirely unforeseen green technology paths in the longer-term. Nevertheless, respective funding commitments should be given as early as possible.

As discussed in previous sections, a prioritization of low-carbon production technologies by policy makers entails high risks of picking wrong winners, especially so because future energy market developments like the evolution of shale gas production and fossil fuel prices may entirely change the benefits and market value of different production technologies. In addition, the value chains of such production technologies are complex and involve many steps – inside and outside the EU. Any European market pull will not only benefit domestic players, but also incentivize investments in e.g. component manufacturing and innovations outside the Union.

The situation is different for certain **consumption-oriented technologies**, comprising mainly energy conservation and efficiency enhancing measures. Several reasons argue for pushing such technologies. As concluded above, there is a consensus that the long-term EU climate objectives cannot be reached without substantial improvements in energy efficiency. Furthermore, different studies show that many investments in efficiency enhancing measures, like in the building sector, can amortize very quickly. Moreover, due to their inherent nature of being less manufacturing-oriented but rather to a large extent relying on installing new appliances, incentivizing smart behavior, improving city smartness, etc., the implementation of energy conservation measures typically is quite labor-intensive, and, therefore, entails a larger positive effect on job creation. In addition, there is only limited labor mobility, implying that new jobs are created within the EU. Both push and pull policies targeting such consumption-oriented technologies will, therefore, have a higher effect on domestic job creation than policies targeting certain production-oriented technologies. Besides, pushing consumption-oriented technologies generally does not lead to large biases in energy markets, as is the case for production technologies where support for low-carbon generation will inevitably crowd out remaining competing (and also incumbent) technologies and, hence, can bias market efficiency in often unanticipated ways.

18 Already in the current policy framework, national frictions become apparent, for example with nuclear power, where much money is spent (see Appendix 2). Many countries where the public and the political process speak against nuclear power will very likely also not benefit from any support to nuclear innovation. Germany, for instance, recently debated cutting its spendings for the ITER project.

Hence, pushing consumption-oriented technologies dominates pushing production-oriented technologies in terms of both feasibility and robustness. First, the above arguments indicate that such push is *politically feasible*: Opposing to a push for production technologies, that often would benefit certain Member States in which the major suppliers are located, energy efficiency enhancing measures benefit all EU industries, those offering energy efficiency products and all industries applying it. Hence, this push strategy is independent of geographic location and creates jobs throughout all Member States. Second, such push is *robust with respect to future energy market developments:* Consuming less is a no-regret policy. The EU might well look after its own 'energy technology and security' revolution in consuming significantly less energy. Energy efficiency is an enormous field of energy extraction open to us Europeans if we were smart and bold enough to tap into.

For similar reasons, pushing **enabling technologies** (such as grids, advanced metering or market facilitation via ICT equipment) is a valuable strategy. As for the technology group discussed above, investments typically are quite domestically labor-intensive. However, for grid infrastructures – as for enabling technologies in general – the appropriate magnitude of investment will depend on the amount and type of renewable energy that enters the power system. The optimal system architecture also will depend on whether we move towards 'European-wide energy superhighways' with massive solar energy being imported from North Africa and huge amounts of offshore wind energy being produced in the North Sea, or whether we move instead towards a system of rising local energy autonomy, featured also by widespread demand side management.

As for funding basic R&D and the **creation of options** for technology breakthroughs, the above arguments in favor of consumption-oriented and enabling technologies however vanish. Energy efficiency enhancing technologies should be prioritized over production technologies that are *close to the market*. In contrast, for technologies early in the innovation chain, be it consumption- or production-oriented, the argument that one or another technology might be more feasible to being pushed and more likely to create green growth stimuli does not apply, since relevant industries do not yet exist. Successful deployment can only be expected at a certain (in many cases low) probability and in the longer-term well beyond 2030, or even after 2050. Nevertheless, support is required today. Technology policy here intersects with science and innovation policy. Whereas Framework Programmes, which were initially intended to support R&D, are now hosting an increasing amount of demonstration projects, the European Research Council, for instance, aims at promoting "bottom-up frontier research".

Because the stage of innovation involves basic research and very early R&D, i.e. projects that entail a low chance of success but a sufficiently high pay-off if successful, the argument for a *broad* technology funding becomes important. Over time and as the probability of success increases, funds should become more concentrated. Moreover, as has been shown in a former THINK report (Olmos et al., 2011), in choosing between projects where the expected benefits are the same, it seems preferable to bias funds towards riskier projects with the same expected return.

4.3.3 Additional "no-regret measures" for any policy

#1 – Create options for technology breakthroughs and bring successfully developed concepts to the market

Funding a certain amount of basic R&D is not only in line with addressing spillovers of innovation and with investing in technologies deployable after 2030, but also a no-regret strategy: Funding basic R&D is needed in all technology policy designs, and should be a main pillar in any future SET Plan. This part of funding will not lead to lock-in effects or stranded investments once a changed SET Plan mandates new technology priorities, as could happen for instance

Box 4: Country cases

The case of the US: Volatile federal support policies

Under President Obama, plans to implement a Clean Energy Standard, which would mandate that 80% of energy consumption come from clean sources by 2035, concretize. However, a proposed national cap-and-trade system for CO_2 emissions failed in the Senate in 2010. It is rather individual States that go ahead with ambitious climate policies, such as California, where a renewable portfolio standard (electric utilities have to have 33% of their retail sales derived from RES by 2020) has been introduced.

Comparing with the EU-27 and China, the US has the smallest clean-tech sector relative to its GDP (Roland Berger/WWF, 2012), and about half of all clean-tech sales come from biofuel production. This situation reflects the relative stability of public support for biofuels. Whereas for other low-carbon technologies federal policies are rather volatile, a scheme of federal tax credits created long-term incentives for the production of biofuels. Recent initiatives also include plans to cut fossil fuel subsidies by $ 39bn, and the Department of Energy (DoE) has announced to co-finance offshore wind demonstration projects with a total of $ 180mn over the coming six years. The Defense Department reaffirmed in April 2012 its commitment to source 25% of its electricity from RES by 2025. The *1603 program*, as part of the American Recovery and Reinvestment Act a direct response to the crisis, provided co-funding to more than 45,000 RES projects. A volume of $ 13bn public money triggered $ 43.5bn of private investments.

Most existing programs, however, will expire soon and there is uncertainty about future energy technology policies. RES electricity *production tax credits (Sec. 45)* expire by the end of 2012; the Congress may (or may not) decide to extend or modify this instrument. *Investment tax credits (Sec. 48)* expire for geothermal and biomass (end of 2013) and solar (end of 2016). And *ARPA-E*, a new agency within the DoE, established in 2007 to fund risky innovation targeting 'transformational' energy technologies, does only focus on shorter-term funding. The economic stimulus package introduced in spring 2009 directed substantial resources towards clean energy projects and the DoE's budget increased from about $ 5bn to $39bn. Though, federal funding and energy technology policies could not be "put on a more permanent footing" (Lester/Hart, 2012, pp. 43 f.), and the DoE budget has fallen back to its pre-crisis levels. Investors and innovators complain about unpredictability of public support policies.

The case of Denmark: A success story, so far

Denmark is the world leader in specializing in clean technology relative to GDP (Roland Berger/WWF, 2012). Even though being a high-wage country, Denmark established comparative advantages. The country is especially successful in the production of wind turbines with Vestas and also Siemens (parts of the German company are based in DK) as main players. This success grounds in both, strong technology push and market pull.

Technology push for wind energy already took off in the 1980s and continued throughout the 1990s, leading to strong learning effects. This technology push had a strong focus on wind energy, and Denmark was able to outspend many other countries. Technology push was accompanied by strong and stable market creation policies. Already in the late 1990s, Denmark implemented a feed-in-tariff for wind, which was changed in 2002 into a feed-in-premium with a conditional subsidy of 1.6 ct/kWh (including compensation for balancing costs of 0.3 ct/kWh), assured for a 20-year period (Ropenus/Jensen, 2009). In 2008 and to guarantee the achievement of 2020 goals, the subsidy was increased for onshore wind to 3.4 ct/kWh for the first 22,000 full load hours. During following hours, energy is sold at the spot market. Besides, Denmark also invested in energy efficiency. Today, the Danish company Rockwool is the world market leader in insulation material.

due to changes in market fundamentals as discussed earlier. For the same reason, building a policy to a certain degree on the creation of options for new advanced technologies offers a policy exit strategy at low costs. As mentioned in Narayanamurti et al. (2010), it is, nevertheless, still important to commit to such funding in the long-run.

It is then equally important to bring concepts that have been successfully developed in the laboratory to the manufacturing phase and to commercial deployment. European support to (incremental) innovation can help to bridge the "valley of death" and to bring first prototypes of new technologies to the market. The *Intelligent Energy Europe II* program (2007-2013) already aims at supporting the overcoming of non-technological barriers (including informational, behavioral, institutional and financial barriers) to innovation and implementation of "promotion and dissemination projects" (i.e. projects that bridge between upstream R&D and downstream market adoption). A successor of this program should have an even stronger focus on raising awareness and skills as well as on improving market conditions to create favorable investment conditions.

#2 – Enable an attractive and stable business environment

A public consultation launched by CEER (CEER, 2012) revealed that – compared to the type and level of support – the *stability* of support policies was considered the by far most important factor for investors, reflecting the need for investment certainty given the high up-front cost and long payback periods of many low-carbon projects. Thereby, stability must not be understood as 'keeping things fixed and unchanged', but instead it relates to predictability and transparency, namely to a clear formulation of policy goals and a reliable investment environment where policy paths are clearly communicated ex-ante. Box 4 provides further insights regarding two exemplary cases: whereas in the US, federal funding and energy technology policies could not be "put on a more permanent footing" (Lester/Hart, 2012, pp. 43 f.), technology push in Denmark was accompanied by strong and stable market creation policies.

Moreover, stakeholders complain about administrative hurdles. Complex and lengthy permit granting procedures are seen as a major barrier to invest (EC, 2012b) increasing project risk, which, particularly in countries with stressed capital markets, results in rising cost of capital. Recent policy initiatives are promising. Compared to former Framework Programmes, *Horizon 2020* aims to improve administrative procedures with a simpler program architecture, a single access point, less paperwork, etc., in order to reduce the administrative costs of participants and accelerate the processes of proposal and grant management. Especially small innovators, as SMEs, should benefit from this simplification. Also the implementation of an *EU patenting system* in 2014, as has recently been ratified by the European Parliament, will substantially decrease cost for innovators.

Last but not least, an important role of EU institutions remains to ensure a functioning internal market and a level-playing field, as has been discussed in-depth in several former THINK reports (Meeus et al., 2011b; Ruester et al., 2012 & 2012b). To set the right incentives for technology deployment and development, it is essential to increase transparency, facilitate market entry of new players, and to improve market price signals also in balancing and ancillary service markets. Political borders should not restrict trade. It is the market that should create its own pliable borders, acknowledging technical and economic aspects. Furthermore, regulated end consumer prices should be abolished in order to provide correct price signals and enable the implementation of various consumption-oriented measures.

#3 – Engage consumers and citizens

Another important aspect is the need to remove barriers to behavioral change and to the implementation of consumption-oriented decarbonization measures. Many studies show that there is a difference between energy efficiency improvements that could be achieved with net benefits and current observed levels (Jones/Glachant, 2010; IEA, 2012) and that a non-negligible part of available public funding is not yet used.

Various barriers prevent action (see e.g. Estache/Kaufmann, 2011). First, regulated energy prices in some Member States provide wrong price signals to end consumers. Second, decision processes involve many local, decentralized, small-scale projects, and actors often do not have appropriate skills and/or information, and tend to apply (too) high discount rates when evaluating respective investments. A lack of information prevents targeted actors from making the right decisions since the menu of options is not fully known and/or they are not able to evaluate options correctly. Information asymmetries lead to wrong incentives. If the potential investor is not the party that pays the energy bill, perfect information alone may not be sufficient for optimal investment. Third, a "not-in-my-term" attitude might make politicians think and act in the short-term. Actions and money spent need to demonstrate clear benefits and added value for their voters, while e.g. the transformation to a sustainable city might take decades (Meeus et al., 2011).

These barriers can be addressed by implementing *regulatory measures* such as minimum efficiency standards for appliances and buildings. *Information policies* including for instance the labeling of products or education programs reduce ignorance and information asymmetries and also can foster behavioral changes. *Technical Assistance Facilities* have been set up to support the documentation of project applications, such as feasibility studies or the formulation of a business plan. Around EUR 200mn have already been devoted to major (JASPERS, ELENA-EIB), medium (ELENA-KfW, ELENA-CEB, ELENA-EBRD) and minor (MLEI) energy efficiency enhancing projects.

Energy Service Companies (ESCOs) can help to overcome constraints in paying possibly high upfront cost and can substantially reduce clients' search and information efforts. Despite the clear advantages that ESCO business models can bring as intermediaries for energy efficiency enhancing investments, this concept is still not well developed in Europe. There are significant differences regarding the growth of the ESCO market among Member States and successful development typically can be associated with improved efforts and measures to enable market building (Marino et al., 2011). In Italy, for instance, the introduction of White Certificates notably pushed ESCO activities.

#4 – Spend the available public money wisely

A financing gap of EUR 47-60bn between current expenditures and those deemed necessary to achieve specified technology targets until 2020 has been identified within the frame of the current SET Plan. In the 2050 context, these numbers will become even higher and the recent economic and financial crisis had a further negative impact on the availability of private and public funds. Experts agree that 2050 is technologically feasible, but that a key challenge will be the mobilization of the required capital.

Subsidies in the form of grants and contracts are by far the preferred policy instruments to fund clean energy innovation of any type. However, this instrument should only be used as an instrument of last resort. Olmos et al. (2011) provide an in-depth analysis on how appropriate financing policy instruments ought to be chosen.[19] The form of direct public support, considering also e.g. low-interest loans, loan guarantees, public equity and technology prizes, needs to be tailored to the features of each innovation project – depending on both the technology targeted and its level of maturity – and to the type of entity best placed to undertake the respective RD&D.

Spending public money wisely also involves a smart design of financing instruments. Public funding should be output-driven whenever this is compatible with the engagement of private innovators, which involves making the release of funds and their amount conditional on the achievement of some minimum objectives, i.e. linking support to performance indicators. Moreover, the institutions set up to allocate funds should be lean and flexible enough to avoid institutional inertia and lock-in. New technologies need to be gradually integrated into the market and a level-playing field needs to be ensured in the longer-run, which has to come with a clear and anticipated phase-out of technology subsidies.

Recent policy initiatives already are a first step towards smart financing support. The *European Energy Efficiency Fund* is a public-private partnership open to investments from governments, international financial institutions, donor agencies and other private investors. It offers different types of debt and equity instruments to projects dedicated to energy efficiency, small-scale RES and clean urban transport projects. The *Risk Sharing Finance Facility* has been jointly developed by the Commission and the EIB to co-finance higher-risk R&D involving complex products and technologies, or being subject to unproven markets and intangible assets. Support of up to EUR 300mn per project is primarily provided in the form of loans and loan guarantees and some equity financing coming from the European Investment Fund. The *Horizon 2020* program will include output-based funding such as technology prizes. Loan and equity financing are expected to play a greater role, too. For the future, it is therefore also important to facilitate the development of exit options for equity investors.

Besides, **new funding sources** should be considered. *Existing fossil fuel subsidies need to be revised*. A substantial amount of (national) public money is still spent to back the production or consumption of coal, natural gas and oil products. Germany for instance did directly support coal producers with about EUR 2bn in 2009. A similar sum was mobilized by the Italian government in 2011 to support the consumption of transport fuels, mainly via tax reliefs. Moreover, policy makers should consider the *wider use of auction revenues from the EU ETS* to fund innovation. In the third allocation period, there are no National Allocation Plans anymore; instead Directive 2009/29/EC sets detailed guidelines for the auctioning of

19 Public loans are well suited to finance lower cost innovations with well quantifiable future market prospects carried out by larger companies. They become relevant if the liquidity of the capital market is low or in recessions when private credit markets' appetite for risk is unduly depressed. Publicly owned equity is suitable to finance risky, potentially highly profitable, innovation preferably undertaken by small entities. Technology prizes can support early low-cost innovation. Tax credits and other benefits related to RD&D investments are best suited to support near-market, incremental innovation conducted by larger companies. Grants and contracts – on the one hand the most attractive form of support from the innovators' perspective but on the other the most expensive instrument – should only be awarded to socially desirable clean energy innovation that would not be undertaken otherwise and where all other instruments would fail.

allowances from 2013 on.[20] A part of these revenues could be dedicated to a centralized EU fund. A substantial amount of money could be collected in this way. For the existing NER300 financing instrument, only 300mn emission allowances have been set aside in the New Entrants' Reserve. Sold at the current CO_2 price of about EUR 7.50 per ton of CO_2 this would yield revenues of about EUR 2.25bn. At price levels of about EUR 25 one would already talk about EUR 7.5bn here.[21]

4.4 Main findings

Best practice for technology push will depend on the overall energy policy context. This context is uncertain, with uncertainty originating from two sources: First, the role of the SET Plan will depend on the context of carbon pricing. Second, there are also possible futures that are not yet recognized in 2050 roadmaps. On the one hand, shifts in paradigm of EU energy policy away from decarbonization and in favor of competitiveness might weaken carbon pricing mechanisms, calling for an even stronger technology support. Similarly, a shift in favor of supply security requires a stronger push for decarbonization technologies to achieve balanced energy portfolios, as well as a strong push for enabling technologies such as networks to guarantee properly working energy systems. On the other hand, technological revolutions, such as a possible global shale gas revolution, could result in the 'rational' price of carbon falling extremely low.

A renewed, post-2020 SET Plan should allow for all possible future policy paths. It should not exclude the possibility to act within a certain future context and, hence, should be more focused than the current SET Plan to provide the basis for planning and prioritization among decarbonization technologies. There are several reasons that justify some directed technology push, instead of building fully on technology-neutral support to innovation. Certain low-carbon technologies are key to achieving the transition to a low-carbon economy and there are reasonable concerns that without such support they will not be developed and deployed at the necessary scale and/or on time. Moreover, European technology push can have its justification as a means to respond to fierce global competition in green-tech markets and to help to keep wealth within the Union.

A prioritization of low-carbon production technologies entails high risks of picking wrong winners. In contrast, pushing energy efficiency enhancing technologies dominates other push strategies in terms of both feasibility and robustness. Also pushing enabling technologies is a no-regret strategy. However, for grid infrastructures – as for enabling technologies in general – the appropriate magnitude of investment will depend on the amount and type of renewable energy that enters the power system.

Finally, the creation of options has to be a main pillar in any future SET Plan. The funding of potential technology breakthroughs will not lead to lock-in

20 Full auctioning should be the rule from 2013 onwards for the electricity sector. For other ETS sectors than power production, a transitional system will be put in place resulting in 70% of allowances to be auctioned in 2020.

21 Another possible option to raise additional EU funds that then can be used for coordinated support to innovation could be an *EU tax dedicated to investments combating climate change*. However, similar to what happened during the 1990s, when a carbon tax was proposed at the EU level but failed due to huge opposition from different Member States, any agreement on an EU-wide tax would be accompanied by severe difficulties. The question then also would be on which competence title the EC could base the respective legislation, i.e. Directive or Regulation, to impose the implementation of such a tax on the Member States. The legal basis establishes the procedure to pursue the respective policy, and, thus, decides if the Council has to act by a qualified majority or unanimously.

effects or stranded investments once a changed SET Plan mandates new technology priorities, but instead is disconnected from future policy paths. It is then equally important to bring to the manufacturing phase and to commercial deployment concepts that have been successfully developed in the laboratory. European support to (incremental) innovation can help to bridge the 'valley of death' and to bring to the market first prototypes of new technologies. Stimulating the 'innovation machine' today guarantees further incremental innovation in the future and a wider technology set to choose from in achieving the decarbonization objective.

5. Conclusions and recommendations

Challenges for policy makers are huge if the EU climate policy goal of reducing GHG emissions to 80-95% below 1990 levels by 2050 shall be reached. In the light of these challenges this report develops and discusses possible paths for a renewed EU energy technology policy. There is no doubt that a new and stable energy technology policy design for the post-2020 period is needed. It is, however, not clear how exactly it will address limitations of the current 2020 framework while, at the same time, taking account of fierce global competition in markets for clean technologies. Moreover, as market actors are calling for a new technology policy framework *now*, the policy will likely be negotiated in times of financial crisis and also institutional frictions in the EU, of which no one can predict its duration.

Departing from a reference case, i.e. the continuation and extension of 2020 policies to the 2050 horizon, we identify two possible directions for a future EU energy technology policy. A first path building on a *strong carbon price signal* will mainly involve technology-neutral support to innovation. After having delivered its initial push, the SET Plan as an instrument to prioritize among technologies and projects ceases by 2020. It would rather function in a "light" version as a platform for open access information exchange and stakeholder coordination and cooperation. In contrast, for a second policy path departing from a *weak carbon price signal* and technology targets, directed push will play a major role to enforce targets and action will predominantly come from decentralized, national initiatives. In this path, an advanced SET Plan would also provide the basis for the determination of an optimal portfolio of low-carbon technologies, as well as for the optimal allocation of public (especially European) funds.

No policy path is clearly superior to another. Our evaluation of these policies shows that whereas price signals are, in theory, the most cost-efficient way to achieve climate goals, in practice the signaling effect of carbon prices might not be strong enough. Policymakers face considerable difficulties to implement 'high-enough' prices and to include all GHG emissions into the scheme. Technology targets and directed push, on the other hand, have a relatively larger potential to enhance green growth and to give (even if biased in magnitude) strong signals to investors. Moreover, technology targets could account for different national technology push programs and adjust the burden of decarbonization among Member States. In times of economic crisis and institutional frictions, these burden sharing and cooperation mechanisms increase the robustness and implementability of technology support.

In a bigger perspective, two major concerns, adding further uncertainties, appear. First, it is not guaranteed that – given the triangle of energy policy goals with decarbonization, security of supply and competitiveness – long-run energy policy will maintain its decarbonization focus. *Shifts in paradigm of EU energy policy* away from decarbonization and in favor of competitiveness might weaken carbon pricing mechanisms, calling for an even stronger technology support. Similarly, a shift in favor of supply security requires a stronger push for decarbonization technologies to achieve balanced energy portfolios, as well as a strong push for enabling technologies such as networks to guarantee properly working energy systems. Second, *technological revolutions*, such as a possible global shale gas revolution, could result in the 'rational' price of carbon falling extremely low.

A renewed post-2020 SET Plan should allow for all possible future policy paths. The fact that there are many possible future policies and uncertainties not recognized in 2050 roadmaps illustrates that the EU policy might change over the course of achieving decarbonization by 2050. A renewed SET Plan should not exclude the possibility to act within a certain future context. It should be more focused than the current SET Plan and provide the basis for planning and prioritization among decarbonization technologies. In the first step and similar to the current model, stakeholders from individual sectors could work together within Industrial Initiatives to identify technological progress and future research needs. In a second step, priority technologies that (a) are key to achieve 2050, and/or (b) can help to support green growth within the Union should be identified based on a *comprehensive approach across sectors*. Such targets have to be determined by carefully analyzing growth potentials of European manufacturers and the degree of competition they face from foreign clean technology producers. Selected technology targets and EU funding of innovation should then be in line with the SET Plan prioritization.

Pushing energy efficiency enhancing technologies dominates other push strategies in terms of both feasibility and robustness. Without detailed cost- and technological data at hand, disaggregated technology-specific recommendations as to what technologies and research activities to push are not possible. However, from our analysis we can draw a conclusion that generally holds. A prioritization of low-carbon *production* technologies entails high risks of picking wrong winners. In contrast, pushing energy efficiency enhancing technologies, first, is politically feasible: Opposing to a push for production technologies that often would benefit certain Member States in which major suppliers are located, energy efficiency enhancing technologies benefit <u>all</u> industries independent of geographic location and create jobs throughout <u>all</u> Member States. Second, such push is robust with respect to future energy market developments: Consuming less is a no-regret policy and minimizes system interdependences of a directed push.

The creation of options for technology breakthroughs has to be a main pillar in any future SET Plan. While strategies for technologies close to the market rely on shorter-run benefits like green growth stimuli up to 2020 or 2030, such push strategies have to be accompanied by long-run funding commitments for a wide range of immature technologies that might be successfully deployable after 2030 and towards 2050. Because the stage of innovation involves basic research and very early R&D, i.e. projects that entail a low chance of success but a sufficiently high pay-off if successful, the argument for a broad technology funding becomes important. Over time and as the probability of success increases, funds should become more concentrated. Such funding of potential technology breakthroughs will not lead to lock-in effects or stranded investments once a changed SET Plan mandates new technology priorities, but instead is disconnected from future policy paths.

The future energy technology policy also has to present a reliable and credible framework to investors and innovators, and also to consumers, who ultimately pay for these policies. In this vein, we present several additional "no-regret measures" being valid for any future policy. Policies should create options for technology breakthroughs and bring successfully developed concepts to the market, enable an attractive and stable business environment, the limited public money needs to be spent wisely, new EU funding sources (such as the increased use of income generated through the auctioning of emission allowances) should be considered, and there is a need to remove barriers to behavioral change.

In contrast, there might be some "regret measures" related to industry and trade policy. Current trade disputes related to clean technologies illustrate the complexity of such policies – there is a fine line between supporting technologies and subsidizing industries. Any industrial or trade policy favoring European players, therefore, must be debated and designed with care and rationales for introducing such measures should only relate to environmental or innovation externalities.

Whatever way taken towards 2050, this analysis shows that a variety of policy fields and instruments can be employed to govern future energy technologies and decarbonization. In times of financial crises and institutional frictions, more aggressive and directed technology policy intervention can be justified.

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Appendix A-1: Pathways towards 2050

(a) Energy Roadmap 2050

		REFERENCE	CPI	High EE	HIGH RES	Diversified Technologies	Delayed CCS	Low Nuclear
GDP & population		GDP growth of 1.7% p.a. EU population of around 515 Million in 2050 EU						
Fuel prices (scenarios included)		Oil price: 106 $/barrel in 2030 and 127 $/barrel in 2050 (in year 2008 dollars)		Oil: 70 $/bbl Gas: 49 $/Mbtu Coal: 21 $/ton. in 2050 (in 2008 USD)				
Sources (generation)	**RES**	40.3%	48.8%	64.2%	83.1%	59.1%	60.7%	64.8%
	Nuclear	26.4%	20.6%	14.2%	3.5%	16.1%	19.2%	2.5%
	Fossil/CCS (CCS viable from)	33.3% (2030)	30.6% (2030)	21.6% (2030)	9.6% (2030)	24.8% (2030)	20.1% (2040)	32.7% (2030)
Transport electrified by 2050		NO		Partly, for transport according to White Paper on Single Transport Area COM2011(144)				
2050 power demand		4130 TWh	3951 TWh	3203 TWh	3377 TWh	3618 TWh	3585 TWh	3552 TWh
Energy efficiency & Infrastructure		According to latest Energy Efficiency Plan in CPI		Energy intensity improvements around 2.5% p.a.				
Carbon price		Around 50 €(08)/tCO2 in 2050		234 €(08)/tCO2 in 2050	285 €(08)/tCO2 in 2050	265 €(08)/tCO2 in 2050	270 €(08)/tCO2 in 2050	310 €(08)/tCO2 in 2050
Climate goal		- 40% emission by 2050		85% emission reduction by 2050				

- **Baseline** (CPI scenario on which all the others build): 2020 horizon: 20-20-20 targets, existing ETS and non-ETS policies, etc. // 2025+ horizon: carbon prices determined such that 2050 targets are reached, equal prices/values for ETS and non-ETS // increasing fuel efficiency in transport sector
- **High energy efficiency:** Political commitment to higher energy savings and additional strong requirements and obligations
- **High RES**: Strong support measures (both MP and TP) // also facilitation and enabling policies (permitting, preferential grid access)
- **Diversified technologies**: No technology preferred // driven by strong carbon pricing scheme
- **Delayed CCS**: Similar to 'diversified supply technologies' with delayed CCS deployment
- **Low nuclear**: Similar to 'diversified supply technologies' without any new built nuclear

(b) Alternative roadmaps

		ECF 40%RES	ECF 60%RES	ECF 80%RES	Greenpeace E(R)	Greenpeace Adv. E(R)	IEA BLUE	IEA 2DS	Power Choices
GDP & population		GDP growth of around 2 p.a. (doubling of GDP by 2050) EU population of around 500-575 Million in 2050 EU							
Fuel prices		Mostly base on IEA world energy outlook 2009 projections for 2030 of Oil: 115 $/bbl Gas: 15 $/Mbtu Coal: 109 $/ton Uranium: 8€/MWh							
Sources (generation)	**RES**	40%	60%	80%	88.5%	97.3%	55%	71%	40%
	Nuclear	30%	20%	10%	0%	0%	29%	21%	28%
	Fossil/CCS (CCS viable from)	30% (2020)	20% (2020)	10% (2020)	11.5% (no CCS)	2.7% (no CCS)	16% (2020)	8% (2020)	32% (2025)
Transport electrified by 2050?		YES, mostly			YES, mostly	YES, earlier and to higher extent than in E(R)	YES, partly	YES, mostly	YES, mostly
2050 power demand (for their regional scope)		4900 TWh			3572 TWh	4274 TWh	3636 TWh	4862 TWh	4800 TWh
Energy efficiency & Infrastructure		All studies assume huge energy efficiency improvements and (power) infrastructure that does not constrain scenarios outcomes							
Carbon price		Ranges by assumption 0-40 €/tCO2: at an avg. of 20-30 €/tCO2 between 2010 and 2050 electricity costs in RES scenarios equal baseline			8.5 in 2015 to 41.5 €/tCO2 in 2050		43 in 2020 to 83 $/tCO2 in 2050	30-50 in 2020 to 130-160 $/tCO2 in 2050	25 in 2020 to 103 €/tCO2 in 2050
Climate goal		- 80% emission to 1990			- 80% to 1990	- 95% to 1990	- 75% to 2005	< + 2°C	- 75% to 2005

Roadmap	Scenarios	Emissions 2050	Scope
ECF Roadmap 2050 (from ECF)	Baseline	80% less to 1990 in all scenarios	EU-27 + Norway + Switzerland
	40% RES (RES share is an input)		
	60% RES (RES share is an input)		
	80% RES (RES share is an input)		
Energy (R)evolution (from Greenpeace)	Reference	16% less to 1990	EU-27
	Energy (R)evolution	80% less to 1990	
	Advanced Energy (R)evolution	95% less to 1990	
ETP 2010, Blue Map (from IEA)	Baseline	8% less to 2007	OECD Europe plus World
	BLUE	75% less to 2007	
ETP 2012 (from IEA)	6DS (worst case)	+ 6°C	OECD Europe plus World
	4DS (baseline)	+ 4°C	
	2DS (vision)	+ 2°C	
Power Choices (from Eurelectric)	Baseline	Not calculated	EU-27
	Power Choices	75% less to 2005	

Appendix A-2: The SET Plan and investments in low-carbon RD&D

The SET Plan

The SET Plan adopted in 2008 has been a first step towards establishing an energy technology policy for Europe. This so called "technology pillar" of the EU energy and climate policy aims at accelerating the development and deployment of low-carbon technologies. Its implementation started with the establishment of the *European Industrial Initiatives* (EIIs) which bring together industry, the research community, Member States and the Commission.[22] Within these Initiatives, strategic objectives have been formulated based on *Technology Roadmaps* that identify priority actions for the decade from 2010 to 2020. More specific *Implementation Plans*, containing descriptions of proposed RD&D activities, as well as suggestions about potential funding sources, are developed regularly for three-year periods. Comparing the current level of expenditures with that necessary to deliver the priority actions up to 2020, a financing gap of EUR 47-60bn has been estimated (Table 3).

In parallel, the *European Energy Research Alliance* (EERA) has been working since 2008 to align the R&D activities of individual research organizations to the needs of the SET Plan priorities, and to establish a joint programming framework at the EU level in order to use available research capabilities efficiently.

To support the SET Plan, the *Strategic Energy Technologies Information System* (SETIS) aims at establishing an open access information system on low-carbon technologies and capacities for innovation. Regular publications include the Technology Mapping (in-depth description of the state-of-the-art of low-carbon technologies, current RD&D activities, industry structure, etc.) and Capacities Mapping (estimation of private and public R&D investment in the priority technologies of the SET Plan). SETIS also works with the *European Technology Platforms* (ETPs), led by the industry, who help defining research objectives.

Investments in RD&D of low-carbon technologies

The scope of energy technology policy is large. Although at present of the total EUR 3bn spent annually on non-nuclear energy R&D in the EU about 70% is funded by the private sector, public co-funding inherits a multiplier and catalyzing effect. The major part of public funding, about 80%, is provided by Member States and only about 20% by the EU, or 7% of the total EUR 3bn spent annually – which equals less than EUR 160mn per year (see Figure 2). These numbers illustrate that, first, effective policies have to exploit Member State and EU sources, and second, not only the amount of technology funds, but the entire EU-wide regulatory framework from R&D to commercialization have to form an environment in which private spending in clean technologies pays off. Total EU funding during the last years remained at quite stable proportions with some increases for solar technologies. Especially for wind, recent increases in innovation expenditures can mainly be attributed to the corporate sector.

Several points emerge from Figure 2. The example of nuclear fusion shows that there is no private funding, and public funding is shared almost equally between

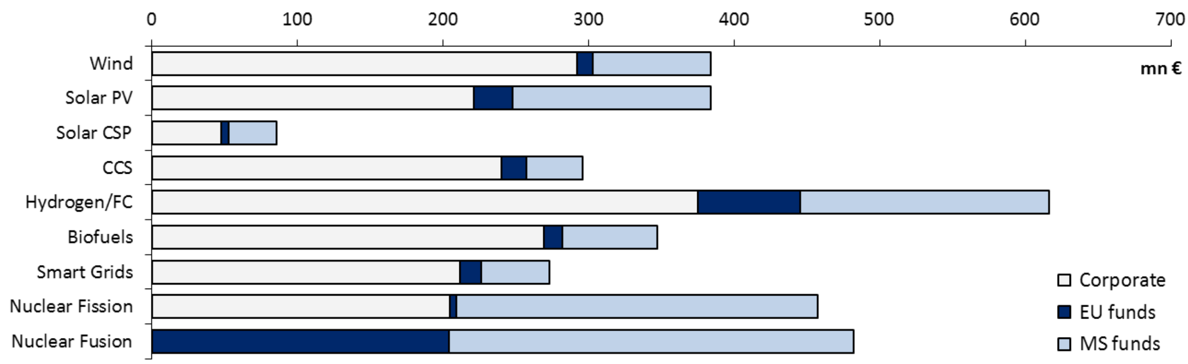
22 These EIIs include the European Industrial Bioenergy Initiative, the European CO_2 Capture, Transport and Storage Initiative, the European Electricity Grid Initiative, the Sustainable Nuclear Initiative, the Solar Europe Initiative and the European Wind Initiative.

the EU and Member States, as no company believes that it will be commercial in anything but the distant future. In contrast, the high level of private RD&D in hydrogen and fuel cells is largely driven by the automobile industry, whose large global companies and research intensity greatly exceed that of the electricity industry.

Table 3: Current funding and estimated financing needs for key SET Plan technologies [mn EUR /yr average]

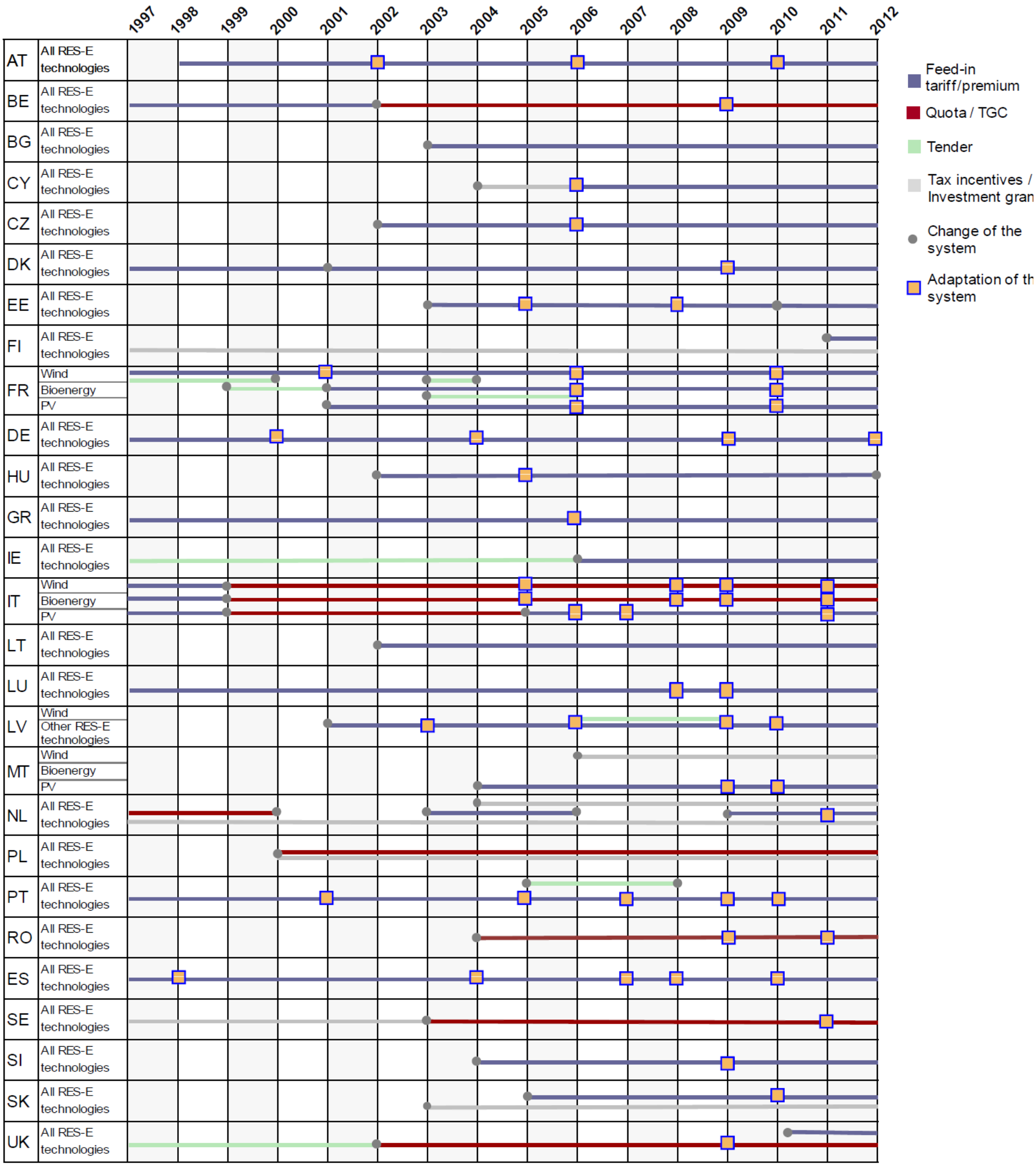
Sector	Public EU current	Yearly total current	Financing need identified in SET Plan
Hydrogen and fuel cells	70	620	500
Wind	11	380	550
Solar (PV and CSP)	32	470	1,600
Bio-energy	13	350	850
Smart grids	14	270	200
CCS	17	290	1,050-1,650
Nuclear fusion	204	485	
Nuclear fission – generation IV	5	460	500-1,000
Smart cities	n.a.	n.a.	1,000-1,200

Figure 2: Investments in RD&D of low-carbon technologies



Source: Own depiction using data from the "2011 Capacities Map" published by the JRC [2007 data]

Appendix A-3: National RES-E support instruments



Source: Ecofys et al. (2011)

Appendix A-4: Conclusions Industrial Council meeting (based on report version "V0", Sept. 2012)

Serge Galant
Technofi

Background: The present annex aims at shedding light on the first round of discussions about the preliminary report on "An EU energy technology policy towards 2050".

The issue: The discussions can be summarized as follows: "the EU needs to evolve from existing policy instruments by adjusting the SET Plan towards a long-term, technology push, energy system-oriented policy at EU level, mixing several ways to fund it".

What lacks in the first draft report: completeness issues?

The present study initiates a changed management process (improve existing energy policy). To make this change process successful, the process must follow three steps: (i) clearly states what must be abandoned from the past, (ii) describe what is the long term "dream" from this technology policy, and (iii) define the first intermediate policy target(s) which must be reached to make the long term dream comes true.

The report must therefore address the following questions:

- What are the energy technology policy components at EU level which have failed, on the basis of indisputable data to demonstrate it?
- What is the collective dream for the revamped energy technology policy? From the discussions during the hearing, it can be described as "a trade-off between environment-driven orientations at the least cost to implement them, provided that the resulting technology is manufactured in Europe". This requires shaping up the long term dream with an appropriate wording (how to describe the new policy orientations: CO_2-free economy, use of renewable, energy/resource efficiency, others…)
- When is the first successful step located (2020, 2030, other?) and what is the indisputable targets which must be reached to make players confident that the long term policy goals will be met.

Comparing the boundary conditions that Europe must face to design and implement such energy technology policy with past successful ones in other continents could help support the new policy orientations.

The first example is the USA where ARPA-E is replicating what has been done by DARPA in Defense technologies and the SBIR in manufacturing technologies:

- Public investments address generic technologies that can be applied in many areas of the energy world (energy storage, smart control devices, metering, etc…)
- Overarching goals drive the first steps of the technology learning curve (over the twentieth century, it has been (proven or fictitious) national security concerns in the USA): the purchase of the first/second generation technology is subsidized by public orders which accept to pay a very high price to construct the learning curve (Defense orders in the case on security concerns)

- Next, technology costs are driven down by volume effects and further innovation in order to reach a market price level where the free market is ready to purchase.

There is recent evidence that the USA is addressing the development of a value chain in biofuels for commercial aircraft (a significant share of the air travel cost) by constructing the learning curve through Defense needs (use of biofuels to reduce the cost of Defense operations in naval and aircraft operations).

The second example is Japan where consumers amortize the R&D costs of new technologies (in many sectors) by placing orders located in the internal market, before they are sold abroad at reduced costs.

For technology push policies, a typical drawback (push the winners) must be underlined: it very often kills opportunities for the development of breakthrough technologies which have a higher pace of improvement when first available.

Last but not least, the aftermath of the present economic and financial crisis will restrain public funding which must be compensated by private contributions. Europe is so far lagging.

What is still fuzzy and must be clarified?

The scope of the work is "energy technology policy for an innovative energy system".

For past energy technology policy failures, provide examples at Member State and EU level. For past policy successes, provide examples at Member States (nuclear in France, wind in Denmark), and EU level.

The proposed policy options, as presented in the first draft report, might oversimplify the policy issues raised by the 2050 Agenda. Make sure that interactions between policy components are clearly appraised: the example was given for two policy implementations the ETS and Subsidies for renewables that are annihilating each other benefits.

The retained policy options must be framed with respect to past energy history. What went wrong in the past 20 years comes probably from the following paradox:

- Member States have their own energy technology policy,

- The EU invests between 15 and 20% above the Member States investments,

- EU investments should address system issues which hamper the implementation of the three pillars of EU energy policy (market efficiency, security of supply, renewables), which in turn mean stronger and stronger interdependences between Member States,

- National energy policy makers do not want to claim that they depend on other Member States (which is less and less time – see the single electricity market)

What are the potential incoherencies in the first draft which must be addressed?

The report aims at highlighting policy options: it should avoid recommending one of them, but should pinpoint the potential benefits and drawbacks of each of them (or a combination).

A mix of policy options is a highly probable recommendation due to the diversity of the energy landscape in Europe whatever the single options to be proposed. The main recommendation for policy option is: market is as stable (robust?) as possible since the journey towards 2050 will be long and bumpy.

One of the challenge is to design a technology push (system-oriented) policy at European level which is as stable as possible irrespective of past technology choices (or absence of choices) at Member States level.

Policy stability can be reached by addressing (generic) crosscutting technologies at EU level. They have multiple applications which make the efficiency of public investment much higher (not all fields of applications can go wrong at the same time). Examples of such generic technologies are: storage, metering, remote digital control, etc.

Since the issue is to promote an innovative energy system in the single EU market, there are many non-technological barriers which can hamper the market acceptance of the energy technologies (IPP, business models, regulations, public acceptance). They must be addressed in the report and, once validated as critical, very early in the development cycle.

Appendix A-5: Conclusions project advisors (based on report version "V0", Sept. 2012)

Wladyslaw Mielczarski
Technical University of Lodz

Technologies. You have correctly identified that in practical terms we have four main technologies: nuclear, CCS, RES and energy efficiency (EE). The current situation with nuclear, in particular after Fukushima, indicates that it is not likely that nuclear will play a significant role in Europe in the future. There are also many concerns relating CCS. From the engineering point of view we can catch CO_2 in power stations, although at high costs. We are also able to transform CO_2 gas into a liquid and transport it by pipelines. The problem lays in CO_2 storage (geological and legal problems). We do not know what will be the reaction of CO_2 with geological structures after several hundreds (or thousands) years. Europe is densely populated so it will be difficult to find safe storage sites. There are also legal concerns. Who will be owner of CO_2 when pumped underground? Do we have to create some kind of a gas storage operator? How can we impose the obligation to finance such an operator and his activities? Who can provide the insurance for such storage? And many others.

Achievability of climate policy targets. In practice, we have only two technologies (or precisely speaking groups of technologies): RES and EE. Of course, EE is the best measure as the energy not generated is the cleanest. However, many countries will need more energy, so in the best case, we can assume that demand will remain stable, but a more reasonable assumption is that demand will grow annually at a rate of 0.5% for the developed European countries and 1% for new Member States. So the reduction of emissions by 80%, or the zero emission power industry, will require increasing RES production from the current 10% to 100%. Is it the realistic assumption? I doubt. Not only regarding costs, but also from the technical point of view. The next question appears. Can we expect breakthroughs in technologies? Rather not. Energy storage or smart networks can lead to the better utilization of the existing power production assets but cannot produce energy themselves.

Support systems for RES. Despite the difficulties we face in the achievability of climate policy targets, we should do the best to increase RES production. Before we go to the features of the best support system we should shortly analyze how the existing systems operate. There are two systems: feed-in-tariffs and green certificates. Both are examples of the open systems, i.e. the systems without expenditure caps, so it is very common experience that costs of RES subsidies exploded causing that some Member States started introducing a limitation on RES support. Italy, Bulgaria, Czech Republic, Spain and Poland are among such countries. The current support systems are directed to the operation of RES separating RES from the competitive market, so if we introduced a Road Map for RES development, keeping the existing systems of subsidies, it would be a Road Map of competitive market limitation. RES can be outside the market when production is below 10%, but if we want to achieve 30% and more, RES must operate in competitive markets under the same rules as other producers. Currently, the decisions on support for RES is left to Member States and such decision can be changed by these countries sending misleading signals to investors.

What should be the main features of the efficient support systems for RES? They should be: (a) stable, (b) uniform in all Member States, (c) allowing for support of large-scale projects such as wind farms in the North Sea and smaller and micro-scale generation; (d) robust to the impact from other system inefficiencies as for example the EU ETS; (e) based on solidarity of support for RES i.e. commitment to the RES funds in proportion to GDP; (f) and - the most important - the support should allow such generation operating in competitive electricity markets. It would be valuable for your report if you can give some examples of such support systems.

Technology impact. There are many fears, in particular recently expressed, that investing in RES in Europe, we are losing competitiveness compared to Asia as the production of RES installations leak to other countries with lower labor costs. It is true to some degree. Europe cannot be competitive in labor cost with Asia and Africa but by controlling the main elements of the chain value we can gain and can keep the technological advances. In the following example you can see elements of the value chain for PV cells production and installation with the suggestion, which elements will stay in Europe or will leak (or already leaked) to Asia or in future to Africa: (i) R&D – Europe // (ii) Design of RES equipment – Europe // (iii) Production of equipment (automation and robots) for RES assembly factories – Europe // (iv) Production of silicon – Asia/ Africa // (v) Manufacturing of PV cells – Asia/ Africa // (vi) Design of installations for PV-cells – Europe/Regions // (vii) Construction of installations for PV-cells – Europe/Regions // (viii) Service and maintenance of PV-cells – Europe/Regions. As you can see, from eight elements of the chain value, six (the most profitable) are in Europe.

François Lévêque
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This report on EU energy technology policy is sound and elegant. The addressed questions are clearly stated as well as the answers given by the authors. My main comment is that the definition of the energy technology policy is too broad. It encompasses both R&D and innovation diffusion. Moreover, tradable permit systems and carbon tax are viewed as energy technology policy instruments. This is astonishing for these instruments are merely seen by economists as technology-neutral. According to the authors, the absence of technology policy is a technology policy and any environmental policy instrument is an energy technology policy instrument. The frontier between energy policy and energy technology policy is therefore blurred.

My second main comment deals with the insufficient interest of the authors for data. Their political science approach is very legitimate and is very appropriate with the topic. However, this is not a reason to neglect numbers and findings based on quantitative analysis. The absence of references on patents is an example. Over the past ten years, research on patent applications and diffusion regarding green and conventional energy technologies has flourished. Its econometric findings have provided interesting insights on the respective role of technology push and demand pull as well as on technology transfers.

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Matthias Finger is also Professor at the Florence School of Regulation and full Professor at the Ecole Polytechnique Fédérale de Lausanne (EPFL), where he directs the Chair Management of Network Industries. After having been Assistant Professor at Syracuse University, New York (1989-1991) and Associate Professor at Columbia University, New York (1992-1994), Matthias Finger was appointed Full Professor at the Swiss Graduate School of Public Administration in Lausanne in 1995. There he developed his research on the transformation of network industries in the postal, telecommunications, railways, electricity, air transport, and water sectors. In his research, he reconciled the liberalization of these sectors with public service objectives by means of new regulatory arrangements, while at the same time promoting a more entrepreneurial behavior of the operators. Matthias was appointed to his present position of Full Professor at the EPFL in October 2002. He is also Professor at the EUI since 2010. Matthias edits the Journal Competition and Regulation in Network Industries. Matthias received Ph.D. in Political Science in 1988 and his Ph.D. in Education in 1986, both from the University of Geneva.

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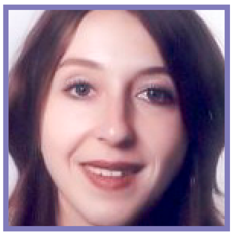

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