THINK《《

Topic 1

Public Support for the Financing of RD&D Activities in New Clean Energy Technologies

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SEVENTH FRAMEWORK PROGRAMME

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Executive Summary

Existing demand-pull measures, namely carbon pricing and the Renewables Directive, will be insufficient to deliver an adequate and timely level of private RD&D in new clean energy technologies. Thus, in order to reach the EU 2020 and 2050 climate objectives, there is a need for direct public support to innovation. Public funds need to be spent wisely, given their limited availability. This report contributes a discussion on (i) how to build a balanced portfolio of RD&D projects; (ii) how to choose among financing instruments; and (iii) how to design public support to minimize the risk of 'funding failure'.

In **Chapter 2**, we discuss the design of the optimal portfolio of existing and new low-carbon technologies given limited public funds. A **balanced portfolio of research, development and demonstration (RD&D) is needed to accelerate the com-**mercialization of more mature technologies that have a large expected potential while, at the same time, adopting a persistent research strategy to develop immature technologies. Project selection should be based on the expected reduction in CO_2 emissions over the relevant time horizon per euro spent. Pursuing competitive parallel projects is desirable when each has a low probability of success but a sufficient expected value, while where the probability of success is high, funds should be more concentrated and competition among alternative research paths becomes less relevant. Cooperation among innovators (with possible competition among consortia) facilitates high-cost projects and avoids costly duplication of RD&D. Cooperation and coordination among Member State and EU support policies need to be improved.

Chapter 3 discusses the rationale for the use of technology-push instruments as well as the optimal choice among these financing instruments to support pre-deployment innovation. Conventional subsidies in the form of grants and contracts should only be awarded to socially desirable innovation that will not be undertaken otherwise – they are an instrument of last resort when all else fails, but may well be needed for immature low-carbon technologies. Alternative, less costly, financing instruments (i.e. public loans and loan guarantees, public equity, technology prices, or benefits related to RD&D investments) are able to meet the support needs of certain types of innovation. Support needs of innovation, thereby, are related to the funding gap to be covered by the public sector, the potential needs to target a particular technology, the level of flexibility required in (re-) directing funds to alternative innovation projects, and/or being suited to supporting certain types of innovating entity.

Chapter 4 addresses the design of the support and release of public funds, including the assessment of performance of both projects and funding support. Financing instruments need to be implemented in a way that encourages efficiency while not discouraging participation by the private sector. If possible, public funds should be allocated by competition, providing incentives for efficiency in RD&D and to reduce the role of the public sector in 'picking winners'. Public funding should be output-driven unless this deters innovators from undertaking the project, making the release of funds conditional on performance. Project progress needs to be monitored using carefully designed Key Performance Indicators. The institutions set up to allocate funds to clean energy RD&D should be lean and flexible enough to avoid institutional inertia and lock-in.

In **Chapter 5**, we present selected case studies, representing three different types of innovation processes. They demonstrate the criteria guiding the selection of the corresponding innovation projects, the allocation of funds to them, the burden sharing among stakeholders, and the design of public support.

Finally, **Chapter 6** concludes and provides recommendations.

Introduction

If the EU is to meet its 2050 climate objectives, the future energy mix will have to rely on a significantly increased share of low-carbon (low-C) generation technologies, much of which is not yet competitive (nor even technically proven). All sectors including energy, transportation, energy-intensive industries and agriculture will have to contribute to the necessary reduction in greenhouse gas emissions. A diverse portfolio of clean technologies has to be employed at a large scale and investments enhancing energy efficiency are needed. Substantial additional RD&D activities are required in order to achieve the ambitious target of limiting global warming to a maximum of two degrees Celsius above pre-industrial levels and cut emissions by 80% or more for industrialized countries (see also Stern, 2006; Allen et al., 2009; IEA, 2010). Substantial policy actions are also required (Jones and Glachant, 2010).

Research intensity in energy is low by comparison with many other sectors,[1] and in the past was heavily oriented towards nuclear fission and fusion, with very modest amounts spent on other low-C technologies. At present a surprisingly high 70% of non-nuclear energy R&D in the EU is private, and of the 30% that is public, 80% is provided by Member States and only 20% by the EU, or 6% of the total €3 billion spent annually – less than €200 million/yr (see Figure 1). While Member States roughly maintained the real level of RD&D investments spent on non-nuclear energy at around €(2007) 1.5 billion/yr, expenditures in nuclear technologies fell from nearly €(2007) 4 billion/yr in 1985 to less than €(2007) 1 billion/yr in 2007 (see Figure 3 in the Annex). France, Germany,

Italy and the UK accounted for three-quarters of the EU total.[2]

Several points emerge from Figure 1. The example of nuclear fusion shows that there is no private funding, and public funding is shared almost equally between the EU and Member States, as no company believes that it will be commercial in anything but the distant future and the cost of the ITER experiment is so large as to dwarf what individual MS are willing to pay. To that extent it is an excellent model of an agreed collaborative form of co-funding a public good. In contrast the high level of private RD&D in hydrogen and fuel cells (FC) is largely driven by the automobile industry, whose large global companies and research intensity greatly exceed that of the electricity industry.

Research intensity in the electricity sector collapsed with the privatization and liberalization of electricity markets. It is clearly easier to support risky R&D under state monopoly ownership (or regulated private franchise monopolies, as in the US before liberalization) as the costs can be passed through to captive consumers without explicit state funding. It is also easier to justify charging consumers for R&D that is directed to reducing the cost of future electricity supply within the country than for R&D that is directed to reducing global carbon emissions that will primarily benefit the rest of the world.

However, substantial additional investments are re-

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[1]   Whereas the R&D-to-sales ratio for the energy sector lies with 1.5% clearly below the industrial average of 4.2%, sectors such as the software or health industries show values well above 10% (Jaruzelski et al., 2005).

[2]   See EC (2009d), IZT & Frost and Sullivan (2006), and the IEA Energy Technology R&D Statistics (http://www.iea.org/stats/rd.asp) for detailed information on RD&D investments in low-C technologies. Different Member States emphasized different clean energy technologies. Figure 4 in Annex A shows that while France, and to some extent also Italy, spent more which might be expected by the size of their electricity sector, Germany and even more so the UK spent less. Relatively speaking, Denmark made the highest contribution per kWh of either generation or consumption.

Figure 1. Investments in RD&D in low-carbon technologies (2007 data) - Source: EC (2009c)

* For the Smart Cities Initiative no data were available.
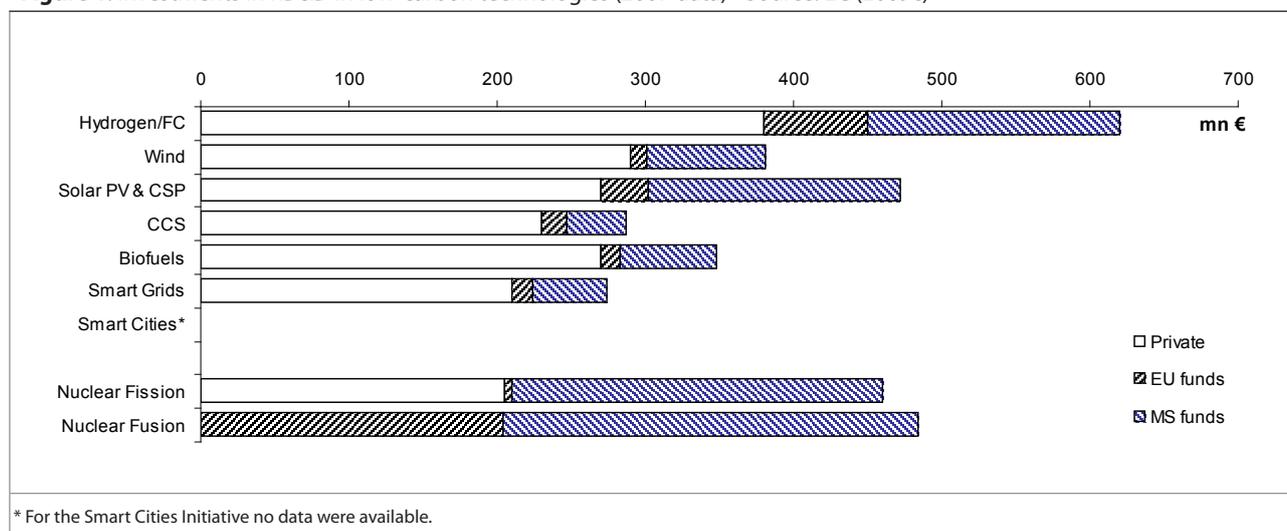
quired in order to approach to the ambitious two-degree target. The financing gap between recent expenditures and those needed to finance innovations in key technologies as identified in the Strategic Energy Technology Plan (SET Plan) amounts to €47 to 60 billion (EC, 2009c). Annex B provides more information on the current financing arrangements of Industrial Initiatives. For reasons discussed below it is most unlikely that the current high private share can be sustained at near treble the scale, and additional sources of public funding will likely be required.

Does an adequate portfolio of existing and new clean energy technologies develop spontaneously? There are several reasons for doubting this. Reducing CO_2 emissions is a global public good, and unless these reductions are adequately rewarded, or the damaging emissions properly charged, the incentive to develop low-C technologies will be too low. Hence, private innovators' RD&D activities in low-C energy technologies rely on the future willingness of governments to impose a charge on CO_2 emissions. In the absence of any other market failure, a credible and appropriate carbon price should provide sufficient incentives for innovators to invest in RD&D of new clean energy technologies. However, the implemented EU emission trading scheme provides neither a sufficiently high current price nor a credible and adequate future carbon price (see also Aghion et al., 2009).

Even if this set of problems were overcome, there remain critically important market failures, some of which apply to many forms of private R&D, and some of which are more specific to low-C R&D.[3] These include the standard problem with R&D (i) that without any further support, innovating firms cannot fully appropriate the returns from their RD&D activities due to existing social, market and/or network spillovers. In addition, (ii) innovations in clean energy technologies often pair very high capital requirements with substantial economic, technical and regulatory uncertainties, which hampers access to finance; (iii) past R&D and learning economies enjoyed by existing energy technologies make it harder for new technologies to achieve unit cost levels at which they can compete in the market; particularly as companies

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3   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-C innovation. For an overview on theoretical analyses of the effects of environmental policy on technological change see Jaffe et al. (2002). For a detailed discussion on the funding gap in the financing of R&D and innovation originating in imperfections of financial markets see Hall and Lerner (2009).

tend to focus on innovations which are expected to lead to more rapid pay-offs whereas the optimal portfolio has a 2050 (or even longer) time horizon; and, finally, (iv) there is a tension to resolve between the need to encourage private sector R&D, which companies argue requires strong enforcement of intellectual property rights (IPR), with the desire to make the resulting discoveries as widely available as possible in developing countries so that they can be deployed at scale.

Without further public support, the level and timing of private investments in the development of new clean energy technologies will be socially suboptimal. These market failures encourage private inventors and investors focusing on projects that pay off in the near term, whereas the optimal portfolio has a considerably longer time horizon – certainly looking ahead to the 2050 target. While the potential market for low-C energy 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 will be far more important than for other types of R&D, such as in the pharmaceuticals sector, that meets new needs or creates products for which there are no close substitutes.

Although the EU's contribution to energy RD&D is modest, it can play a number of important roles. In particular, EU funding can encourage a coordinated increase in Member State's low-C energy research in promising areas; support high risk, high cost, long-term programmes that would be challenging even for the larger Member States; encourage cross-border partnerships to transfer skills from stronger to weaker partners; play a strategic role in rebalancing the portfolio of projects to offset any tendency that Member States might have to concentrate on a subset of more immediately prospective innovations; encourage the

wider dissemination of RD&D; and, finally, may create a more credible future funding environment by requiring joint agreements that take precedence over domestic funding allocations.

This report is the first in a series written under the EU FP7 project THINK. Its aim is to guide European energy policy makers in the framing and implementation of the SET Plan objectives, i.e. raising the level of RD&D in identified key technologies to deliver the highest social benefit given the inevitable constraints on funding. We focus on pre-deployment innovation, namely research, development and demonstration activities that need direct public support (i.e. technology-push rather than market-pull instruments) and belong to the highly risky stages of the innovation chain. This report does not discuss possible sources of the public funds required to meet the SET Plan objectives as these will be addressed in Topic 4 within the THINK project.[4]

In Chapter 2, we discuss the design of the optimal portfolio of existing and new low-C technologies taking account of the limited public funds available. Chapter 3 discusses the rationale for the use of technology-push instruments as well as the optimal choice among these financing policy instruments. Chapter 4 addresses the design of the release of public funds, as well as the performance assessment of technologies, innovation projects and funding support provided. In Chapter 5, we present selected case studies to illustrate the application of principles derived in Chapters 1-4. Finally, we provide conclusions and policy recommendations in Chapter 6.

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4   Topic 4 will discuss the impact of EU climate policies on the public budget of Member States taking into account all three pillars of EU climate policy, namely carbon pricing, the Renewables Directive, and the SET Plan.

1. Building the portfolio of RD&D projects to support the SET Plan

This chapter addresses the selection of projects building the optimal portfolio of RD&D activities in low-C technologies supporting the achievement of EU 2020 and 2050 climate objectives. Section 2.1 provides background information on the SET Plan; Section 2.2 discusses the trade-off between collaboration and competition in RD&D; Section 2.3 highlights the major factors determining the potential social returns of innovation projects; Section 2.4 provides a guide to project selection in the framework of the SET Plan; and finally, Section 2.5 addresses the issue of coordination of support policies among the EU and Member States.

1.1 The SET Plan

The EU's SET Plan is a response to the evident need to stimulate research and development in low-C technologies. The Plan covers eight Industrial Initiatives corresponding to eight technologies (or technology fields) identified as key to a future clean energy technology mix required to meet the 2050 climate targets.[5] Within these Initiatives, strategic objectives have been formulated based on Technology Roadmaps that identify priority actions for the next decade (2010 to 2020). More specific Implementation Plans are developed for three-year periods (starting with the first period running from 2010-2012). These Plans contain more detailed descriptions of proposed RD&D activities, as well as suggestions on potential

funding sources.[6] Authorities estimated a financing gap of €47-60 bn over the decade, comparing the current level of expenditures with that necessary to deliver the priority actions (see Table 1). Given the size of this financing gap, substantial additional funds will be required and projects prioritised, given the possible shortfall facing EU funds.

The SET Plan also distinguishes among different degrees of maturity of technologies; with Group 1 being close to market competitiveness with an expected mass market deployment in the short- to medium term (2010-2020), Group 2 comprises emerging technologies expected to become cost competitive between 2020 and 2035, while Group 3 consists of new technologies that are immature and not expected to become competitive before 2035. The relative importance of demand-pull to technology-push decreases as one moves from Group 1 to 3, and so EU-funding through the SET Plan will be primarily targeted at Groups 2 and 3.

As both EU and Member State public funds are limited, the main criterion for allocating these funds is to maximize the resulting social benefits, leveraging first MS public funds and ultimately private sector contributions. There are good reasons for making an initial allocation of funds to each sector, as comparisons across sectors are likely to be more difficult than across projects within sectors. As experience in project evaluation accumulates and confidence in the quality and predictive power of these evaluations improves, it will be possible to reallocate funds between sectors, from those with lower pay-offs to those with more promise.

The SET Plan puts strong emphasis on joint strate-

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5   See Annex C for an overview on SET Plan technologies (i.e. wind, solar PV/CSP, electricity grids, bio-energy, CCS, nuclear fission, smart cities and hydrogen/FC). A preliminary allocation of funds in the nearer-term to the designated technologies has been provided by the EC applying four selection criteria: EU added value, the willingness of actors to joint forces, potential market penetration of the technology in different time horizons, and its potential contribution to CO_2 reduction, security of energy supply, and competitiveness.

6   Currently, the time lag between a call for proposals and the start of a project may be up to a year and a half, and will need to be reduced to accelerate innovation.

Table 1. Current funding and estimated financing needs for key SET Plan technologies [€ mn/yr average]

Sector	Public EU current	Yearly total current	SET Plan resources needed
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
Carbon capture, transport and storage	17	290	1,050-1,650
Nuclear fusion	204	485	Under ITER?
Sustainable nuclear Generation IV	5	460	500-1,000
Smart cities	n.a.	n.a.	1,000-1,200
Total	366	3,325	6,250-7,550

gic planning and a more effective implementation of programs, since the analysis of the public spending under the EU FP6 clearly demonstrated a lack of transnational cooperation (EC, 2009c). Johnstone et al. (2010) find evidence that public environmental policies have had a very significant influence on developing renewable technologies, with different support schemes having different impacts depending on the stage of maturity of the technology. In addition to Member States public support, there is additional evidence that EU co-funding and collaboration will enhance the pay-off to R&D. Verdolini and Galleotti (2009) show empirically that energy R&D in one country produces beneficial spillovers to neighboring countries, and these effects are larger, the closer geographically, economically and socially the neighbors are. The EU fits these requirements admirably, and has the economic scale to make a substantial impact if Member States recognize the joint advantages of collaboration. Their findings are questioned to some extent by Braun et al. (2010) who find that energy R&D spillovers are primarily a domestic phenomenon (and international spillovers play a negligible role, which is of particular concern as developing countries are increasingly important contributors to CO_2 emissions). However, they also acknowledge important benefits of coordination concluding that "coordination of

R&D efforts, priorities, and the exchange of failure and success stories could avoid […] duplication and, moreover, accelerate overall technological progress." The SET Plan thus justifiably has coordination as one of its central objectives.

1.2 Collaborative RD&D or competing parallel projects?

The arguments for implementing cooperation rather than competition seem compelling – if many firms cooperate in a single RD&D joint venture they can better capture knowledge spillovers, reduce duplication, exploit economies of scale, and thus accelerate commercialization. The danger is that by agreeing on a single strategy they foreclose other options and reduce creative diversity. Evidence from various US programmes aimed at industrial collaboration suggests that they tended to concentrate on low-risk short-term projects as the ones most likely to be widely supported by the consortium, and avoided investigating disruptive technologies (e.g. fuel cells for vehicles) that would threaten existing market strengths.

At a theoretical level, Annex D shows some of the trade-offs between collaborative and competitive research in a very simple model. In allocating funds, the

funder can choose between concentrating resources on a single or very small number of projects, or diversifying by funding parallel projects following different strategies, with independent chances of success. As the probability of success increases, funds should be more concentrated. On the other hand, high-risk projects with a low chance of success (but a sufficiently high pay-off if successful) warrant increasing the number of parallel projects. In choosing between sectors where the expected benefits are the same, it seems preferable to bias funds towards riskier projects with the same expected return.

This is consistent with the empirical evidence: "one of the historic strengths of US science and technology policies has been their ability to accommodate uncertainty. Federal agencies have often supported multiple, competing technology pathways. In contrast, where government has sought to define technical attributes or design features and 'pick winners' in the marketplace, failure has been a common outcome" (Alic et al., 2003, p. 11).[7]

1.3   Estimating the potential social returns to a project

Factors determining the future social benefits of innovation include the rate of penetration of the corresponding technology, the size of the market, its reliability and the reduction in emissions and operation costs that it is expected to achieve, which, with the potential capital and operation costs determine the po-

tential future benefits of this innovation. The ultimate market size will be determined by the resource base and unit costs for this technology. Thus, the global resource base for concentrated solar power is huge (in terms of TWh of insolation), but the market is limited by the hours of sunlight (daily and seasonally) and the distance of prime sites from demand centres (North Africa being an attractive location in terms of W/m2 but distant from major demand centres). Wind is limited by wind speed (in the UK to perhaps an average in good on-shore locations of 2 MW/km^2) and the land take required. The land take for biomass is even more of a constraint while tidal stream has a limited resource base. Reasonable estimates are available for most technologies, although there is considerable uncertainty about some constraints, for example the location and size of reservoirs for storing CO_2.

The potential cost advantage is more difficult to determine, as it will depend in large part on relative rates of learning-by-doing and the ultimate physical constraints in terms of material requirements and thermodynamics. The importance of relative, rather than absolute, rates of cost reduction is often ignored – the early forecasts of the competitiveness of the British nuclear programme were predicated on an unchanging thermal efficiency of coal-fired power stations. In fact they were experiencing steady and cumulatively substantial improvements as turbine size rose from 60 to 660 MW units, undercutting any cost reductions in nuclear power.

Annex E works through an example to illustrate the relative importance of the various factors that will influence the social returns to an R&D project, highlighting the considerable uncertainty about almost all the relevant factors. If the R&D project is successful, it should lower the costs of some specified clean technology. The projected rate of capacity expansion of this technology turns out to be critical not only in de-

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[7]   The breeder reactor programme, discussed in Cohen and Noll (1991), is a paradigmatic example of the limitations of the public sector to efficiently conduct innovation and identify winning technologies. This programme was the major focus of US federal RD&D activity from the early 1960s until the cancellation of its demonstration in 1983. Authorities persistently overestimated demand and underestimated the required cost of the development of the technology. When costs exploded, the industry left the project and the federal government took complete control committing further amounts of public funds presumably driven by political considerations rather than socio-economic ones.

termining the future market size and hence future social value, but also in driving the pace of cost reduction through learning-by-doing, and hence the date at which the technology no longer needs subsidy. This should not be surprising, as the power of compound growth over long periods is enormous, and hence so is the projected future size of the market for the technology. Some reality checks on ultimate market penetration are therefore clearly needed.

Learning rates are important for determining total support costs and the date of commercialization, but higher learning rates lower the value of a current R&D project that lowers costs today, assuming that the resulting cost reductions lead to a lower cost base to which these learning effects are applied. Another way of putting the same point is that a given percent reduction in the initial cost as a result of the R&D project translates into a shorter period of time gained when exogenous learning rates are higher, and hence is worth less.

Discount rates have a predictably large effect on present values. So do diffusion rates, suggesting that policies addressing intellectual property will be important. Finally, the project success rate, whether it will penetrate the global market, and whether it creates an enduring improvement that can be built on, all have powerful effects on its value, as does the generosity with which global rather than EU benefits are valued and counted.

Ofgem's Low Carbon Development Fund (Ofgem, 2010) sets out a useful set of criteria for selecting projects to be supported by funds that it controls (that have been collected from electricity consumers). The projects should (i) accelerate the development of a low-C energy sector; (ii) create new knowledge that can be shared by the relevant users; (iii) have the potential to deliver net benefits to existing and/or future

consumers; and (iv) would not otherwise be adopted on commercial grounds. The SET Plan has wider ambitions than just delivering benefits to the electricity customers, but the principles are still valid.

1.4 Guide to the selection of projects within the SET Plan

1.4.1 Background

As highlighted above, the SET Plan contains eight Industrial Initiatives corresponding to eight promising low-C technologies. The SET Plan does not appear to have selected technologies, research paths and priority actions on the basis of cost-benefit analyses, making it difficult to prioritise if there is a short-fall in the funds forthcoming. Not surprisingly, given the current financial crisis, several Industrial Initiatives are encountering great difficulties in raising the sums needed to fund priority projects. Moreover, current European clean innovation policy seems tilted in favour of developing near-market technologies by large incumbent companies. Thus, tools like the Framework Programme, which were initially intended to support R&D, are now hosting an increasing amount of demonstration projects. All this confirms the need for a sound framework for selecting priority SET Plan actions.

This will require evaluating the different technologies' potentials and choosing suitable Key Performance Indicators (KPIs). As there is considerable uncertainty about the most cost-effective clean technologies over the period to 2050, it will be necessary to pursue a variety of research paths. As more information about their potential becomes available, some technologies may be abandoned and resources concentrated on a narrower range of options.

In many cases, particularly where it is not clear what

research strategy will deliver the required break-through or learning, it will make sense to pursue a number of parallel RD&D projects all directed to achieving the objective of the corresponding priority action, as described in Section 2.2 and Annex D. The expected value of any single project will be determined by its value if successful, V, per euro spent, and the probability of success, p, each of which are key determinants of the optimal portfolio. Comparing across technologies, some may have a high value per euro spent if successful but a low chance of success, while others may be more likely to succeed but deliver a lower value per euro spent if successful, possibly with the same expected value pV. The optimal number of parallel projects will increase as the probability of success of any of them decreases, holding constant the expected value, pV. For each priority action, its cost and probability of overall success will depend on the number of projects undertaken in parallel, and it is the optimal portfolio of parallel projects that should be considered when comparing options within and across technologies.

1.4.2 Project selection process

Priority actions to be funded should be selected at the beginning of each three-year period corresponding to new Implementation Plans, or more frequently if funds are to be reallocated within that period. The three steps to be followed within this selection process include (i) estimating the funds available, (ii) assessing the expected value of alternative projects, and, finally, (iii) selecting the portfolio of projects considering both mid-term (2020) and longer-term (2050) climate objectives.

The first step involves making a reliable estimate of the funds available over the planning period (i.e.

three years).[8] The degree of flexibility in (re-)allocating funds in response to the level of achievement of KPIs may be constrained by funding sources, particularly those from private companies with more narrowly focused interests and expertise. That is where the careful prior elaboration of the conditions under which public co-funding takes place is important.

In a second step, the expected value of alternative projects must be assessed based on a single evaluation criterion. The natural objective is to maximize the overall lifetime contribution of projects funded to GHG reductions given the limited funds available.[9] Thus, we are assuming that the benefits produced by a project (its value) correspond to the size of the reduction in CO_2 emissions it is expected to produce in the relevant time horizons compared to not adopting that option (and perhaps waiting for a more promising future project). The size of emission reductions caused by a project, in turn, depends on the contribution of this project to the development of new technological options, which can be assessed in terms of the time at which these options reach the deployment stage if successful, their probability of success, and the reduction in emissions that would result from their deployment. Prospective emission reductions in turn depend on the expected extra system costs associated with this technology per tonne of CO_2 it saves compared with those of competing technologies, as that

8   In some cases longer term funding commitments may be available, where the funds can be sequenced over successive three-year periods, while if possible preserving the option of reallocating funds within and between technologies as information about the expected returns to further RD&D is gathered.

9   There is an interesting question about whether the CO_2 reductions should be discounted, and if so at what discount rate, but as a first approximation, as the damage done per tonne of CO_2 is rising at the rate of interest (at least until atmospheric CO_2 concentrations stabilize), discounting the damage avoided is equivalent to summing the total CO_2 reductions over the relevant time period (e.g. until 2050). Obviously projects should be compared over the same time periods, and it may give assurance to have the totals available up to intermediate dates, as nearer term projections are likely to be more reliable.

will affect the size of market penetration achieved, and the rate at which it is deployed.

System costs caused by a technology include both direct and indirect costs, such as the extra reserves or storage required to achieve the desired level of security of supply in the system as a consequence of the deployment of the technology. These depend, among other things, on the reliability, availability and intermittency levels of the newly deployed technology.

Estimating the contribution of a project to the development of new technologies and the expected contribution of the latter to the reduction in CO_2 emissions to 2020 and, especially to 2050, may be challenging. This amounts to comparing the consequences for emissions reductions if this project is successful against the counterfactual, in which the project is not undertaken, but the rest of the world carries on as before (and the rest of the world will also be undertaking RD&D, and pursuing climate strategies that are likely to induce innovation elsewhere). One of the hardest parts to assess is whether a successful outcome for a particular project will influence the starting point from which all future technology developments take place. If so then its leverage may be enormous, but if it merely accelerates developments that would otherwise have happened slightly later, then its value is clearly lower. The critical, and challenging part of the evaluation, is therefore to determine what the additional benefit of this project is, over and above everything else that is also going on to reduce emissions.[10] However, estimating the relative size of CO_2 emission reductions per euro spent from different technolo-

gies may be easier than computing the absolute value of these reductions. That may be sufficient to guide funding allocations across technologies and between different priority actions.

Finally, the third step involves the proper selection of projects to be undertaken. Projects should be ranked in terms of their expected additional contribution to cumulative CO_2 reductions over the period to 2020 and, with less confidence, up to 2050. The case for intermediate targets such as 2020 is strengthened as it gives urgency to, and is a means of monitoring, Member State contributions to longer term targets. Obviously, projects focused on achieving 2020 policy objectives are likely (if the corresponding technologies remain competitive) to help achieve 2050 targets, but an over-emphasis on near-term delivery goes against the grain of the SET Plan, which is to compensate for a failure to fund projects that only deliver over longer time periods. The purpose of the SET Plan is to supplement the near-market support mechanisms provided through the 2020 Renewables Directive with support for promising but less mature technologies.

1.5   Coordination of EU and Member State support

If the EU is to encourage Member States and the industry to support innovation in immature technologies, the careful design of the institutional framework, including the relevant regulatory and legal framework, will be critical to success. This section discusses ways of coordinating EU and Member State support policies and the criteria for determining burden sharing among stakeholders.

1.5.1   Joint programming or the EU as a 'residual' funder?

Member States can provide direct funding in a decen-

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10   Annex E illustrates some of the steps and the issues that have to be addressed for a very stylized case of PV RD&D (which could usefully be updated with more reliable information). Similar exemplary illustrative calculations could usefully be undertaken for other technologies as a first step in providing the information needed to better allocate the scarce public RD&D funds.

tralized manner, or alternatively, the European Union can do this in a centralized one in collaboration with Member States by pooling funds. Cooperation among Member States is preferable whenever the common interest is larger than the sum of the individual states' interests (Lévêque et al., 2010).

There are two main coordination strategies between national and EU funding. In the first, priority actions (and their associated projects) would be jointly chosen by the Commission and Member States according to a framework of the type provided in Section 2.4. This will require decisions on:

(i) The fraction of the estimated project cost covered from public funds. This should be large enough to engage innovators in the project. However, as explained in Section 3, public funding should aim to trigger private investments instead of replacing them. In this regard, it is worth mentioning that non-energy businesses may make significant contributions to clean energy innovation funding if the right support is in place; e.g. IT companies may push innovation to develop highly energy efficient devices for their technology solutions.

(ii) National/European origin of public funds. Projects and calls for proposals can be financed by the EU or Member States alone or they can be funded jointly by them. If Member States finance/co-finance a project, the subset of those contributing funds should also be defined and counted towards the overall burden sharing arrangements within the SET Plan. Criteria guiding burden sharing among stakeholders are listed in Section 2.5.2 below.

The second form of coordination accepts that Member States will design their national research plans independently, but require them to provide a mapping of their proposed RD&D activities to the Commission. The EU would then aim to support those social-

ly valuable projects that have been left out of these national plans. In these cases, the Commission should carry out a "bounded" selection of socially valuable projects that deserve European public funding support but are not nationally planned, while encouraging Member States to co-finance as many as possible, perhaps encouraging them to substitute funds for less socially beneficial national choices for a share of a larger and better co-funded project.

The first and more ambitious strategy, also called Joint Programming, will result in a more efficient allocation of funds for two main reasons: First, Joint Programming avoids costly duplication of similar projects conducted independently by several Member States. This is more relevant the closer the innovation to be funded is to the market, since later-stage innovation typically involves higher capital investments and competition among parallel technology options normally is not a priority in late innovation due to the higher success probabilities. Second, pooling part of the funds spent separately by countries within their plans would allow authorities to fund high cost immature technologies that otherwise run the risk of not receiving enough support. Increasing the level of coordination among the support programmes of the different directorates and units within the EC would also increase the efficiency of this support.

Even when Joint Programming would be more efficient, countries are unlikely to renounce their right to fund projects deemed crucial for their national interests. Thus any feasible scheme will probably involve the coexistence of Joint Programming with some weaker form of coordination. Even where coordination is limited, pooling Member State and EU innovation funds may be necessary to finance high-cost projects. The initiation of European Energy Research Alliances – aimed at realizing pan-European RD&D by pooling and integrating activities and resources,

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combining national and EU sources – is a step into the right direction. Their successful implementation should therefore be fostered and progress monitored.

Designing a common EU/MS coordination strategy could take place at a cross-technology forum including all Industrial Initiatives and, for each technology, in the regular Industrial Initiative meetings. The EU's main task will be to amplify the impact of national research agendas by, for example, encouraging a programme of simultaneous competing projects across Member States where this is suggested by a portfolio approach to cost-benefit analysis, and "buying" the sharing of Intellectual Property Rights (IPR) among Member States (and possible non-Annex I countries).

1.5.2 Criteria determining the burden sharing among stakeholders

A number of criteria helping to determine the desired level of involvement of the EU in the funding of a project are listed below:

— The level of funding provided by the EU should in general increase with the EU added value of the project.
— Projects likely to produce long-term benefits to the EU as a whole tend not to be so appealing for individual Member States. The EU should help to fund these projects if they contribute to a more balanced future portfolio of technologies. The EU share of public funds could be large for cheaper innovations.
— Funding high-risk, high-cost, projects that are deemed to produce benefits only in the long-term is normally challenging even for the largest Member States. In this case, a contribution by the EU, even when marginal compared to total investment needs, could trigger further investments by Member States and private investors and therefore pro-

mote the creation of large international funding consortiums (clubs of funders).

The level of involvement of the different countries in the funding of a project should depend on the global amount of financial resources they have available and their natural strengths and priorities.

2. Direct public support to RD&D in low-carbon technologies

This chapter deals with direct public support to RD&D in new clean technologies. Section 3.1 provides background information on the economic rational for public support; Section 3.2 introduces an analytical framework to be used when choosing among alternative support instruments. The way support is provided should be tailored to the relevant features of each innovation process (particularly their cost and level of maturity). Section 3.3 assesses the application of main available financing policy instruments and provides conclusions on the adequate format of direct support for different types of innovation projects.

2.1 Rationale for public support

Current levels of privately financed clean energy innovation will not be sufficient to deliver a mix of technologies able to meet EU climate objectives, and the required portfolio will not develop spontaneously. This section discusses the rationale for public support including the trade-off between the intellectual property protection that provides incentives to innovate and knowledge dissemination; briefly summarizing the role of indirect public support to the deployment of clean technologies; and, finally, arguing the need for direct funding support.

2.1.1 Protection of intellectual property versus knowledge dissemination

Private companies undertake RD&D in order to obtain the rights to exploit their findings profitably. Where RD&D is entirely privately financed, intellectual property rights (IPR) are the logical reward for success in producing knowledge that might readily be copied. In contrast, where RD&D is co-funded by the public sector, the public has an interest in the exploitation of that knowledge, and there may be a conflict between maximizing the private (company) and social benefits of that knowledge. How public funders should treat any intellectual property (IP) developed in partnership or under co-funding will depend sensitively on the nature of the IP, the objectives and position of the company, and the objectives of the funder. It is hard to make any simple generalizations in this report. We note, however, that the issue has to be addressed at a very early stage in any public-private RD&D partnership to avoid possibly costly and extensive delays. Developing standard forms of contract might be a valuable activity in its own right that the EU might consider.

Reaching ambitious climate objectives requires the wide use of clean technologies, also in developing countries, as well as achieving a high enough rate of knowledge diffusion that allows building on this knowledge. However, most of the existing innovation revenue appropriation mechanisms (including patents and secrecy) represent an obstacle to the free dissemination and use of knowledge produced.[11] Henry and Stiglitz (2010) discuss whether IPR, with

their increasingly global reach, furthers or hinders the production and dissemination of knowledge and the development of a sustainable economy. They argue that reforms in the intellectual property regime are necessary to increase the pace of innovation.

Authorities and funding institutions must aim to implement effective mechanisms to encourage the participation of private parties in innovation while delivering a high enough transfer of technology. Without a public requirement to make knowledge available and thus accelerate diffusion, there is a danger that innovators will attempt to delay such diffusion in order to increase their own market revenues. The risk is that such public requirements might adversely weaken the private sector incentive to participate, not only in publicly funded projects, but also in competing parallel privately funded projects. In this case, publicly funded innovation would not complement but replace privately financed one, i.e. clean innovation would end up being almost completely publicly financed and managed. This is clearly undesirable where innovation is more efficiently managed by the private sector (and whose potential commercial appeal is high enough).

The UK Energy Technologies Institute (ETI, 2010) provides an interesting example of how to resolve this trade-off. The ETI has set up a flexible system to manage IP resulting from the RD&D activities it finances or co-finances. This IP (including patents) is normally owned and managed by a member of the research consortium. However, industrial members (funders) of ETI and programme associates have free access to it. Members of the research consortium may or may not have access to IP produced depending on their contribution to the project in terms of knowledge, own IP and their remuneration for participating in this project. Third parties do not have access to produced IP for a certain period (normally seven years);

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11   The effectiveness of each of these mechanisms depends on the nature of innovation carried out as well as on the design of the mechanism itself. Whereas e.g. secrecy tends to be more effective to protect process innovation, patents are more effective at protecting product innovation (see Cohen et al., 2000; Levin et al., 1987). In addition, different mechanisms may have different impacts on the rate of knowledge dissemination and technology transfer.

hence, a sort of club of funders is created. After this exclusive access period, third party access to IP is provided subject to the payment of a limited royalty. Background IP owned by project participants that is deemed relevant to the project should be made available to the consortium on a free basis for the use in activities related to the project.

IP schemes should normally reward innovators in proportion to the successful use of the technologies they helped develop. Hypothetically, clean energy IPR might provide geographical limitations on protected use. Thus, for example, patents issued could grant private entrepreneurs and companies exclusive rights that only apply to developed countries. Developing countries could be free to make use of the IPR for their domestic use, although there might need to be some system of royalty payments on exports to developed countries. Alternatively, a system of royalty payments could be created whereby the level of payments depends on the country where licensed technologies are used. Both a system of geographically differentiated royalty payments and one of geographically limited patents should probably be complemented by a centrally administered fund compensating innovators for foregone revenues in developing countries.

Another alternative could be to buy out IPR from successful innovators or entrepreneurs in order to provide open access to the IP. On the other hand, private companies might be willing to voluntarily restrict their IPR in exchange for up-front public support, effectively providing co-funding, possibly proportionate to the predicted sales to countries granted open-access to the IPR.

Barton (2007) advances a contrary view, arguing that in most cases, mechanisms currently applied to appropriate revenues from innovation are unlikely to represent a significant obstacle to the penetration and use of clean energy technologies in developing countries. Competition among global suppliers of new technologies will limit license prices or the prices of products sold by global clean-tech manufacturers. The prospects for the creation of leading clean-tech companies in developing countries with large research capabilities vary depending on the technology considered, with China, and to some extent India, as the most likely successful entrants in wind and some other low-C technologies. Perhaps a more serious danger to the adoption of clean technologies in the developing world is the high concentration within the industry, which could lead to cartel behaviour by global manufacturers, and selective licensing and broad patents used by developed governments to protect local companies. It would be preferable if these governments concluded international agreements with developing countries to jointly develop clean technologies.

In the remainder of this report we assume that steps have been taken to make wide and rapid adoption of clean technologies and diffusion of knowledge compatible with the active involvement of private companies in RD&D activities, even when the latter need to be publicly co-funded.[12]

2.1.2 The role of support for deployment

Achieving a socially efficient level of market penetration of clean technologies requires correcting the positive environmental externality they produce through an appropriate carbon-pricing scheme. The relative merits of different carbon pricing schemes are discussed in Grubb and Newbery (2007) or Goulder and Parry (2008). However, the correct level of car-

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12   Wherever the mechanism chosen to protect private returns from innovation involves the use of IP rights, implementing a centralized European IP regime would significantly reduce transaction costs, which is especially relevant for Small and Medium Enterprises (SMEs).

bon prices will not suffice to create adequate market demand for immature low-C technologies. As long as their costs remain higher than those of more mature technologies (assuming an adequate carbon price) and their costs are falling as a result of learning-by-doing, there is a case for additional support. How this is best achieved will depend on whether the buyer is regulated or not.

For technologies used in competitive markets, their deployment can either be mandated in certain sectors or directly subsidized. Thus, technologies that are assured of becoming cost-effective could be supported through standard setting. Standards can also assist in increasing the market size (e.g. for smart meters, where scale economies will reduce unit costs).[13] For those products used by the public sector, niche markets can be created.[14] If the potential public sector demand is not large enough, but wide-scale deployment is socially justified, then either the installation or the use of these technologies may be subsidized: (i) technologies that do not need to be extensively used to overcome existing barriers (where, for example, the learning takes place in their manufacture and installation) may be better supported through capacity (installation or availability) payments; (ii) technologies that need to be extensively used to demonstrate success can receive output support payments, possibly in addition to capacity subsidies.

Where the new clean technologies are deployed in regulated (mainly network) industries their use can be encouraged through regulation. Pérez-Arriaga (2009) discusses the regulatory instruments needed

for enhancing electricity grids to integrate intelligent demand response, distributed generation and storage.[15] Under rate-of-return regulation each specific investment proposal is assessed by the regulator and, if approved, its cost will be remunerated. It allows public authorities to decide which technologies need to be supported, and can support immature technologies, although there are many examples where the regulator was unwilling to risk consumers' responses to higher prices for untried inventions.[16] Investments can be directly included into the regulated asset base. Rate-of-return remuneration schemes have traditionally been applied to transmission companies, though they had not been designed to reward the use of advanced, immature network technologies. The UK Low Carbon Network Fund (LCNF) set up recently by Ofgem is a scheme specifically aimed at encouraging the adoption of new low-C technologies. This fund is used to reward the implementation of new technology; operating and commercial arrangements by distribution system operators supporting a reliable and economic low-C electricity system (see also Ofgem, 2010).

Incentive-based remuneration schemes (such as price-caps) provide financial incentives for network companies to increase the efficiency of the development and operation of their networks. These are output-driven schemes that reward the achievement of pre-set objectives through the use of any kind of technology at the disposal of the regulated company. In other words, incentive-based schemes encourage competition among technologies and, therefore, the use of those that are already cost competitive. Ofgem aims to place greater emphasis on rewarding innovation in its proposed replacement for price-cap regula-

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13   Again there are drawbacks to prematurely freezing a standard, for e.g. smart meters, and discouraging further market research and innovation that might deliver better products and standards.

14   This has been the case e.g. for compact, low-cost, fluorescent lamps in the US, whose demand in public schools and housing was guaranteed by the Department of Industry (National Research Council, 2001). Much energy R&D was effectively conducted for military purposes.

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15   See e.g. Olmos et al. (2010) for a discussion about barriers evolving when implementing response measures aimed at mitigating the impact of intermittent electricity generation.

16   Hausman (1997) argues that FCC's refusal to allow AT&T to introduce early mobile phones into the asset base delayed innovation by years at high cost to the economy.

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tion (RPI-X) for network utilities in its RIIO model (Revenue=Incentives+Innovation+Outputs).[17]

2.1.3 Need for direct public support

Market-pull (even with efficient carbon prices) is unlikely to be sufficient to stimulate the development of immature pre-deployment technologies. These technologies face a number of barriers including (i) that immature low-C technologies typically pair high capital requirements with substantial economic, technical and regulatory uncertainties, hampering access to finance; and (ii) past considerable cost reduction from dynamic scale economies enjoyed by existing (clean) energy technologies, which impede the entry of new technologies unless they are granted adequate technology-specific support.[18]

Consequently, there is a gap between the cost of financing the development of new clean technologies and the funds that private parties are willing to contribute, and hence, a need for direct public support. The size of this financing gap depends on the technology and can be determined by carrying out the same cost-benefit analysis that potential private investors would undertake before committing to any R&D project. Direct public support may also play an important role by certifying firms to outside investors (Lerner, 2002), who might then be more willing to contribute financial resources.

2.2 Choosing among alternative financing instruments

There are three types of policy instruments that can directly mobilize public funds to support innovation: public loans/loan guarantees, public investment in the equity of innovating companies (Public-Private-Equity-Partnerships, or PPEPs), and subsidies. We here distinguish among three classes of subsidies: prizes awarded to the winner of a contest to carry out a certain innovation; tax credits and other benefits granted in proportion to private expenditures on RD&D; and grants or contracts that are awarded ex-ante to an innovating entity or consortium, whose size may or may not be conditioned by performance, and which may or may not require co-funding from the company (usually depending on the form of IPR allowed under the contract).

Guidance on the choice of financing instruments provided in this report must necessarily refer to general types of clean innovation for two main reasons. First, there are many types of innovation processes in the SET Plan. Providing specific recommendations for each is not feasible within the time frame of the project. Recommendations for three specific innovations are derived in the case study chapter (Section 5). Second, deriving clear-cut recommendations requires carrying out a rigorous cost-benefit analysis to determine the size of the existing financing gap. This is clearly beyond the scope of our analysis.

The choice of financing instruments should be guided by the stage of development of the technology and its characteristics. These include its cost (size of investments required for the development of this technology),[19] the interdependence between this technology and other new technologies, the radical

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17   For a description of Ofgem's RIIO model aimed at replacing price-cap regulation used for the last 20 years see http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=10&refer=About%20us/CL

18   Different market failures to (low-C) innovation are also discussed in Martin and Scott (2000) and Foxon (2003). For an overview on theoretical analysis of the effects of environmental policy on technological change see Jaffe et al. (2002). For a detailed discussion on the funding gap in the financing of R&D and innovation originating in imperfections of financial markets see Hall and Lerner (2009).

19   Projects with costs below a few tens of million euros can be deemed to be lower cost.

vs. incremental nature of knowledge involved in the development of this technology and the status of the innovating entity (regulated vs. non-regulated). Following the classification provided by the EC (EC, 2009c), we distinguish between a) close-to-be-mature technologies, which are, therefore, close to the market and whose deployment within the period 2011-2020 seems feasible; b) those technologies that could be deployed within the period 2020-2035; and c) those that are still farther from the market and are therefore highly immature. References throughout the report to the level of technological maturity should be understood in terms of this classification.

The type of financial support required will then depend on: (i) the size of the financing gap to be covered by public funds; (ii) the project's ability to compete for public funds against other clean technologies; (iii) the likelihood that support to this technology will need to be cut off because it fails to deliver according to authorities' expectations and (iv) the type of entity that is best suited to carry out this innovation.

» Size of the financing gap: The funding gap is the level of support needed to induce a company to undertake the RD&D. It depends on the likely costs of the innovation relative to the expected future revenues, which depend on the probability that the technology reaches the market and the time profiles of market revenues in the case of successful deployment. The cost and market revenues depend on the stage of the innovation, its cost intensity, its dependence on other innovations or infrastructure to be built, the type of knowledge to be acquired through this innovation (radical versus incremental) and the regulatory status of the innovating entity.

» Capacity of this technology to compete with others for public funds: This depends on the maturity of the technology. If the technology is less mature than alternative clean technologies that also require direct public support, public authorities will have to earmark and directly assign the necessary support funds. Where clean technologies are mature enough, they should be left to compete for general low-C public funds, since this competitive pressure will drive down costs and favour innovation.

» Likelihood that the support for this technology will be cut off: Where the probability of a technology reaching the market is low but the ex-ante potential gains if this happens are high (e.g. fusion reactors in the 1950s) experience may allow a more realistic assessment of the potential of this technology. The information collected during the project may reveal that the initial prospects now seem far less favourable and this technology no longer deserves support. In such cases anticipating the need for possible future exit should condition the way the original support is provided.

» Type of entity carrying out the innovation: Public support will only trigger innovation if it reaches the entities likely and able to undertake the desired RD&D, which will depend on the cost and nature of the innovation (radical or incremental) the past innovation record of the entity, and whether this innovation requires integration with a small or large number of related innovations and/or processes. Costly RD&D can only be afforded by large companies, who are also best placed to deliver incremental improvements. Radical innovation typically is best carried out by small innovating entities. The comparative advantage of universities and related research institutes lies also in more basic, early-research and smaller-scale projects.[20] Finally, an innovation involving several

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20   The experience of funding universities has been generally very positive, usually with higher estimated social returns than allocating funds to other recipients (see Haskell and Wallace, 2010, and references therein). Their strength lies in the strong international and domestic competitive pressures to which they are

Figure 2. Analytical framework to be applied to select appropriate financing instruments
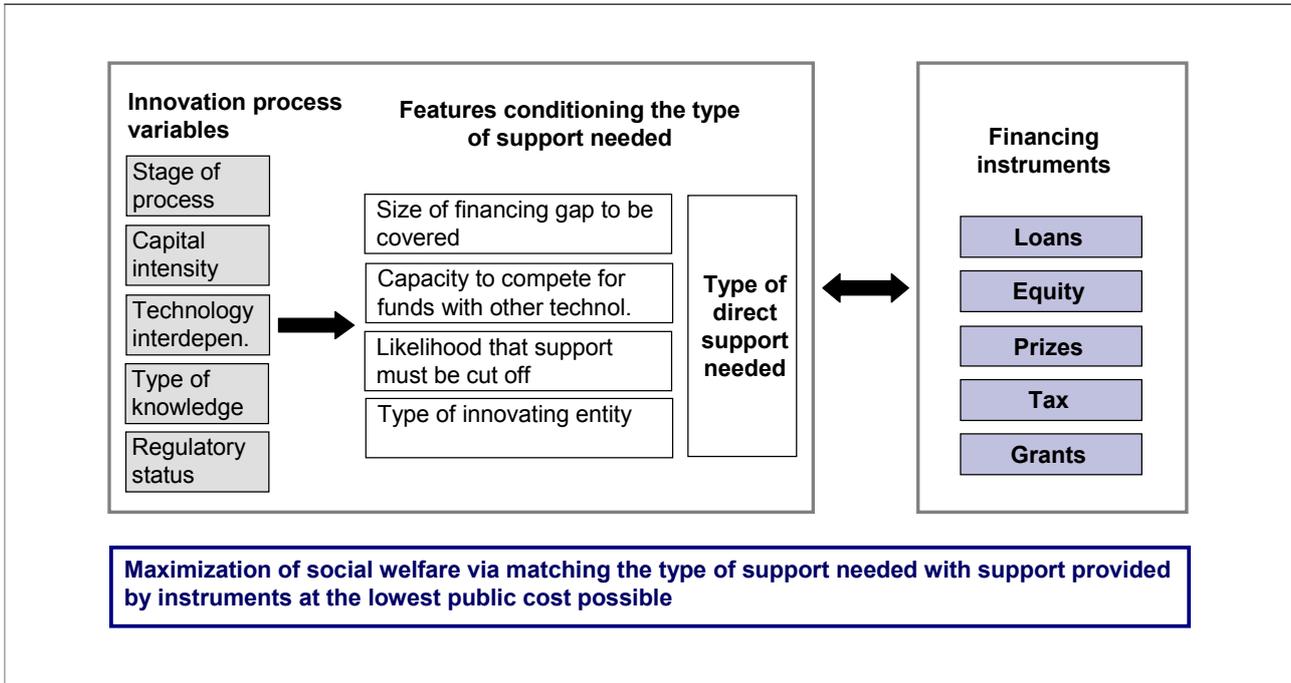
technologies is better carried out by entities with cross-technology expertise or through collaborative research partnerships.

Funding support provided to an innovation project should not only match its characteristics but at the same time be aimed at maximizing the expected social benefits produced by this project. The greater the ratio of private or MS support per euro of EU support, the larger the number of projects that can be supported, and, other things equal, the higher the expected overall social welfare increase. Therefore, direct support provided to an innovation process should have the lowest (EU) public cost possible that is compatible with the project being undertaken and the results being effectively disseminated.

The choice of support instrument should then be made according to the following features of instruments: (a) their ability to trigger innovation at rea-

sonable public cost; (b) their ability to target a specific technology and redirect support to others if necessary, and (c) the type of innovator that is best suited to receive the type of support provided through them. Figure 2 illustrates the application of the analytical framework that has just been laid out.

2.3   Assessing available instruments

Criteria to guide the selection of direct support instruments – as identified in the previous subsection – are now employed to determine the type of innovation that is best supported by each of the main types of instruments considered. Available experience on the application of instruments is also discussed.

2.3.1   Public loans or loan guarantees

Public loans (or loan guarantees) shall replace private ones when capital markets are not liquid enough or when, due to asymmetry of information, the public administration is better informed than private inves-

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subject (for faculty, post-docs, grants, etc.).

tors about the risks involved in an innovation process and, therefore, is prepared to offer more advantageous interest rates.

Experience with the use of this instrument: Loans have mainly funded expensive innovations in later stages of development. We have not found any evidence of the successful application of public loans to fund pre-deployment clean energy RD&D. Loans provided through the Risk Sharing Financing Facility loans[21] in the EU have managed to leverage a significant amount of private investments in RD&D either alone or in combination with other support instruments. Projects financed include the demonstration of CSP plants (also backed with deployment support systems) and the development of bio-ethanol technologies (EIB, 2010). According to US federal government plans, loan guarantees shall be used in the US to overcome barriers to the construction of Generation 3 nuclear plants and demonstrate their commercial viability, though some difficulties are being found to make the financing deals (Reuters, 2010).

Ability to fund innovation at a reasonable cost: Loans are less attractive to innovators than subsidies, since the amount of funds obtained must be paid back to the investor together with the agreed interest rate. However, they may be able to close the financing gap of low-cost, pre-deployment innovation that is expected to render large market revenues to private investors at a high enough probability. If the innovating entity is deemed to be able to pay back a loan with a

high enough level of certainty, public loans turn out to be less expensive for the tax payer than any other form of direct support.[22]

Targeting of technologies: Public loans or loan guarantees allow authorities to target a specific technology or technological option. The choice of which innovator or project-company receives a loan is with authorities, while loan provisions can specify the use to be made of funds provided. Loans can lead to a financing lock-in, when, in order not to write off the funds provided to an innovating entity that is not able to pay credits back, public authorities keep providing further support to avoid its bankruptcy. Thus, loans should not be applied to fund highly risky innovation conducted by small entities.

Type of innovating entity: Public loans are best suited to fund pre-deployment innovation conducted by large innovating entities whose financial capability is proven.

2.3.2 Publicly Private Equity Partnerships (PPEPs)

Experience with the use of this instrument: Most equity investments in innovation have traditionally addressed technologies that were already available for their wide-scale deployment, though seed equity investments have also been employed at the pre-deployment stage. Evidence on clean energy innovation suggests that, within the pre-deployment stages, PPEPs have predominantly been used to fund inexpensive innovation in the early stages of R&D. The

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21   The RSFF has been jointly created by the European Investment Bank and the EC. For more information, see http://www.eib.org/products/loans/special/rsff/index.htm. A successful example is the provision of a €200 million RSFF loan to the Spanish wind turbine manufacturer Gamesa co-funding its 2008-2011 research program. Additional funds come from Spain and the private innovator. A sustainable R&D strategy, including diverse projects in turbine and storage technologies is followed based on cooperations with third research centres. Numerous patents could be filed.

22   Public guarantees for private loans, which involve the same allocation of risks as public loans, could have a lower public cost than public loans if the liquidity of the capital market is sufficiently high. In effect, the public sector may be able to borrow risky funds at lower cost as it has a wider cost base (the entire public budget, a significant fraction of GDP) to bear that risk. Against that, it may be less well-informed about the real success probability and more prone to optimism bias.

Carbon Trust provides an interesting example. Carbon Trust Investments Ltd is the seed and venture capital investment arm set up by the Carbon Trust to push clean innovation in the UK. It has invested in various technologies (CSP, wave, bio-fuels and energy efficiency). Investments are never larger than a few million pounds and never represent more than 50% of the equity of a company. They have attracted investments by other private parties that are several times the amount provided by the Trust. The Trust closely monitors funded companies' activities and participates in its management. During the first five years of operation, the internal rate-of-return (IRR) on these investments was about 19% (MHB, 2007).

Ability to fund innovation at a reasonable cost: External equity financing is less attractive to innovators than subsidies, since revenues obtained by the innovator from the process undertaken must be shared among equity holders. Despite this, and according to Carpenter and Petersen (2002), equity may be able to engage small entities in risky innovation that loans are not able to trigger. Unlike loans, equity does not create financial distress in these entities because payments to investors are contingent on the success of innovation. Besides, publicly owned equity provides small entities with the collateral they need to obtain additional debt-based funds. Finally, public equity investments allow the administration and other investors to help drive innovation, which can increase its probability of success and, therefore, can also help to close the existing financing gap. On the other hand, large companies may find loans more attractive than publicly owned equity, given that (i) the risk premium they will have to pay when getting credit is lower than that paid by small innovating entities; (ii) unlike small entities, they will not be so subject to financial distress caused by loans; and (iii) they are likely to have access to the (private) equity market on more acceptable terms.

PPEPs allow the public to profit from supporting successful RD&D, and should reduce the support cost relative to grants. On the other hand, given the risky nature of innovation and difficulty faced by authorities in identifying winning technologies, equity may have a higher cost than loans.

Targeting of technologies: PPEPs allow authorities to choose which innovation processes to back but it may be harder to introduce competition for these funds – although the act of choosing in which company to invest represents a form of competition. Thus, public equity should only be used to support technologies that cannot yet compete with other clean options. Project failure (and criteria to determine success or failure need to be negotiated in the original equity injection) allows projects to be terminated before they become too expensive and, to that extent, this instrument allows a more flexible reallocation of support funds over time than conventional subsidies or loans might permit.

Type of innovating entity: It is only the market value of small entities or project companies that is intimately associated with the success of each innovation project they undertake. Therefore, only equity investments in these entities allow the public sector to profit from the success of the innovation it funds.

2.3.3 Prizes awarded to the winner of a contest

Experience with the use of this instrument: Prizes have typically been awarded to successful innovators in contests organized to conduct inexpensive, radical R&D including the construction of first prototypes. The NASA Centennial Challenges Power Beaming Competition (NASA, 2010), for example, was launched in 2005 to develop a technology that could allow photovoltaic cells in the outer space to beam power to earth. At the end of the year 2007, no

winner had been found, but the US$ 900,000 prize triggered a significant amount of research from numerous participants that allowed the technology to be pushed forward. Another example is the MIT Clean Energy Prize, which has funded revolutionary innovation like an electrode able to increase the amount of light penetrating PV panels by 12% (MIT, 2010).

Ability to fund innovation at a reasonable cost: Prizes place techno-economic risks of RD&D activities on the innovator (see also Newell, 2007). Thus, prizes must be much larger than those grants that would suffice to trigger the corresponding innovation process. Prizes offered to undertake costly processes would then have to be very large in size. Besides, up front investments in this type of processes could probably not be afforded by small innovators participating in a contest. Hence, prizes should typically trigger inexpensive innovation.

Prizes are a form of subsidy and, therefore, must be deemed expensive compared to loans or publicly owned equity. However, by rewarding outputs rather than inputs, prizes provide efficiency incentives to the innovator, thus eliminating the risk of moral hazard behaviour and increasing the probability of success, which ultimately reduces their public cost. Besides, prizes result in contenders exploring parallel research paths, which is highly advisable in risky innovation and could, alternatively, only be achieved by funding several research projects.

Targeting of technologies: In prize contests, competitors choose how best to meet the target set by authorities. Given that prize givers do not commit resources to any specific process, they do not run the risk of being locked into funding it.

Type of innovating entity: The administrative burden born by participants in prize contests is smaller than that created by other instruments, which favours the participation of small entities. However, small entities may have liquidity problems when facing high upfront costs to be paid by innovators in a contest.

2.3.4 Tax credits and other benefits associated with private expenditures on RD&D

Experience with the use of this instrument: Ofgem's Innovation Funding Incentive (IFI) is an interesting example of cost-sharing stimulus to clean innovation. It has triggered a significant amount of innovation by distribution network operators (DNOs). DNOs in the UK are recompensed up to 80% of the cost of new technologies that contribute to reliable networks operation in a low-C system. The innovation supported under IFI tends to be relatively inexpensive (less than one million pounds). Incentives from IFI are combined with those created by the RPI-X scheme (see Bauknecht, 2007). Newell (2007) concludes that tax credits in the US are successfully supplementing rather than replacing private innovation funds and estimates that tax credit schemes in place have resulted in several billion dollars of extra investments in innovation.

Ability to fund innovation at a reasonable cost: Evidence collected shows that tax credits and rebates for RD&D expenditures may trigger a significant amount of additional innovation. However, both tax credit and rebate schemes normally leave the decision on which innovation to undertake in the hands of private entrepreneurs and investors, who find close to the market activities more attractive than early, risky ones. Thus, private revenues from these schemes are unlikely to be used to fund a significant amount of pre-deployment RD&D. Rebate schemes applied to regulated utilities may be an exception to this general trend, since the resulting investments can be guided by the regulator when determining whether to include them in the asset base.

Tax credits and rebates are a form of subsidy. Therefore, their cost is likely to be higher than public loans or public equity. However, the former are less likely to crowd out private investments than conventional grants, since the former are granted on the condition of private investments in innovation already taking place. Therefore, the public cost of the innovation triggered by benefit schemes is probably lower than that of innovation funded with conventional subsidies.

Targeting of technologies: Targeting a technology with tax credits is not possible because the decision on which specific RD&D activity to fund is left in the hands of innovators. Therefore, assuming that private entities are more agile than the administration in redefining investment priorities, tax credits should be more flexible than conventional subsidies in being directed to successful innovation.

Type of innovating entity: Tax exemptions can only reach large companies paying a significant amount of taxes. Rebates can be provided to smaller entities as well. In any case, entities receiving this form of support must be large enough to bear upfront investment costs on their own, since these benefit schemes only reward innovation already undertaken.

2.3.5 Conventional subsidies (grants, contracts)

Experience with the use of this instrument: Grants and contracts are by far the preferred policy instruments to fund clean energy innovation of any type. Evidence suggests that competition for funds increases the probability of innovation success, and so do co-funding (receiving funds from several investors) and continuous performance monitoring. Most successful close-to-the-market subsidized projects normally receive output-driven support. The ability to redefine project objectives if necessary has also played

a relevant role in overcoming barriers in successful projects[23]. Additionally, consistency between the innovating institution's objectives, its research strategy and internal policies on issues such as the control of intellectual property is also important. Lack of consistency normally creates obstacles to sustainability and success, impeding revenue development and potentially also demotivating staff as shown in Ferrari (2009), where R&D activities in nuclear institutes at Central and Eastern Europe are discussed.[24]

Ability of this instrument to fund innovation at a reasonable cost: Grants and contracts can engage innovating entities in the least commercially attractive projects, like expensive, early-stage research or RD&D activities carried out by regulated entities, whose revenues tend to be limited. Conventional subsidies reduce the fraction of the project costs born by the innovating entity, including upfront costs, while not reducing its revenues from the project. However, if innovators in subsidized projects are restricted in the terms of any resulting IPR, the private profitability of these projects may be significantly reduced, which may probably require the provision of a larger subsidy. Conventional subsidies are the most expensive pubic support instrument. Output driven subsidies are less expensive than input driven ones, but are not attractive to innovators in projects where risks involved are high.

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23   The PV Commercialization Program undertaken in the 1970s and 1980s in the US (Cohen and Noll, 1991) is an interesting example of the successful use of innovation subsidies. Creating competition among different technological concepts allowed authorities to identify the most promising options; the menu of alternatives was gradually reduced. Despite the fact that subsidies were input-driven, authorities managed to create some pressure to achieve good results by dropping projects that made slow progress.

24   Funding typically is provided to a substantial share in the form of government grants. Many cases reported a lack of any business plan or a policy for the protection and management of IP, staff rewards not linked to the institute's objectives, and disconnected communication between innovators and funders.

Targeting of technologies: Authorities must choose which innovation to subsidize. This allows them to target even the least commercially appealing processes but is, at the same time, a source of potential inefficiencies. The public sector is not necessarily the best informed nor the most experienced in making such choices. Private investments may thus be crowded out if subsidies are provided to projects that would otherwise be financed by private parties. Besides, due to the inability of authorities to precisely assess the social potential of innovation processes and encourage efficiency in their management, the share of failed innovation projects that are subsidized is likely to be higher than that for projects receiving other forms of public support. Finally, the use of subsidies may lead to a financial lock-in. An example of this is the US Algae Biofuel research program, where funding spanned 20 years despite poor results (Cagw, 2010).

Type of innovating entity: Grants and contracts can be provided to any type of innovating entity.

2.3.6   Summary and conclusions

From the assessment conducted above – which is also summarized in Table 2, the following conclusions can be drawn: Loans are well suited to finance lower cost, potentially profitable innovation carried out by large companies. Public loans should be used instead of private loans if the liquidity of the capital market is low or if the innovation targeted is related to activities where the public sector is more experienced (e.g. RD&D in nuclear). Public loans are also attractive in recessions when the private appetite for risk ("animal spirits") is unduly depressed. Public equity is suitable to finance risky, potentially highly profitable, innovation preferably undertaken by small entities. Public equity investments should be of modest size, though they may be used to marginally fund expensive innovation to signal that it has a high potential. Prizes

can be used to fund early low-cost innovation preferably conducted by universities and research institutes, though they may be received both by small and large entities. Tax credits, rebates and other benefits on private innovation expenditures are probably only suited to supporting close-to-the-market, incremental innovation conducted by large companies or that conducted by regulated entities. Grants and contracts, especially input-driven ones, should only be awarded to socially desirable clean energy innovation that will not be undertaken otherwise. This is clearly the case of a significant number of early-stage, capital-intensive processes. Some other pre-deployment RD&D activities may also need to be subsidized. Subsidies and rebates on innovation investments are especially relevant in RD&D activities carried out by regulated entities (like energy transmission and distribution companies).[25]

3.   Framing the release of public funds

Public support should avoid wasting public money while encouraging private sector's participation in innovation. This chapter discusses the framing of the release of public funds to minimize the risk of 'funding failure'. It builds on evidence gathered from past RD&D projects, the body of academic literature and industry reports. Section 4.1 discusses conditions for the release of funds for both low- and high-risk projects. Section 4.2 provides guidelines for optimal contract design. In Section 4.3 we carry out an analysis of the measurement of performance of innovation projects. This is relevant to identify which innovation projects to fund,

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[25]   Revenues of regulated entities are also regulated and, therefore, unlikely to increase very significantly as a result of the use of innovative technologies or processes. Hence, the funding gap of innovation conducted by these entities tends to be larger than that of otherwise similar innovation conducted in deregulated entities. Besides, the size of regulated entities (medium to large in most cases) makes them generally unsuitable to be supported through publicly owned equity or prizes.

Table 2: Summary of the characteristics of technology-push instruments

Instruments		Public loans/ loan guarantees	Publicly owned equity	Subsidies		
				Prizes	Tax credits and other benefits related to investments	Grants and contracts
Ability to trigger innovation at a reasonable cost	Size of the financing gap it is able to cover	Lower than subsidies. Larger than public equity for large innovating entities	Lower than subsidies. Larger than public loans for small innovating entities	Medium. Able to fund low cost early research but not expensive innovation	High. But only applicable to RD&D close to market	Very high. Capable of engaging entities in any kind of innovation stages
	Public cost	Very low	Lower than subsidies	Medium	Relatively high	High
Targeting of the technology	Targeting of a specific technology	Yes	Yes	Yes	No	Yes
	Flexibility in redirecting funds	Low	Relatively high	High	Relatively high	Low
Targeting of the innovating entity	Type of innovating entity well suited to receiving this support	Large entities with proven financial capability or small entities addressing low-risk innovation	Small to medium entities	Any (more suitable than other options to small entities when undertake low-cost investments)	Addressed at large entities that 1) pay large taxes; 2) already perform RD&D	Any
Conclusions Type of innovation processes that are well suited to be supported by these instruments		1) Low-risk innovation; 2) Risky, potentially profitable innovation by large firms. Only if illiquid capital markets or little private expertise	Low cost, potentially profitable innovation whose risk of failure is high and that is carried out by small innovating entities	Low cost innovation processes involving a large amount of applied R&D	Processes in the last stages of the innovation chain carried out by large entities (incremental innovation)	Processes in the early stages of innovation, facing significant barriers and spillovers. Some processes in regulated entities.

to learn about the type of support that best adapts to each type of innovation, and to redirect funds to alternative projects if a certain project is not delivering as initially expected. Thus, performance measurement is also related to the discussions presented in Chapter 2. Finally, Section 4.4 highlights selected important issues related to institutional support.

3.1 Conditions for the release and withdrawal of funds

Funding low-risk projects requires providing strong efficiency incentives. One option is to make the release of funds and their amount conditional on the achievement of some minimum objectives. Given the high probability of success in these projects, linking support to project performance should encourage the innovator to carry out his function efficiently and reduce the public cost of support, while not prejudicing his willingness to undertake the project. A lack of innovators' liquidity or their concern about the credibility of the funding may indicate releasing some or all the funds up front or at stages during project execution on condition that they are returned if the project is not undertaken as agreed.

Demonstration projects, like that of the CCTS value chain discussed below in one of the case studies, are good candidates for conditional funding. Tax credits and rebate schemes, where the provision of public support is conditioned on the realization of RD&D investments, can also be used to provide efficiency incentives.

Provided the innovation targeted is socially desirable because of its high potential, high-risk projects should not be supported based on performance, since otherwise innovators might not be willing to undertake them, nor will they attract private investment at an acceptable cost. Prizes are an exception, since they make the financing of risky innovation conditional on success. However, they are only likely to be useful if the research undertaken is inexpensive and the prestige associated with winning a prize is of great value to the innovator. Thus, prizes are likely to be best suited to universities and research institutes.

Even when the funds provided do not depend on performance (in terms of success or failure), authorities can still impose input-related conditions on the release of funds. The UK Carbon Trust makes equity participation conditional on the presence of external investors. Co-funding allows the Trust to share the risk of early innovation, creates incentives on the innovator's side to carry out its function efficiently (including the early termination of the project) if he is contributing significant resources and provides a third opinion on the value of innovation undertaken (MHB, 2007).

Given that RD&D is inherently risky and few early-stage projects will evolve into viable technologies, it is also important to predetermine the conditions under which support will be withdrawn if it becomes clear that the approach followed is unpromising. Again, co-funding private companies or ensuring that those undertaking the R&D have committed valuable resources reduces the risk of the innovator continuing beyond the point of evident failure, while fully funded public research laboratories have no such reason to stop. There is a balance to be struck between premature evaluation and institutionalizing continued funding, which is less likely with project-specific support but a greater risk with automatic subsidies.

3.2 Contract design for public funding

For the innovator, the most attractive contract is up-front funding unconditional on project performance. However, since this is the most expensive option from a public point of view, it should be reserved for high-risk projects, such as grant-funded early-stage research in universities or laboratories, and only used if other approaches will not deliver. Providing assured funding to centres of excellence (contingent on continued performance) attracts researchers and keeps research groups alive. Up-front unconditional funds may be provided as a fixed amount. However, providing instead funds covering a certain fraction of project costs might allow the public investor to benefit from below-budget delivery (successful projects that meet objectives at a cost lower than expected).

Public funding of low-risk projects should be output-driven, i.e. it should depend on project performance. Thus, the EU's proposals for the funding of each of the 12 different CCS plants to be demonstrated in Europe within the CCS Industrial Initiative make receipt of public funds "dependent upon the verified avoidance of CO_2 emissions".[26] Here, a clear distinction must be made between the risk affecting future market revenues from innovation, which in the case of CCS demonstration projects can be deemed high, and the risk of failure of the project itself, which tends to be quite low in demonstration projects of already reliable technologies. In order to measure the degree of accomplishment of the objectives of a project, Key Performance Indicators (KPIs) must be defined (see Section 4.3).

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26   There are apparent attractions in linking the funding of RD&D in low-C technologies to the sale of EU emission allowances (EUAs). Thus, each of the approved CCS demonstration projects will receive up to 45 million EUAs. This, however, has drawbacks, as it magnifies the carbon price risk facing the projects (CCC (2008) forecasts an EUA price of €40-45 which is about three times the current price). Increasing the project risk will increase the support cost. Member State Governments could nevertheless take on all that risk by immediately selling the EUAs, but then may face a shortfall if, as has happened, the EUA price has since fallen.

Performance-related funding can either be disbursed on successful conclusion or sequentially based on reaching intermediate objectives. Setting intermediate objectives and monitoring their achievement allows the early termination of projects not delivering results or a reorientation in objectives or research strategy if that raises the probability of eventual success. This should be the approach followed in high cost projects (mainly demonstration) and in large RD&D programmes involving a large number of interconnected projects.

3.3   Performance determination

Measuring or estimating the performance of innovation projects serves two main purposes. First, it allows funds to be (re-)targeted on the technologies that demonstrate or are expected to have the largest potential. Second, it allows estimating and learning about the most appropriate form of support to each type of innovation project. The resulting experience gained should guide the design of support programmes. However, monitoring is costly and it is important to strike the right balance when deciding how many and which variables to monitor, how frequently to measure performance, and which evaluation methods to use.

3.3.1   Designing an assessment methodology

The first step in designing an assessment methodology is to identify the relevant performance criteria or Key Performance Indicators. Low-level KPIs measure the progress made in meeting the objectives of each specific project. High-level KPIs relate to the broader objective of cost-competitively reducing future carbon emissions. The fulfilment of SET Plan and EU energy policy objectives should be assessed at program, rather than project, level in order to drive the design of innovation programs or the SET Plan itself.

The second step is to decide on how and when to measure the KPIs. This includes:

» The frequency and timing of assessments: Assessments may take place (i) ex-ante, to select which projects to undertake, as discussed in Section 2; (ii) during project execution to monitor its evolution and decide on potential extension, early termination or a shift in objectives; and/or (iii) ex-post to assess the overall impact of the project and draw lessons for future support schemes.

» The computation methodology adopted: Main options in this regard are (a) direct measurement of the variable, as in field experiments; (b) top-down methodologies based on econometric analyses identifying aggregated functions linking inputs and outputs (KPIs) of the project/programme focusing on market feedbacks and interactions; and (c) bottom-up methodologies determining the impact of project inputs on outcomes (KPIs) through the detailed modelling of technologies. As McFarland et al. (2004) explain, market or economy-wide feedbacks and interactions, like the impact on electricity prices of the massive use of more cost-efficient clean technologies, are not normally modelled in bottom-up models.

3.3.2   Measuring the performance of clean energy innovation projects

Performance measurement addresses two issues. First, the measurement of technology (i.e. project) performance and second, the measurement of the performance of support provided.

A// Measuring technology performance

The performance of clean technologies should be estimated ex-ante to guide the selection of projects to be funded and set performance targets guiding decisions

on funding continuation and/or termination. That requires periodic monitoring of actual performance against these target values and the performance of other technologies in order to assess whether a reallocation of funds or a redefinition of technology objectives is necessary. While the KPIs used to set ex-ante targets and those monitored ex-post (during project development) are the same, the ways in which they are specified and/or measured normally differ.

» KPIs to use: KPIs used to assess technology merits can be related to economic efficiency (cost reduction), technical or environmental performance. Thus, most of the sector-specific KPIs set out in EC (2009c) unsurprisingly are related to economic efficiency and target percentage equivalent production cost reductions or levels by 2020 (e.g. for CCS cost reductions by 30-40%, production cost level of bio-energy in electricity production to below €0.05/kWh), costs of abating CO_2 measured through the impact of abatement on energy efficiencies (e.g. for CCS > 40% with capture, > 50% without capture) or, for process innovation related to the implementation of network solutions, operation and investment costs. KPIs targeting the environmental impact of technologies mainly refer to the use of natural resources, like the use of water by CSP or the use of land/sea space by off-shore wind and transmission installations. KPIs monitoring economic or environmental performance are most relevant for technologies that are relatively mature (medium to low distance to the market) since the functioning of these technologies has already been proved, normally, but they are still subject to significant cost risks that impede their commercial deployment.

Finally, KPIs dealing with technical performance typically have to do with availability standards (e.g. capacity factors for virtual wind farms > 80%, CO_2 capture in CCS > 90% with availability > 80%, PV lives > 40 years, and of inverters > 25 years), standards for data ac-

curacy (wind resource identified within 3%), technical efficiency in the production, transmission or consumption of energy (like the efficiency of electricity consuming appliances) or, for network process innovation, the capacity of the network to host active demand and/or low-C generation. KPIs measuring technical performance (efficiency, life-time) are relevant throughout the whole technology development process. However, those focusing on reliability are critical during the early stages when technology still needs to be proved.

To the extent that objectives set are realistic, these KPIs seem appropriate, and will presumably be subject to revision in the light of the experience gained.

» Computation methodology: Estimating ex-ante the performance of a technology is only possible by computing the relevant KPIs through bottom-up methodologies. The accomplishment of technical and environmental objectives of an innovation project (ex-post or during project execution) should be directly assessed (measured) if possible. Bottom-up methodologies would probably have to be applied to compute the value of those KPIs related to the economic objectives of a project.

B// Measuring the performance of the support provided

KPIs addressing the performance of support provided should measure the quality of project management including variables such as the fraction of total project expenses covered by private funds; the ratio of actual project expenses corresponding to predefined activities to expenses for them considered in the project budget; the time to contract or the time to undertake predefined activities.

In judging the suitability of the chosen form of support, one should also check whether the assump-

tions guiding the choice were correct and whether other successful projects of the same type received the same type of support. KPIs that compare performance against similar projects similarly financed can test this aspect.

3.4 Further institutional support

There is more to supporting innovation than the mere provision of public funds. As Branscomb and Auerswald (2002) highlight, authorities should also focus on the quality of support. Institutions supporting clean RD&D may provide innovators not only with financial resources but also with a set of services including professional advice on the assessment of their business case and the management of their project and a network of contacts including potential investors, clients and research partners. Networking efforts at all these three levels may be necessary to produce a significant amount of publicly supported (and conducted) innovation that is of use to the industry. It is clearly desirable to remove existing barriers between national research policies as far as possible.

Authors in MHB (2007) analyze both the funding and institutional support provided by the Carbon Trust in the UK. Non-funding support can best be provided by public entities, or private ones publicly funded, that have the cross-technology knowledge required to promote clean RD&D involving any of the relevant SET Plan technologies (cross-technology support institutions).

The advisability of creating pan-European entities of this kind has been assessed in EC (2009c). Authors analyze different institutional frameworks for the support of innovation including (i) a business-as-usual scenario (BAU), where institutional arrangements and level of funding remain unchanged; (ii) an increase in funding through existing investment vehicles; (iii) the strengthening of the relationships

or links among funding and innovating entities that already exist (formalizing these relationships) and, finally, (iv) the creation of new institutional arrangements, including the creation of new pan-European entities managing and partially conducting clean research and innovation. They conclude that more funds and stronger, official, commitments on collaboration among entities must be put in place to produce clean innovation needed.[27] However, according to the EC, pan-European holistic research institutions may only be cost effective to conduct or promote expensive cross-technology innovation where international cooperation is critical (like nuclear fusion).

The US has a long-lasting experience with federal agencies with mixed results. As a funding body, the US Defence Advanced Research Project Agency (DARPA), with no in-house R&D capability, has been highly successful in allocating funds primarily to private firms, partly because it has a very well specified mission with strong political support. This would seem to be an attractive institution to replicate – perhaps a 'Low aCARPA' along the lines of President Obama's Advanced Research Projects Agency-Energy. In contrast, the US Advanced Technology Program (ATP) was set up to provide R&D funds to private firms for

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27   The case of international R&D in hydrogen and fuel cells reveals the risk of inefficient public spending when collaboration among institutions – even though highly important – is missed out. In the 1980s/1990s, Norway had four (comparatively large) hydrogen R&D projects (see Godoe and Nygaard, 2006). Three of them had been driven by the objective to use abundant natural gas reserves as a feedstock for fuel cells. Reasons for the failure of the latter are diverse; they include a lack of strong strategic leadership on a national level, a lack of long-term commitment by the stakeholders, and an inefficient duplication of effort in pursuing similar technological goals. Only the fourth project, targeting the development of unmanned submarines, has been a successful innovation, even though the application moved from military to non-military use. This is in line with the discussion of Stoft and Dopazo (2010) who even argue, when discussing the case of Hydrogen research, that "no single economy (either US or EU) can reasonably and profitably face required efforts in isolation" (p. 290). They also underline that "despite its faults, the US centralized research approach has been much more successful than the less-structured and fragmented EU pursuit" (p. 290).

pre-commercial R&D with high social benefits that promises eventual commercial benefits but which would not be carried out in the private sector without government support. It has been widely criticized as an inappropriate use of public funds, and lacks the political support enjoyed by DARPA.

As argued in Section 3, the key to success may be more related to the features of support institutions than with their footprint. Cross-technology institutions providing funding and institutional support can also be created at the national level. National institutions with the required technical and managerial expertise should be well-suited to identifying research centres of excellence and setting up stable relationships with them. Again, the Carbon Trust is a good example.

Institutional support may be critical to the success of innovation conducted by small- and medium-sized entities (SMEs). Institutional arrangements relevant to make the support to innovation in SMEs effective and efficient have been discussed extensively within several European research projects. An example is the EUROMAPLIVE[28] project, where the consortium proposed the creation of a European executive agency to select innovative projects from SMEs deserving support; allocate public subsidies to cover the costs of the early innovation stages; and connect these SMEs with private investors willing to invest in equity to support subsequent commercialization of the resulting products.

4.   Case Studies

This chapter presents three representative case studies of innovation process that are of interest within the European Industrial Initiatives of the SET Plan: (i) the first large-scale demonstration of the CCTS value chain, (ii) R&D in the design of new solar PV materials, and (iii) RD&D to develop new innovative solutions for electricity network operation. These case studies illustrate the different requirements of a range of technologies and are intended to demonstrate the criteria guiding the selection of the corresponding innovation projects, the allocation of funds to them, the sharing of their financing burden among stakeholders and the design of public funding support.[29] Appropriate market conditions (critically, the future carbon price) are deemed to be in place to guarantee the deployment of the corresponding technologies once they reach maturity. Thus, the following discussions, as the rest of sections in this document, focus on technology-push instruments.

4.1   Case 1: First large-scale demonstration of the CCTS value chain

Case studies are presented in three steps. First, after a brief description of the innovation targeted, we discuss the rationale for public support. Second, the adequate type and design of direct public support are assessed. This also includes some first ideas on suitable KPIs which could be used to monitor project performance. Finally, we provide some insights into the criteria to be used to select projects targeting this innovation and decide on the release of public funds to support them.

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28   EUROMAPLIVE was a FP5 project run by a European consortium made of I.CON INNOVATION (Germany), CAPITALIA (Italy), OXFORD Innovation (United-Kingdom), ASESORIA INDUSTRIAL ZABALA (Spain), ASCENT (Belgium), and TECHNOFI (France).

29   However, no analysis has been conducted to determine the social value of the corresponding technologies, and so no final conclusions are drawn on the advisability of supporting or pursuing these technologies, on the optimal number of parallel research paths to pursue, or the optimal allocation of funds between projects and/or priority actions. Such analyses clearly fall outside the scope of this project.

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4.1.1 Description and rationale for public support

Interesting features of this case study include the following:

— Significant capital investments are needed (these are billion euro projects);
— This is a clear example of the non-linear nature of innovation. A significant amount of R&D is needed to make this technology cost competitive once it has been demonstrated; and
— It represents the combination of several technologies within the same project. However, the exploitation of CCTS plants is not dependent on the availability of any outside technology, nor does any other new technology depend on the availability of CCTS.

Furthermore, decisions on the funding of CCTS demonstration projects have to be taken now to meet EU 2050 goals. EU investments in CCTS research projects amounted to €296 million in 2007 (EC, 2009c) with public funding representing 19% of this (6% EU funds such as FP6, 13% from the Member States). Compared to other low-C technologies this is a relatively low share of public funds. However, CCTS has become a priority area for RD&D only recently and even though large-scale value chains including carbon capture from the power sector are still in the developing phase, most underlying technical processes are already rather well proven.

The Industrial Initiative for CCTS has specified two strategic mid-term objectives: to enable the cost competitive deployment of CCTS after 2020 and to further develop the technologies to enable their application in all carbon-intensive industrial sectors. The first Implementation Plan (ZEP, 2010) specifies a number of related actions. These include (i) making the final investment decisions for up to 12 CCTS demonstration projects including capture, transport and storage, (ii) establishing a network for knowledge sharing, and (iii) coordinating R&D activities addressing the commercialization of new technologies by reducing costs. There are a small number of European pilot projects focusing on different capture and storage technologies (i.e. between initial engineering work and full-scale CCTS demonstration). In contrast, there are more than 30 proposed large-scale demonstration projects including capture, transportation and storage. Besides R&D concerning the improvement of technological processes, these are the major priority for the near-term.

CCTS is presently at the demonstration (and hence still pre-deployment) stage and so future profits from successful deployment cannot be relied upon, since they are subject to numerous risks. CCTS demonstration plants will earn market revenues from the electricity sold and the reduction in the number of allowances they need compared to unabated coal plants. However, these revenues are deemed to be far too low to recover the investment costs of these projects. Expectations about future market profits from deployment are indirectly captured in the alleged willingness of companies to co-fund demonstration projects in order to acquire IPR or other know-how and to better position their company in the future market place. Co-funding by the public sector is deemed to be necessary due to the large uncertainties that exist about the time when revenues from these projects will raise above costs.

4.1.2 Adequate type and design of public support

As discussed in Chapter 3, variables characterizing the innovation process should influence the choice of support mechanism. This case study addresses the first large-scale demonstration of a technology. Hence, there

is a low risk of technological failure, though significant R&D is still needed to reduce costs and increase the efficiency of the process. The potential future market size for this technology is strongly determined by the carbon and coal price trajectories and the development of the costs of competing low-C technologies. The innovation targeted is based on the integration of a number of technically proven processes. Thus, it is deemed to be incremental. Investments involved in this innovation process are relatively cost intensive (according to (ZEP, 2010), in the range of about € 1bn). Entities deemed to participate in the demonstration of these plants provide deregulated services.

This characterization of the innovation allows us now to determine its support needs. The size of financing gap to be covered using public funds is relatively large. CCTS plants will make revenues for electricity sold. It is not advisable to provide support payments to encourage the massive deployment of this technology since it is still in the pre-deployment stage so it is not yet mature enough to be deployed at scale. Net revenues will be higher than those of conventional plants due to the reduction in the number of allowances CCTS plants need compared to unabated coal plants. Expected market revenues, which vary with the CO_2 price, are nevertheless deemed to be too low to recover investment costs. This technology has a very high cost compared to other clean and more mature technologies. Thus, it cannot compete at adequate commercializable demonstration scale (300+ MW) with the latter for funds allocated by private parties (where private funders tend to prefer to back nearer-to-the-market or cheaper options). The likelihood that the support for this technology will be cut off is low, since this technology is likely to be part of the future technology mix implemented to achieve long-term energy policy objectives. Finally, the demonstration of CCTS plants typically will be carried out by large companies and incumbents.

Public loans alone are unable to cover the existing large financing gap. As innovators will be large companies (and plants are not yet commercially profitable), public equity is also unattractive. Tax credits are similarly unsuitable while prizes only provide strong enough incentives for cheaper innovations. That leaves subsidies as the most suitable form of support in the form of either grants or contracts. EU grants should encourage co-funding from Member States. Besides providing funding support, regulatory obstacles need to be removed to initiate the start-up of planned industry activities within this field.

Funds should be provided sequentially with a certain share up-front to alleviate liquidity and commitment problems. Up front payments should be returnable if the project is not started by a target date because of failures on the part of the company. An additional share of funds should be released on the completion of certain project work packages on time and the fulfilment of technical requirements. The remainder fraction should be proportional to agreed outputs (CO_2 stored). Table 3 proposes various possible Key Performance Indicators to measure project performance. This list may be exhaustive, but not all KPIs should necessarily be used, given the need for balancing the costs and benefits of monitoring.

4.1.3   Project selection and provision of funds

CCTS demonstration requires high up-front investments and its aim is to explore a range of options for capture and also transport and storage, indicating the need for coordination in allocating funds. The EC – in cooperation with the Member States – must play an important role in deciding which projects to back as well as the amount of funds provided and financing policies applied, thus allowing appropriate targeting of options. Competition for funds is possible as there are several proposals to demonstrate most of

Table 3. Suitable KPIs [case study 1]

	Performance of project output (technology)	Performance of support instrument applied
KPIs to measure	Primary objective: demonstration of the technology within time meeting technical objectives Technical sub-objectives: amount of CO_2 captured; average level of plant production; net efficiency of power plants	Construction within time and budget Time necessary to apply for and receive grant (fund management) Ratio of public over private funds
Frequency and timing of assessment	Primary objective: ex-post Technical sub-objectives: intermediate and final measurement (e.g. every 1-2 years during the construction; at start-up of the project; ex-post measurement of CO_2 capture rate annually)	Ex-ante anticipation and ex-post measurement of realization Time and budget control continuously
Computation methodology	Direct measurement	Direct measurement

the technical options. Competition should increase efficiency, reduce funding costs and increase the probability of public authorities choosing the best projects. Technical objectives to be reached (e.g. share of CO_2 captured, post-capture efficiency of electricity generation) should be (and are) specified ex-ante. The aim should be to maximize the range of learning from the portfolio given the extent and willingness of Member States' contributions. As the projects involve distinct technologies (capture, transport and storage), different companies will need to work together and a large part of the learning will comprise finding out how best to achieve this and at what cost and with what preferred solutions. Disseminating the results of this knowledge discovery should be a key criterion for making public funds available, in order to accelerate the decarbonization of international electricity markets. If continued public support seems justified once this first generation of large-scale demonstration value chains is operating, it can be more narrowly targeted at the most successful options.

4.2   Case 2: R&D on the design of new PV materials

4.2.1   Description and rationale for public support

Interesting features of the case study on the R&D of the design of new PV materials include the following:

— This innovation mainly involves undertaking early-stage research activities. Therefore, knowledge to be obtained is radically new.
— As a consequence, there is high uncertainty about the outcome of the project and its probability of success.

Solar PV is expected to contribute up to 12% of European electricity supply by 2020 (EC, 2009b). A total amount of €384 million was invested in PV-related research projects in 2007 with public funding accounting for 42% (of which 7% came from the EU, e.g. FP6, and 35% from Member States).[30] The solar PV Industrial Initiative specifies two main strategic objectives for the mid-term: the improvement of the technology's competitiveness and its integration into the electricity grid.

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30   Countries where solar PV has been deployed at large scale, such as Germany, France, Italy, and the Netherlands, provide most of public funds. Despite the limited deployment of the technology in the UK, this country's public R&D investments are relatively high as well (EC, 2009c).

Related actions include (i) a longer-term R&D programme to enhance the energy yield and reduce cost and (ii) development and demonstration programmes to achieve the uptake of PV-generation. Within the first action, this case study focuses on early research in the design of new PV materials.

As it is typical for early-stage research, there is substantial uncertainty about the outcome of R&D activities addressed with respect to both their technical feasibility and the future competitiveness of technologies building on the respective new technological options. Thus, even when investment costs are deemed to be low, this innovation probably needs to receive some sort of public funding support in order to be undertaken.

4.2.2 Adequate type and design of public support

As explained above, this case study addresses very early-stage R&D, which naturally involves a high technological risk. Investment needs for this kind of radical innovation are low compared to other innovation processes in low-C technologies. The adaptation of existing technologies in PV panels might be necessary in order to build those using new PV materials. Innovating entities operate in deregulated activities.

Based on its features, we can now determine the type of direct support required by this process. The size of financing gap to be covered is relatively high, despite the fact that investments required are relatively low. This is due to the significant uncertainty faced by investors about the project outcomes. This technology is not able to compete with others for public funds in the market because it is quite immature (the production of new materials is being researched and therefore technologies using them are deemed not to be cost competitive). There is a strong likelihood that the

support for this technology will be cut off. Existing uncertainties about R&D outcomes imply that there is still a high probability of failure in the sense of not reaching techno-economic objectives and needing to terminate R&D activities and cut off support. This innovation is likely to be carried out by SMEs, e.g. specialized solar PV firm or research institution.

Public loans are not appropriate given the high risk that the innovator would be unable to pay them back (being a small entity). Tax credits are equally inappropriate given the low chance of taxable profits. Public equity can be a suitable form of public support in this case.[31] It should be able to engage innovators in early inexpensive innovation work that could result in significant profits if successful, with a consequent return to the funding body. Public equity furthermore might attract third investors. It may be preferable for the public funds to be given to a professional venture capital firm that in turn invests them in the equity of entities undertaking promising research. Conventional subsidies should be avoided if possible because they are more expensive for the public sector than equity investments. Prizes may also be a suitable option if research to be conducted is quite cheap, since they are well suited to induce very low-cost early innovation activities by small innovating entities.

There is a high risk of project failure (high uncertainty about its output) and so support cannot be made conditional on reaching technical objectives. That does not rule out making funding dependent on the willingness of other investors to co-fund or share equity in the project. Support for subsequent stages could be contingent on the success in the previous stage,

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31   Under FP7, the European Investment Fund manages the 'High Growth and Innovative SME Facility' (GIF), which provides venture capital to SMEs investing in clean technology innovations. Thereby, 'GIF 1' is targeting early-stage investments and could be an interesting tool to support this type of innovation project.

Table 4. Suitable KPIs [case study 2]

	Performance of project output (technology)	Performance of support instrument applied
KPIs to consider	Number of patents produced Level of cost-reduction Efficiency and lifetime of new PV material	Time to sign the contract and receive funds R&D within time and budget Ratio of public over private funds; level of R&D intensity achieved
Frequency and timing of assessment	Assessment at the end of each stage of the innovation process Ex-post assessment of progress made regarding technological features	Continuous monitoring as well as ex-post assessment of timing and expenses. Ex-ante and ex-post assessment of sharing of burden between private and public sector
Computation Methodology	Direct measurement or bottom up depending on the KPI considered	Direct measurement

possibly providing additional equity at each successful milestone. A tentative list of KPIs to be used to measure the performance of this project s provided in Table 4.

4.2.3 Project selection and provision of funds

R&D in the design of new solar PV materials may produce knowledge that could assist many companies across the EU, justifying a significant share of public support from EU funds. ESII (2010) proposes a funding ratio of 60% from the EU and 40% from Member States for pre-competitive research. For demonstration activities that are nearer to the market, Member States shall take more responsibility and the funding ratio could be EU/MS: 40/60. This ratio is recommended to increase even further in favour of MS support for deployment, i.e. EC/MS: 20/80, presumably on the grounds that the locally based companies will reap a larger share of the benefits as the technology becomes more mature and market ready.

Given that the level of support required is relatively modest, funding decisions could be devolved to the Member States. As it is early-stage high-risk research, competition for funds among parallel research paths is highly recommended in order to increase the prob-

ability of publicly supporting the most promising R&D projects. This might suggest a degree of coordination between Member States to ensure adequate portfolio diversity.

4.3 Case 3: RD&D to develop innovative solutions for electricity network operation

4.3.1 Description and rationale for public support

Most relevant features of this case study include the following:

- This is a clear example of process innovation; i.e. the implementation of a new concept or solution to improve the functioning of the system (in this case the grid). The aim of this innovation is to facilitate the integration of RES and demand, not through the development of a new product, but by enabling the use of technologies that make the network smarter and more robust, and hence facilitate the deployment of other low-C technologies on the supply and demand side;
- Innovators participating in this project are largely also the users of the project outcome (distribution

and transmission companies); and

- These are regulated utilities.

The European electricity network faces a huge challenge to host and balance the large – and increasing – amounts of electricity coming from highly variable renewable sources and distributed generation facilities. The current rate of innovation in transmission and distribution networks is not enough to meet this challenge. The Industrial Initiative for Smart Grids has proposed a nine-year RD&D programme[32] to accelerate innovation in the development and operation of electricity networks, i.e. the implementation of the smart grid concept. Total investment needs are estimated to be in the range of €2 billion (EEGI, 2010).

Its objectives are the reduction of capital and operational network expenditures as well as achieving a high-quality, low-C and market-based pan-European electricity system (EC, 2009b). Actions required to achieve these objectives include (i) RD&D to develop new network technologies; (ii) R&D aimed at developing planning tools to help drive the long-term evolution of electricity networks; (iii) demonstration activities to support the activation of demand-side responses; and (iv) R&D to devise innovative market designs. Our third case study is related to both the first and third actions. It is not aimed at developing new network technologies but at developing and implementing new network operation procedures. In this case, innovating entities and users of the technological solutions developed coincide. They are large transmission and/or distribution network operators and, therefore, regulated utilities.

An incentive-based remuneration scheme is deemed

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32   The EEGI program is initiated by major European distribution system operators (DSOs: Enel, EON, RWE, Vattenfall, CEZ, Iberdrola, Edf) and transmission system operators (TSOs: Amprion, Elia, Red Electrica, RTE, Tennet, Transpower, 50Hertz).

to be in place encouraging the implementation of network solutions that, like those considered here, are potentially able to reduce the cost of the transmission or distribution service. However, the level of cost reductions in network service provision, and therefore the level of increases in the revenues of network companies, resulting from the implementation of network solutions devised here critically depend on the level of participation of generation and load in the active management of the network. Significant uncertainty exists about the fraction of generation and load that will become active, which is a source of risk that network companies cannot efficiently manage. Therefore, project risks, and therefore also costs, should be shared between network companies implementing innovative solutions and the system (meaning its users).

4.3.2   Adequate type and design of public support

This case study addresses mainly development and demonstration activities. Capital investments required are highly dependent on the respective RD&D project; e.g. whether new network infrastructures are required or not. Revenues from the resulting innovations depend on the development and use of other technologies. There is a need to make changes to the network as well as on load and generation sites to reap the potential benefits of the implementation of the new solution developed. Knowledge produced will normally build on that already available, even though some projects also might include radical innovation. As already mentioned, innovating entities are regulated utilities.

Based on this characterization of the process, we can now identify its public support needs. As already mentioned, market revenues from the implementation of this new network concept depend on the regulation adopted and the implementation of the

Table 5. Suitable KPIs [case study 3]

	Performance of project output (technology)	Performance of support instrument applied
KPIs to consider	KPIs still need to be defined based on a new approach to the estimation of the benefits of "Smart Grids" technologies Should probably relate to the level of implementation of the network solution and its outcome.	Time to get approval for the project Project within time and budget Ratio of public over private funds; level of R&D intensity achieved
Frequency and timing of assessment	Assessment both ex-ante and ex-post	Regular assessment during project execution as well as final ex-post measurement
Computation Methodology	Direct measurement	Direct measurement

necessary changes in demand and generation sites, which is highly uncertain in the short-term. Thus, the financing gap to cover can be deemed relatively high but might legitimately be charged to end consumers (see also the Third Energy Package; EC, 2010). The solution adopted can compete with others on a cost basis if generation, consumers and the rest of the network make the changes required to fully use it. There is a low probability that the support for this technology will be cut off, since the implementation of the network solution explored here makes use of already mature enough technologies so as to be used at scale. The innovation lies with the way these technologies are employed, not on the development of new technologies themselves. Entities undertaking these innovations are deemed to be medium to large in size (i.e. typically regulated TSOs and DSOs, but also technology solution companies).

Given the large size of the financing gap to cover and the fact that innovating entities involved typically are large and regulated utilities, public equity instruments are deemed not to be appropriate. Prizes would require addressing cheaper innovation to be effective in triggering it and are unsuited to regulated utilities. Loans would not be able to trigger this innovation without some guarantee that the companies could re-

cover their costs from their regulated activities. However, rebates could successfully been applied since, due to the regulated nature of entities involved in this innovation, revenues from these rebates can be more easily directed to a specific type of activity (in this case, RD&D involving the implementation of innovative network solutions). Unlike grants or contracts, rebates allow TSOs or DSOs to decide which technical solutions to implement, thus preventing public authorities from having to 'pick winners'. Given that network companies have a superior knowledge on the challenges faced by electricity grids than public authorities; this is considered a good feature.[33]

Network solutions to be developed face a low technical risk of failure. Only the revenues from this innovation that companies may earn and keep are uncertain. Rebates could therefore be made conditional on the successful implementation of the concept developed (its installation and successful operation). Given that

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33   Ofgem is supporting this kind of innovation in the UK through the IFI and RPZ schemes. They combine the use of rebates involving a pass-trough to consumers of a fraction of the cost of this innovation with an efficiency driven regulation (RPI-X) to encourage an efficient implementation of the solution devised. Thus risks of innovation undertaken are shared between the innovator (network entity) and consumers. It has been quite effective in leveraging a significant amount of investments by network companies.

the relevant companies are large and well capitalised, rebates could be delayed until the investments have taken place and the functioning of the new network scheme adopted has been demonstrated. In those cases where the participation of generation or demand in the implementation of this solution is guaranteed (they are encouraged to do) success could be measured in terms of the amount of generation or load integrated in the system through the new concept.

Measuring the benefits produced by "Smart Grid" technologies is far from straightforward. A standardized approach is needed to estimate the benefits and costs of Smart Grid research and demonstration projects. An initial attempt was made through the definition of KPIs proposed by the EEGI. However, further work is still needed to converge on a well accepted set of KPIs. The existing programme and project KPIs need to be upgraded in order to be clearly linked with the measurable benefits of these projects, like, for example, the resulting increase in the capacity of the network to host active demand and/or low-C generation, or the reduction in the grid operation and investment costs (in line with solutions promoted for instance in the US; see also EPRI, 2010). Additionally, KPIs employed should probably measure the level of implementation of the network solution concerned including the level of use of those technologies involved in it.

4.3.3 Project selection and provision of funds

RD&D projects on the implementation of new network solutions could be financed from both public (EU and MS) and private funds, as well as from end consumer contributions through increases in transmission/distribution charges. The share of EU funds should depend on whether innovations are to be applied at transmission level, where benefits realized could have a very large footprint, or at distribu-

tion level, where benefits will mainly be local (EEGI, 2010). Pooling of national and EU funds should be restricted to high-cost network solutions which have a broad application to the European grid. For other types of projects, competition among different solutions implemented by different network operators should increase the number of different options explored and the resulting knowledge gained, which should be widely disseminated to network operator ex-post.

5. Conclusions and recommendations

Existing demand-pull measures, namely carbon pricing and the Renewables Directive, will be insufficient to deliver an adequate and timely level of private RD&D in new clean energy technologies. Thus, in order to reach the EU 2020 and 2050 climate objectives, there is a need for direct public support to innovation. Public funds need to be spent wisely, given their limited availability. The following paragraphs provide guidelines on (i) how to select RD&D projects to be supported; (ii) how to choose among financing instruments; and (iii) how to frame public support to minimize the risk of 'funding failure'.

R1 // There will not be sufficient funds to carry out all proposed actions at the described scale, scope and time horizons. How to allocate limited public funds; i.e. select projects to be supported?

— Building a balanced portfolio of technologies requires supporting a balanced portfolio of innovation activities comprising research, development and demonstration. This will support (i) the acceleration of decarbonization to reach mid-term 2020 climate objectives by bringing to maturity some of those technologies that are closer to the market, but also (ii) the development of a diversi-

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fied technology mix enabling the achievement of long-term 2050 objectives, which requires funding innovation targeting immature but promising technologies. Given existing tight budget constraints, project selection should be based on one single evaluation criterion, namely the expected overall reduction in CO_2 emissions over both time horizons per euro of support provided.

More mature technologies with a large expected potential need to be brought to competitiveness quickly. The allocation of funds among technologies and within Technology Roadmaps should be based on detailed quantitative cost-benefit analyses building on objective estimates of success probabilities and CO_2 saving potentials realized once the technologies reach deployment. Regular updates of the allocation of available funds within allocation periods, taking into account knowledge gains, are important. Immature technologies, require continuity in the research strategy. Project evaluation typically will be based on ordinal rankings taking into account that early research mainly generates options for new low-C technologies. Therefore, very high predicted CO_2 saving potentials in the case of successful innovation can support the acceptance of very low success probabilities and/or delays in the achievement of technological milestones.

As the probability of success increases, funds should be more concentrated and competition among alternative research paths becomes less relevant. Cooperation among innovators (including competition among consortia) might facilitate the undertaking of high-cost projects and avoid costly duplication of RD&D focusing on very similar technological principles.

— In order to achieve the SET Plan objectives, cooperation and coordination among Member State

and EU support policies have to be improved. The joint selection of projects and allocation of their financial burden is especially relevant for highly immature (i.e. highly risky) and capital-intensive projects (e.g. nuclear fusion). The EU added value, cost and uncertainty about returns of projects are the major criteria determining the appropriate burden sharing among EU, Member States and private investors. In those technology areas where joint programming is not possible, the EU should act as a residual funder with Member States providing a detailed mapping of national RD&D activities and support programmes employed.

The initiation of European Energy Research Alliances – aimed at realizing pan-European RD&D by pooling and integrating activities and resources, combining national and EU sources – is a step into the right direction. Their successful implementation should be fostered and progress monitored.

R2 // How to choose among available financing instruments?

— Policy makers should select and design financing instruments such that they directly support the achievement of policy objectives. The form of direct public support needs to be tailored to the features of each innovation project. Relevant features of innovation include (i) first and foremost, the size of the financing gap to close using public funds; (ii) the ability of the corresponding technology to compete for public funds in the market and, therefore, the possible need to explicitly target it (which is possible using public loans/guarantees, public equity, subsidies in the form of prizes, grants or contracts); (iii) the probability that public funds have to be (re-)directed to alternative innovation projects (e.g. public loans have a low

flexibility in redirecting funds whereas subsidies in the form of benefits related to RD&D investments are more flexible); and (iv) the type of innovating entity that is likely to conduct the targeted innovation.

— Financing instruments selected should maximize the amount of socially valuable RD&D subject to the public sector's funding by leveraging private sector funding as far as possible within each stage of project maturity. Loans are well suited to finance lower cost, potentially profitable pre-deployment innovation carried out by large companies. Public loans should be used instead of private loans if the liquidity of the capital market is low or if the innovation targeted is related to activities where the public sector is more experienced (e.g. RD&D in nuclear). Public loans are also attractive in recessions, when the private appetite for risk is unduly depressed. Public equity is suitable to finance risky, potentially highly profitable, innovation preferably undertaken by small entities. Public equity investments should be of modest size, though they may be used to marginally fund expensive innovation to signal that it has a high potential. Prizes can be used to fund early low-cost innovation preferably conducted by universities and research institutes, though they may be received both by small and large entities. Tax credits and rebates for private innovation are best suited to supporting near-market, incremental innovation conducted by large companies. Input driven grants and contracts should only be awarded to socially desirable clean energy innovation that would not be undertaken otherwise, which includes a large number of early stage, capital intensive processes, as well as pre-deployment innovation activities conducted by regulated entities. Rebates on investments may also be useful to support a significant amount of innovation conducted by these entities. Output-

driven conventional subsidies should be used to fund closer to the market innovation where risk of project failure is low.

R3 // Financing instruments need to be implemented in a way that encourages efficiency while not discouraging participation by the private sector. How to design public support to minimize the risk of 'funding failure'?

— Use competition for funds whenever possible in order to first, set incentives for high efficiency in RD&D and, second, minimize public intervention. The public sector should avoid having to identify 'winning technological options' whenever possible and instead leave these decisions to the private sector.

— Public funding should be output-driven whenever this is compatible with the engagement of innovators in the RD&D addressed. This involves making the release of funds and their amount conditional on performance. Project progress needs to be monitored using carefully designed Key Performance Indicators. Funds should be provided either ex-post after a project's successful conclusion or sequentially based on the achievement of intermediate objectives. This allows for early termination if the project is not delivering expected results or for a re-orientation in objectives or research strategy if that raises the success probability. However, the presence of high project costs may require releasing at least part of the funds upfront.

— The institutions set up to allocate funds to clean energy RD&D should be lean and flexible enough to avoid institutional inertia and lock-in. The risk of financial lock-in is especially high for technologies of a low maturity.

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Annexes

Annex A: Data on RD&D in low-carbon technologies

Figure 3. Aggregate EU Member States public R&D funding (excl EU funds)

Source: EC (2009d)
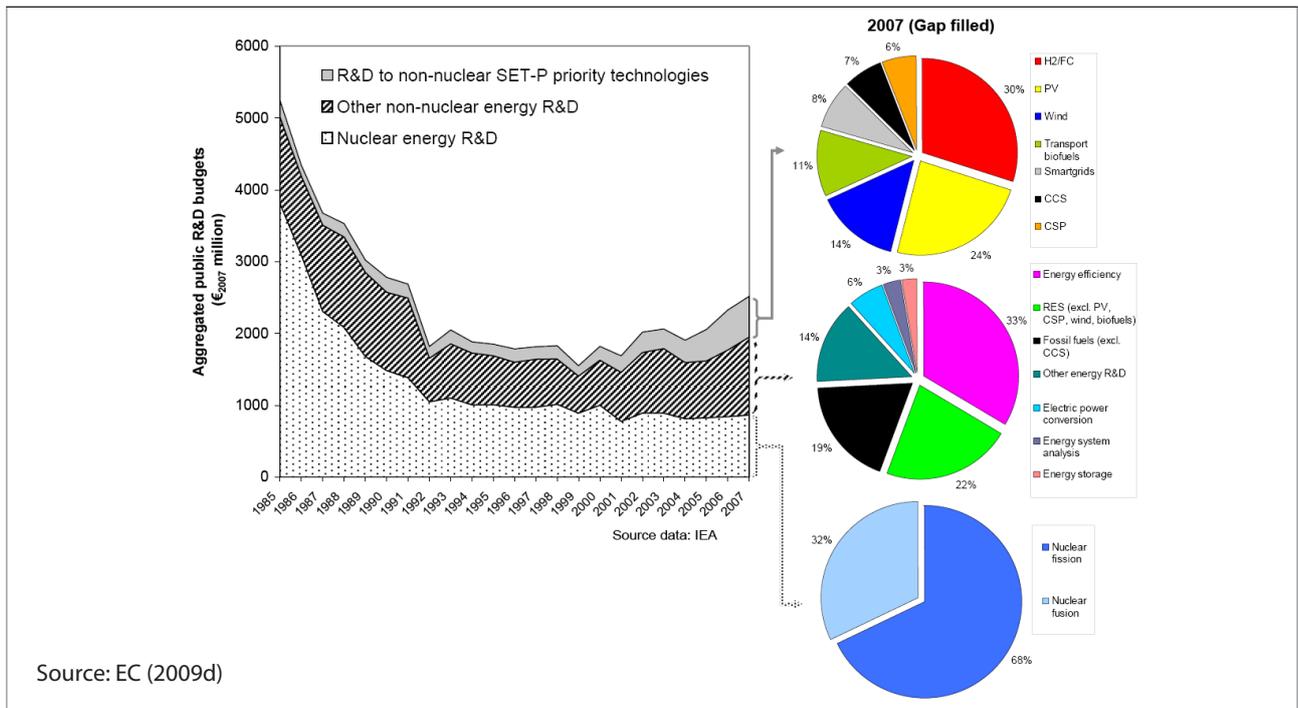
Figure 4. R&D in SET Plan sectors in relation to generation and consumption by member state.
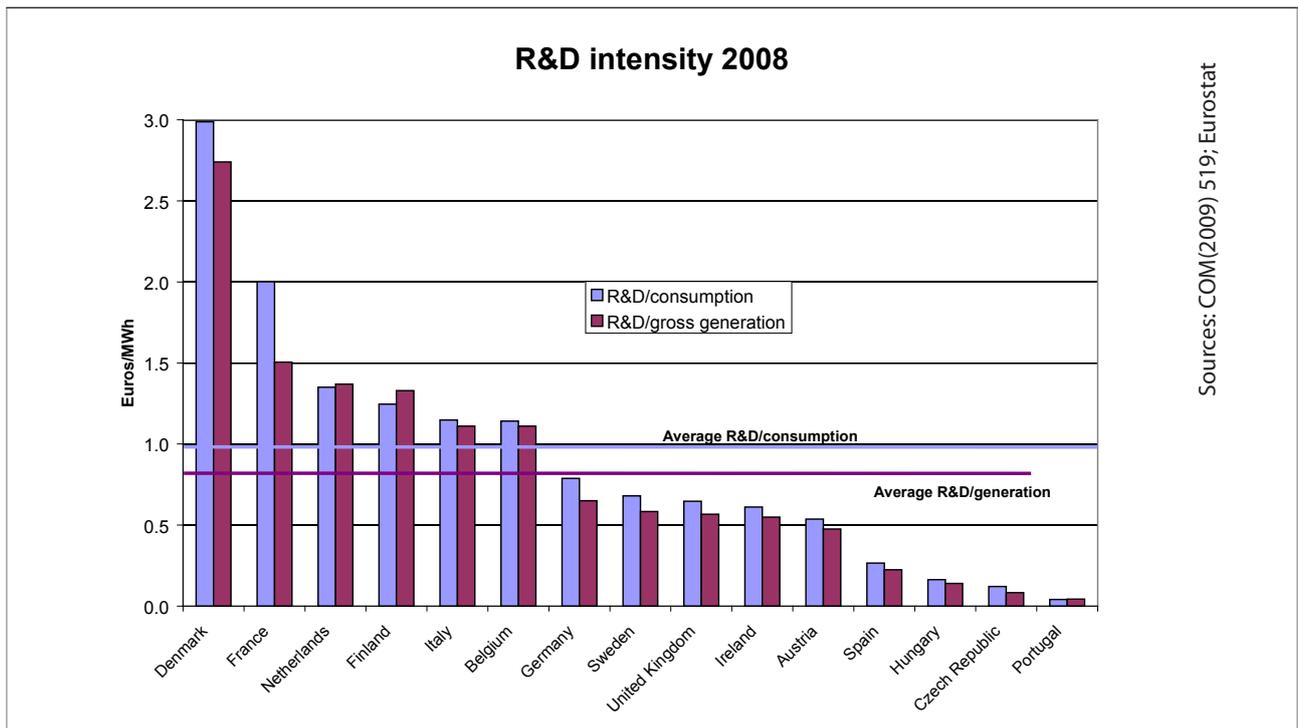
ANNEX B: Designing the SET Plan funding allocation

The expert committee has identified a preliminary allocation of funds to the designated technologies, after applying the following selection criteria: (i) EU added value/additionality; (ii) willingness of actors to join forces; (iii) potential market penetration of the technology in different time horizons; as well as (iv) potential contribution to CO_2 reduction, security of energy supply, and competitiveness.

The key technologies/sectors identified and the annual average amounts of funding currently allocated and proposed for the next ten years are shown in Table 6.

Table 6: Current funding and estimated financing needs for key SET Plan technologies

	Private	EU	MS	Estimated for next 10 years	Justification
	Million € in 2007			Billion €	
Hydrogen/ fuel cells	380	70	170	5	Updated estimation of resources needed made by stake-holders – 'Implementation Plan' of the hydrogen and fuel cell technology platform (Study by the JRC)
Wind	290	11	80	5.5	Estimation of resources needed made by stakeh. –Costing of the Wind Industrial Initiative
Solar PV/ CSP	270	32	170	16	Estimation of resources needed made by stakeh. –Costing of the Solar Industrial Initiative
CCS	230	17	40	10.5-16.5	Estimation of resources needed made by stakeh. –Costing of the CCS EII (including the 7-12 B€ CCS demonstration projects - Study by McKinsey)
Biofuels	270	13	65	8.5	Estimation of resources needed made by stakeh.–Costing of the Bio-fuels Industrial Initiative
Electricity grids	210	14	50	2	Estimation of resources needed made by stakeh. for transmission and by EC for distribution – Costing of the Smart Grid Industrial Initiative
Smart cities				10-12	Estimation based on experience from CIVITAS and CONCERTO initiatives and reviewed by the JRC
EERA				5	Estimation of resources needed made by the Commission in consultation with EERA – Based on input from EERA assuming that 30% of their future activities are jointly planned and implemented.
Nuclear fission	205	5	250	5-10	Estimation of resources needed made by stakeh. –Costing of the Nuclear fission Industrial Initiative
Nuclear fusion	0	204	280	-	-

ANNEX C: SET Plan European Industrial Initiatives

Table 7. SET Plan European Industrial Initiatives

EEI	Solar PV		Solar CSP				Electricity Networks (Smart Grids)			
Strategic objective EII	Improve competitiveness, ensure sustainability of technology, facilitate large-scale penetration **(Solar PV)** Demonstrate competitiveness and readiness for mass deployment of advanced CSP plants through scaling-up of the most promising technologies to pre-commercial or commercial level **(Solar CSP)**						To transmit and distribute up to 35% of electricity from dispersed and concentrated renewable sources by 2020 and a completely decarbonizesd electricity production by 2050, to integrate national networks into a market-based truly pan-European network			
State of the art	Small scale: Commercialized; large scale: Development; thin films: Development (state in 2007)						Long overhead lines: centralized network control (2007)			
Current market share	0.1% of electricity demand (2007) 3.4GWp Installed Capacity (2006)						75-85% of generation at transmission level (2007)			
Projections (by 2020)	**12%** of electricity demand		**3%** of electricity demand				./.			
Inv. needs (2010-20)	16 billion Euro						2 billion Euro			
Industrial sector objectives EII	Establish PV as a clean, competitive and sustainable energy technology		To demonstrate competitiveness and readiness for mass deployment of advanced CSP; to contribute around 3% of European electricity supply by 2020 with a potential of at least 10% by 2030 (if DESERTEC)				To substantially reduce capital and operational expenditure for the operation of the networks while fulfilling the objectives of a high-quality, low-carbon, pan-European, market based electricity system			
Technology objectives EII	1) PV Systems to enhance the energy yield and reduce costs (further develop and demonstrate advanced manufacturing processes)	2) Integration of PV-generated electricity (develop and validate innovative, economic and sustainable PV applications)	1) Reduction of generation, O&M costs (To develop advanced plant monitoring and control technologies)	2) Improvement of operational flexibility and energy dispatchability (To develop and improve thermal energy storage)	3) Improvement in the environm. and water-use footprint (To demonstrate CSP-specific sustainable water desalination processes)	4) Advanced concepts & designs	1) Developing and validating advanced network techn. to improve flexibility and network security and to mitigate future CAPEX/OPEX	2) Preparing the long-term evolution of electricity grids to ensure the proper investments	3) Engaging the active participation of customers in energy markets and energy efficiency	4) Elaborating and testing innovative market designs
Related actions EII	(1) collaborative technological development programme focused on enhancing performance and lifetime, manufacturing process development to address twin challenges of PV device innovation (2) longer-term research programme	(1) technology development and demonstration programme for Building-Integrated PV, stand-alone and large ground-based PV systems (2) Introduction of new storage technologies in pilot units for large-scale field trials	R&D & demonstration programme to address individual components as well as the overall conversion efficiency and to reduce investment cost	R&D and demonstration programme addressing thermal energy storage and CSP plant hybridization	R&D and demonstration programme addressing water cooling needs, dry cooling, water desalination and purification	A longer-term R&D programme aimed at supporting the longer-term CSP industry development	(1) RD&D to validate state-of-the-art power techn. from offshore sources and to develop new control systems to ensure integration of large RES and to operate pan-European nets (2) Demo activities for automating distribution network control and operation	R&D activities to develop modeling and planning tools for the long-term evolution of the grid	Demonstration activities on different solutions to activate demand response for energy saving	R&D activities on cross-cutting issues to proposing market designs that provide incentives for all actors to contribute to the overall efficiency

EII	Hydrogen and Fuel Cell				Nuclear			
Strategic objective EII	Expected to play an important role in achieving EU vision of reducing GHG emissions by 60-80% by 2050				A vast increase in the sustainability of nuclear energy through demonstrating the technical, industrial and economic viability of Generation-IV fast neutron reactors, thereby ensuring that nuclear energy can remain a long-term contributor to the low carbon economy and building on the safety, reliability and competitiveness of current reactors			
State of the art	Large scale transport of hydrogen is already commercialised (2009) Large scale hydrogen production: commercialized or under development (2007) Small scale hydrogen: demonstration/commercialized (2007) Fuel cells: demonstration (2007)				**Nuclear Fission:** Gen-III: Mature technology; Gen-IV: depends on concept. Basic research still required for all designs leading to strategic decisions by 2012 at the latest. First of a kind and demo plants (VHTR and SFR) by 2020 **Nuclear Fusion**: Committed construction of ITER as prototypic experiment aimed at demonstrating the technological feasibility of fusion energy			
Current market share	Null				Nuclear Fission (31% of demand in 2009 ~ 135 GWe installed capacity) Nuclear Fusion (None market share - needing another 30-40 years to reach maturity)			
Projections (by 2020)	Max. estimated market share of H2 vehicles in EU-27 up to 1.4% in 2020 and 12% in 2030; by 2020, mass market roll-out expected to be kick-started in transport sector; by then, 1-5 mn vehicles would be on the road with plus 0.4 to 1.8 mn vehicles/a; 8 to 16 GWe would be produced by CHP fuel cells				The installed capacity of nuclear fission power for the EU-27, with respect to the baseline, is: 115 GWe in 2020 and 100 GWe in 2030			
Investment needs (2010-2020)	470 million Euro				5 - 10 billion Euro			
Industrial sector objectives EII	To develop and validate efficient and cost-competitive technologies for various applications				To enable the commercial deployment of Generation-IV FNRs from 2040, while in the meantime maintaining at least a 30% share of EU electricity			
Technology objectives EII	1) Technology development with focus on cost reduction	2) Design and implement a technology specific support framework for hydrogen &	3) Planning and financing of infrastructure build-up & large scale demonstration project	4) Pre-commercial technology refinement & market preparation	1) Through design, construction and operation of a prototype sodium fast reactor	2) The refurbishment and/or design, construction and operation of infrastructures needed to support the design and/or operation of prototype and demonstrator FNRs	3) Supporting infrastructures for prototype and demonstrator	4) R&D supporting all aspects of the design, construction and operation of the prototype, demonstrator and support infrastructure
Related actions EII					(1) Design, construction and operation of a prototype SFR coupled to grid (2) Finalise design and obtain a license for construction of SFR prototype (250-600 MWe), startup by 2020	Design, construction and operation of a demonstrator (not coupled to the grid) of alternative technology, either gas or lead cooled fast reactor (GFR or LFR)	(1) Supporting infrastructures for prototype and demonstrator (2) Design, construct or upgrade a consistent suite of experimental facilities for component design,	Basic and applied research to support the activities foreseen in the actions above

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EII	Wind				CCS	
Strategic objective EII	To improve the competitiveness of wind energy technologies, enable the exploitation of offshore resources and deep waters potential, and facilitate grid integration of wind power				Demonstrate the commercial viability of CCS technologies in an economic environment driven by the EU-ETS	
State of the art	Onshore wind = mature technology (ongoing R&D efforts primarily focused on maximising the value of wind energy and taking the technology offshore; main technological development in recent years is a trend towards ever larger wind turbines)				Pulverized coal (state-of-the-art 45% efficiency),GTCC (efficiencies 57%-60%); capture technology is at an advanced stage of research; large scale transport of CO_2 using pipelines commercialised in N. America; industrial CO_2 storage operational around the world (~3 Mt of CO_2 p.a.)	
Current market share	Installed capacity in the EU is about 50 GW, contributing 3% to European gross electricity consumption				0	
Projections (by 2020)	Capacities for EU-27 in the baseline are 120 GW in 2020 and 148 GW in 2030; estimated max. potential is up to 180 GW by 2020 and 300 GW by 2030 representing ~11 (18) % of projected EU gross electricity consumption by 2020 (2030)				From the technology point of view, ZEP plants can be commercialised as of 2020, with first-of-a-kind plants coming into operation by 2015; estimated max. potential in EU-27: up to 190 GW by 2030 (represents ~32% of projected EU gross electricity consumption)	
Total investment needs (2010-2020)	~ 6 billion €				10.5-16.5 billion €	
Industrial sector objectives EII	To enable a 20% share of wind energy in the final EU electricity consumption by 2020				./.	./.
Technology objectives EII	1) New turbines and components (to lower investment and O&M costs)	2) Offshore technology (focus on large-scale turbines and deep water technologies)	3) Grid integration (i.e. techniques for large-scale penetration of variable supply)	4) Resource assessment and spatial planning (to support deployment)	1) Providing the technical and economic feasibility of CCS using existing technologies (i.e. test fully integrated value chains at large scale; reduction of costs)	2) Developing more efficient and cost competitive CCS technologies (i.e. improve efficiency of power plants, develop new capture concepts and technologies for transport and storage; expand use of CCS to other sectors)
Related actions EII	(1) R&D program focusing on new turbine designs, materials, etc. (on-/offshore) + demonstration program for 10-20 MW turbines; (2) Network of 5-10 European testing facilities; (3) Cooperation and demonstration program	(1) Development and demonstration program (at least 4 structure concepts); (2) Demonstration program on advanced mass-manufacturing processes	Demonstration program focusing on wind farm management as VPPs	R&D program for forecasting distribution of wind speeds and energy production	Realization of 8 to 12 large-scale demonstration programs (incl. capture, transport and storage); Establishment of a network (knowledge sharing, joint activities)	Establishment of an R&D program addressing i) improvement of fossil fuel power plant efficiency, ii) improvement of capture process efficiency, iii) transport and storage concepts, iv) use of CCS in other industrial sectors

EII	Bio-Energy			Smart Cities		
Strategic objective EII	Address techno-economic barriers to further development and accelerated commercial deployment of bioenergy conversion techn.			Demonstrate feasibility of rapidly progressing towards the energy and climate objectives at a local level while proving to citizens that their quality of life and local economies can be improved through investments in energy efficiency and reduction of carbon emissions		
State of the art	Biomass already used in CHP (increasing importance), biofuels used					
Current market share	Almost 4% of the EU gross energy demand covered by biomass; in 2005, ~5% of the biomass consumption for energy purposes was dedicated to biofuel production (about 4 Mt)		./.			
Projections (by 2020)	Biomass CHP in EU-27: up to 42 GWe by 2020 and 52 GWe by 2030 (would generate ~4.7 (5.3) % of projected EU gross electricity cons. ; Biofuels in EU-27 transport (baseline): 7.5% in 2020 and 9.5% in 2030; max. estimated market share are up to 14% in 2020 and 20% in 2030		./.			
Inv. needs (2010-2020)	~ 9 billion €			10-12 billion €		
Industrial sector objectives EII	To ensure at least 14% bioenergy in EU energy mix by 2020			./.		
Technology objectives EII	1) Bring to commercial maturity the currently most promising technologies and value chains (i.e. advanced biofuels and heat&power)	2) Activities in biomass feedstock availability assessment, production, management and harvesting	3) Longer-term R&D program	1) Buildings - New buildings with net zero energy requirements or net zero carbon emissions by 2015 - Refurbish of existing buildings to minimize energy consumption maintaining or increasing performance and comfort	2) Energy networks Heating/cooling: - Innovative and cost effective biomass, solar thermal and geo-thermal applications - Innovative hybrid heating and cooling systems Electricity: - Smart grids, Smart metering and energy management systems, Smart appliances - To foster local RES electricity production	3) Transport - 10-20 testing and deployment programs for low carbon public transport and individual transport systems - Sustainable mobility
Related actions EII	Optimization of most promising value chains within a) thermo-chemical (2-4 demonstration and 10-15 first-of this-kind industrial size plants and b) bio-chemical pathways (5-8D, 4-7F) -> technology pathways and value chains see detailed table (incl. estimated number of pilot, demonstration etc. plants)	Assessment of biomass availability; development/ optimization of technologies and logistics for sustainable production, management & harvesting (2-3 Pilot plants, 1 demonstration plant)	Construction of pilot and demonstration plants ~2018 -> identification of new value chains, exploitation of new raw materials (1-2P, 1-2 D)	(a) Test 100 new residential and 100 new non-residential buildings for different design options for zero energy buildings in different climatic zones (b) Test and assess through 5-10 programmes, strategies for the refurbishment of at least 50% of existing public buildings (c) Test and assess through 5-10 programmes, strategies for the complete refurbishment of 50% of all existing buildings	Heating/cooling: 5-10 demo programmes for large deployment of RES heating/cooling in cities supplying 50 % of heat/cooling demand from RES 5-10 demo programmes for large scale RES heating/cooling integration in energy efficient buildings in pioneer cities supplying about 50% of the heat and cooling demand from RES Electricity: Development and deployment programme focused on high efficient appliances lighting and SM 5-10 development and deployment programmes for smart grids in cities	(a) 10-20 testing programmes for the large deployment of alternative fuel vehicles including the fuel/energy supply infrastructure (b) Development and testing programmes focused on sustainable mobility

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ANNEX D: Allocating funds to low-carbon R&D projects

David Newbery[*]

January 13, 2011

Abstract

There is urgency in finding commercializable low-carbon options to mitigate impending climate change. If individual research projects have independent chances of success, the probability of at least one succeeding increases in the number undertaken and shortens the time to discovery, but at increased cost. This note considers how to choose the optimal number of such projects within a sector, and how to allocate funds across different sectors.

1 Choosing a portfolio of projects

There is considerable urgency in finding cheaper ways to decarbonize the economy to offset the apparently inexorable rise in CO_2 emissions. There are therefore compelling reasons for pursuing low-carbon R&D options in parallel rather than sequentially, to reduce the expected time to finding a viable solution. As Marschak et al (1967) and Nelson (1963) argue for R&D projects, the optimal search strategy is normally the pursuit of a number of simultaneous options. Sah and Stiglitz (1987), in examining the impact of market structure on the level of R&D, argued that individual firms would typically find it profitable to diversify and pursue parallel projects, and established conditions under which the total number of parallel projects was independent of industry structure, although Farrell, Gilbert and Katz, in their.informative extension of this model, showed that in general this finding was not robust to alternative specifications of competition

On the other hand, if projects yield information that is valuable in determining the subsequent research strategy, then parallel R&D forgoes the option of learning from prior projects (Loch et al, 2001). This note[1] provides a very simple model of choosing the number, n, of paral-

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[*]Faculty of Economics, University of Cambridge, Research Director, EPRG. Research support is from Florence School of Regulation under the EC project ThinkTank. I am indebted to RJ Lange and Rich Gilbert for helpful advice.

[1]The literature on searching for the best alternative (price, employment offer, etc) is extensive, as is that for R&D, which distinguishes between sequential search (e.g. Weitzman, 1979), parallel search (e.g. Vishwanath, 1992) and the optimal combination (e.g. Loch et al, 2001).

lel R&D projects if each has an independent chance of success, p, and allocating funds between different kinds of projects with differing success rates. Projects last one unit of time (which is likely to be a number of years) and cost (in present discounted value) C. The value of success after the elapse of this unit of time is $V = Ae^g$, and if all projects are unsuccessful, another set of projects can be undertaken, with expected net value at the end of the first period θV.[2] The ratio of the NPV of the portfolio of projects to their individual unit cost, C, at date 0 when the discount rate is r per period, is

$$W = (1 - (1 - p)^n)\frac{V}{C}e^{g-r} - n + (1 - p)^n \frac{\theta V}{C}e^{g-r}.$$

Define the individual project benefit-cost ratio, $B \equiv V/C$, then the optimal choice of n satisfies

$$\frac{\partial W}{\partial n} \quad = \quad (1 - p)^n \ln(1 - p)(-B + \theta B)e^{g-r} - 1 = 0, \tag{1}$$

$$(1 - p)^n \ln(\frac{1}{1-p}) \quad = \quad \frac{e^{r-g}}{B(1-\theta)}, \quad \text{or taking logs,} \tag{2}$$

$$n \ln(1 - p) + \ln \ln(\frac{1}{1-p}) \quad = \quad r - g - \ln B - \ln(1-\theta). \tag{3}$$

To see how n varies with the benefit-cost ratio, B, and the probability of success, p, differentiate (3) w.r.t. these variables:

$$\frac{dn}{dB} = \frac{1}{B \ln(\frac{1}{1-p})} > 0,$$

so, unsurprisingly, the number of projects to pursue increases with the benefit-cost ratio, B. Also, differentiating w.r.t. p

$$\frac{\partial n}{\partial p}(\ln(1 - p)) \quad = \quad \frac{n}{1 - p} - \frac{1}{(1 - p)\ln(\frac{1}{1-p})},$$

$$\frac{\partial n}{\partial p} \quad = \quad \frac{n + \frac{1}{\ln(1-p)}}{(1 - p)\ln(1 - p)}.$$

That shows that as the probability of success per project increases, so fewer projects should be undertaken.

The response to varying B and p can be illustrated numerically as follows. If $\theta = 0$ (no follow-on projects), $g = 0.15$ (e.g. a period is 5 years and benefits grow at 3% p.a.), and $r = 0.25$ (annual discount of 5%), so that $e^{g-r} = 0.905$, then if $p = 0.5$, and $B = 10$, 3 projects are optimal, but only 2 if $B = 5$ and 4 if $B = 20$. If, instead, all variables remain the same except $p = 0.25$ and $B = 20$, then 6 projects are optimal, but at $B = 5$ only one project is viable (has a positive value for W).

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[2] Vishwanath (1992) models the sequential aspect in a proper dynamic programming framework, and shows that if projects are independent, as here, and success terminates search, then if the discount rate is zero there will be no sequential projects.

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2   Allocating funds between sectors

The net value of the portfolio strategy is W, but the ratio of net value to initial cost is W/n, which may be relevant if funds are limited. If that is the case, then it may be better to ration choices through the interest rate, and it is readily established by differentiating (3) w.r.t. r that

$$\frac{dn}{dr} = \frac{1}{\ln(1-p)} < 0,$$

so the number of projects to pursue (and the total cost) will be lower for higher discount rates. It is also clear that W/n will decrease in n before $W' = 0$, so again budget constraints indicate fewer projects. The more interesting question arises at a higher level, where the government or organization needs to choose how best to allocate funds to very different sectors (for example, between wind, solar, bio-energy, nuclear fission and CCS), each with very different probabilities of success, p_i, and eventual pay-offs, V_i, and costs, C_i. Consider the simple case in which $\theta_i = 0$ (if not then the overall payoffs are merely scaled up by some factor). The problem can be formulated as choosing the vector of n_i's, $\boldsymbol{n}$, to maximize

$$\begin{aligned}
S(\boldsymbol{n}) &= \sum_i (1 - (1-p_i)^{n_i})V_i e^{g-r} \text{ s.t. } \sum_i n_i C_i \le C, \\
\mathcal{L} &= \sum_i (1 - (1-p_i)^{n_i})V_i e^{g-r} + \lambda(C - \sum_i n_i C_i), \\
\frac{\partial \mathcal{L}}{\partial n_i} &= (1-p_i)^{n_i} \ln(\frac{1}{1-p_i})V_i e^{g-r} - \lambda C_i \ge 0, \perp n_i = 0.
\end{aligned}$$

The solution, if positive, is then

$$n_i = \frac{\ln B_i + \ln\ln(\frac{1}{1-p_i}) - r + g - \ln\lambda}{\ln(\frac{1}{1-p_i})},$$

where λ solves the budget constraint - the smaller is λ, the larger will be the n_i. To take an example, suppose there are two projects, one with a standard potential return B and a reasonable chance of success, p, the other with a high potential return, kB but a small chance of success, p/k, $k > 1$. Define $f(p) = \ln(\frac{1}{1-p}) \simeq p + \frac{1}{2}p^2$ (with an error of less than 10% for $p < 0.5$). Note that $f(p) > kf(p/k)$. Then

$$\begin{aligned}
n_1 &= \frac{\ln B + \ln f - r + g - \ln\lambda}{f} \simeq \frac{\ln B + \ln p + \ln(1 + \frac{p}{2}) - r + g - \ln\lambda}{f}, \\
n_2 &\simeq \frac{\ln k + \ln B + \ln\frac{p}{k} + \ln(1 + \frac{p}{2K}) - r + g - \ln\lambda}{f_2} > k\frac{\ln B + \ln p + \ln(1 + \frac{p}{2k}) - r + g - \ln\lambda}{f}, \\
n_2 &= kn_1 + \frac{\ln(1 + \frac{p}{2k}) - \ln(1 + \frac{p}{2})}{f} > kn_1.
\end{aligned}$$

Thus the project with the same expected return $pB = \frac{p}{k}kB$ but the lower individual chance of success should have more a relatively larger share of the funds than would be allocated on a

straight expected return basis where the number of projects is set just k times the reference level. The reason is that the ability to pursue parallel projects raises the overall chance of success.

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ANNEX E: Valuing low-carbon R&D

David Newbery[*]

November 14, 2010

Abstract

Renewable electricity generation in general and PV in particular are likely to require subsidies for a considerable time while learning-by-doing and R&D drive down costs. If eventually economic, these technologies will thereafter create social value by reducing carbon emissions with value greater than the cost of abatement. This note points to the various factors that influence the value of current R&D in PV or similar technologies.

1   Choosing R&D projects under the SET-Plan

The EU's Strategic Energy Technology Plan (SET-Plan, COM(2009) 1297) aims to nearly treble R&D in specified low-carbon energy technologies over the next decade. Where public funds are involved, R&D projects will need evaluation, and ideally some form of cost-benefit analysis to determine whether the expected benefits exceed the predicted costs. This note works through an illustrative example of a possible R&D project for improving photovoltaic (PV) technology.

2   The example of PV

The SET-Plan documents (EC 2009) report a steady learning rate of 22% for PV since 1979 (meaning that for each doubling of installed capacity, unit generation costs fall 22%), and forecasts that a cumulative installation of 380 GW would reduce system costs to below €1,500 /kW$_p$.[1]

As capacity factors are typically below 25%, this would be the capital cost to deliver 1,750 kWh/yr at a cost of just under 7 eurocents/kWh at 5% discount rate over 20 years (any running

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[*]Faculty of Economics, University of Cambridge, Director, EPRG. Research support is from Florence School of Regulation under the EC project ThinkTank.

[1]Solar capacity (like that of wind power) is measured by peak output (hence the subscript p), which varies with location.
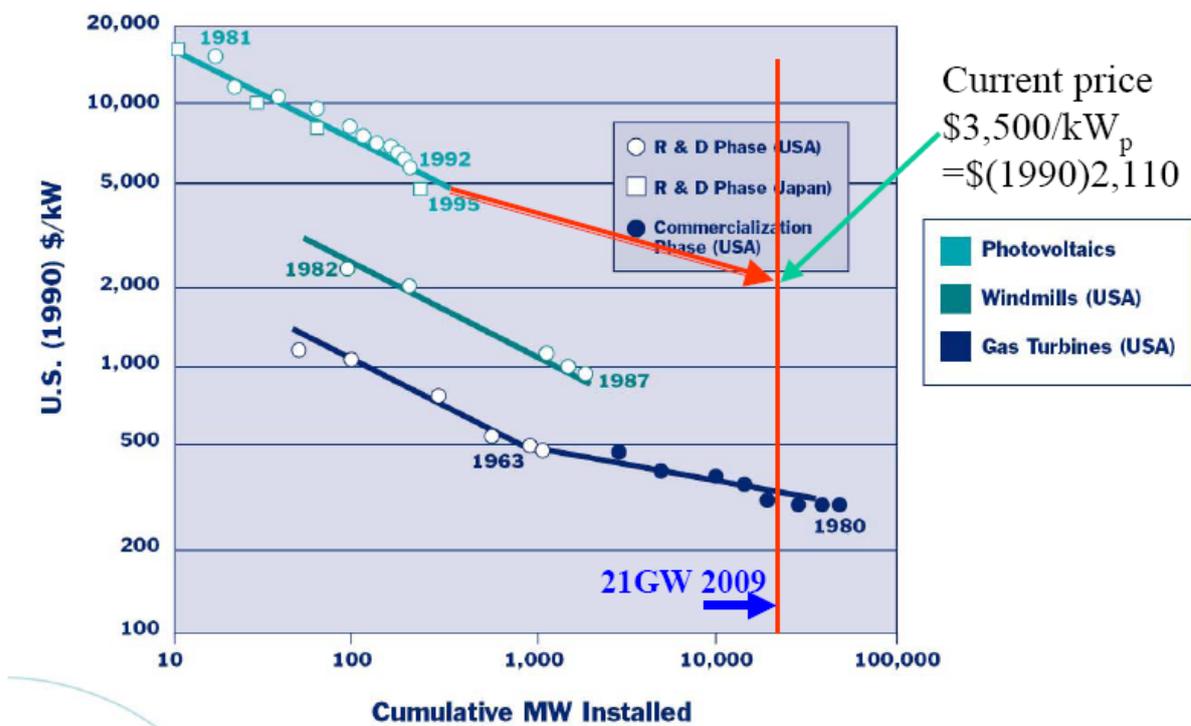
Figure 1: Source: N. Nakicenovic, A. Grübler, and A. McDonald, eds., Global Energy Perspectives (CUP, 1998).

or maintenance costs would be extra). The SET-Plan cost estimates were based on earlier data and have been superceded by events. In 2010 industry sources reported crystalline silicon module ASP prices as low as $1,600/kW$_p$ (€1,250/kW$_p$) with predicted prices (not necessarily the same as costs) of $1,420 (€1,110/kW$_p$) by the end of 2010.[2] These costs are only part of the installed costs, the other part being the balance of Systems or BOS costs, that might account for 50-60% of the all-in cost for silicon systems, but perhaps less for other thin film technology, where figures for potential (2012) BOS costs of $700/kW$_p$ (€550/kW$_p$) have been suggested.[3] Thus a very rough estimate of all-in costs at the end of 2010 (assuming no rebound in silicon prices) might be €2,700/kW$_p$

Between 2004 and 2009, grid-connected capacity increased at an annual average rate of 60%, to some 21 GW (REN21, 2010), so to reach 380 GW the rate of growth in the next 10 years would need to be 33% p.a. Whether PV would then be widely competitive would depend on the cost of electricity from alternative sources, which would depend on fuel and carbon costs and the capacity cost, efficiency and longevity of these alternatives.

Learning rates are observed ex post, and are the result of a number of factors. R&D in its broadest sense will include research in industrial labs and universities into materials, fabrication, power conversion, and a range of other elements in the system, directed to reducing costs, increasing reliability, efficiency, etc. Experience and scaling up the manufacture will allow further cost reductions, through better process design, economies of scale and the like. An individual R&D project may, with some success probability, reduce the cost per kWh generated in a number of ways (extending life, increasing efficiency, reducing materials and/or installation costs, etc.). If this innovation is successful, then it will gradually diffuse and benefit future production, and may lower the cost base from which future learning-by-doing (including that part more accurately described as R&D) can proceed. As a result the date at which PV becomes competitive against other generation technologies will be advanced and the costs of supporting deployment before then will be reduced.

In estimating the social value of a particular R&D project an alarmingly large number of assumptions must be made, each of one which is uncertain. The purpose of this note is to indicate their relevance and relative importance, although there remain a number of important issues that will affect the evaluation of the project.

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[2] http://www.renewableenergyworld.com/rea/news/article/2010/08/keeping-pace-with-cost-reduction-as-module-prices-continue-to-decline dated 12 Aug 2010 accessed 14 Nov 2010

[3] See the article at http://www.electroiq.com/index/display/photovoltaics-article-display/1325663433/articles/Photovoltaics-World/industry-news/2010/november/can-solyndra-reconcile-cost-per-watt-and-sale-price.html that thin film technolgies, currently costs $3.50/W$_p$ were aiming at panel costs of $1.30/W$_p$ and an all in system cost of $2/W$_p$ by 2012.

2.1 Predicting future PV capacity

Learning-by-doing requires a continued expansion of installed capacity, so the rate of growth of installed capacity is a crucial element of the valuation. Current PV costs are of the order of 3,000 €/kW$_p$ and possibly less, but if we take the growth rate predictions seriously (33% p.a.), the capacity doubling time is 2.43 years, after which, if we assume a continuation of the past learning rate of 22%, costs will fall to 78% of their initial value. After 10 years on this trajectory, costs should have fallen to $0.78^{4.12} = 0.36$ of their initial value, which if we take the figure of €3,000/kW$_p$ would be €1,080/kW$_p$, below the predicted value (which is consistent with a predicted 2010 cost of €4,000/kW$_p$).

In 2007 world electricity consumption was 16,330 TWh. If this grows steadily by 49% up to 2035 (Report :DOE/EIA-0484(2010)),[4] the annual rate of growth would be 1.33%, and in 2019 (10 years from our start date) the predicted world electricity consumption would be 19,135 TWh. At a load factor of 18%, PV generation would be 600 TWh or 3.1% of total consumption. However, there are two obvious objections to these predictions. The first is that PV capacity can sustain such a high rate of growth as its installed base increases. While 33% of 21 GW is only 7GW, 33% of 380 GW is 125 GW, a truly substantial annual rate of investment, which at the predicted future cost, is €188 billion. The IEA was considerably more cautious in projecting PV penetration. and estimated that it might take until 2050 to reach even a 2% penetration (IEA, 2006). IEA (2008) projected world PV generation as 230 TWh in 2030, representing a growth rate from 2009 of only 10% p.a.

A more plausible projection might suppose that the rate of growth of PV capacity is 30% in 2010 but thereafter its rate of growth decreases from the previous year by 1.5% until it reaches the rate of growth of electricity as a whole (so that in 2014 it is only growing at 24% p.a.), then capacity reaches 380 GW by 2031. Assuming an 18% load factor, its share of global generation first exceeds 2% in 2023, outpacing the IEA projections (although the purpose of the SET-Plan is to accelerate low-C technologies like PV, so that is to be expected).

The second problem is assuming that costs will continue to decrease by 22% for each doubling of installed capacity, which, with the original capacity expansion assumptions, would have unit costs down to 3.6 eurocents/kWh by 2024, an implausibly optimistic level. One must be cautious in projecting learning rates into the indefinite future, as this would suggest that costs could be driven to zero, although clearly there will be material, processing and installation costs that will reach some irreducible minimum (for example much of the BOS costs are area related and less likely to be driven down so rapidly as the silicon or other module costs). The PV panel to deliver

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[4] available at www.eia.doe.gov/oiaf/ieo/excel/ieokayatab_2.xls

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the 1 kW$_p$ would need to be more than 1 sq. m. in size in favourable locations,[5] and clearly that will require that area of suitable material, quite apart from the power converters, connection and installation costs. It may be better to project that the difference between current and ultimately achievable cost decreases with each doubling of installed capacity, suggesting a decreasing rate of cost reduction. A key parameter is then the level of this irreducible minimum cost, and the rate of learning to apply to the excess of current costs over this minimum cost.

2.2   Valuing cost reductions

If the R&D project succeeds it should reduce future capacity costs (and hence the cost of generation, which is primarily the capital cost). The first question is whether the cost reduction will benefit the whole future market or some subset (e.g. the market for PV as a cladding on office buildings). Once the ultimate market is defined, the next question is how rapidly the cost reduction will diffuse and be taken up. The standard diffusion model would be a logistic, characterized by the time taken to penetrate half the market and the initial rate of growth (or, equivalently, the time taken to reach 25% of the total market). The final and critical step is how the innovation affects future innovation possibilities and cost trajectories. At the most optimistic end, the innovation would contribute to future cost reductions by lowering the cost base from which learning and/or R&D drives down future costs. The most pessimistic assumption is that the innovation has no effect on future cost reductions, which will, after some lag, arrive at the same cost level as had this innovation never occurred. Finally, if the innovation does indeed accelerate the entire cost-reduction process, it will advance the date at which the technology can start to earn social profits (which will include the wider carbon benefits, that may not be fully reflected in carbon prices).

The future benefits from a successful innovation will therefore be made up of two parts: reductions in the cost of subsidy needed to deploy PV while it remains uncompetitive against market prices (including the carbon price), and the extra value of advancing the date of earning social benefits, assuming that the technology is pursued to that point and not abandoned in light of future information. These benefits accrue partly to the country undertaking the project, partly to the rest of the EU (the quid pro quo for a collective SET-Plan approach, in which other countries will undertake support actions that will generate benefits for this country), and partly to the rest of the world. It is an important ethical and political question whether and if so how much to credit benefits that are external to the EU. One can imagine a global bargain in which we agree to count these benefits (and hence justify more R&D) in return for other countries imposing a carbon price or agreeing other mitigation plans. Alternatively, we might make the

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[5]E.g. see http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/colorgifs/208.GIF

ethical judgement that we should take account of the external benefits, if only to compensate for our earlier lack of taking account of the external costs.

2.3   Numerical examples

To illustrate the impact of these various factors, consider first the more realistic expansion path considered above (30% falling by 1.5% p.a. until the rate is no higher than total demand growth), and suppose that the 2010 cost base of PV is €2,700/kW$_p$ and that the rate of cost reduction is only 15% (not the past rate of 22%) and that moreover it only applies to the excess cost above an assumed irreducible minimum of €1,250/kW$_p$, and that this learning rate falls to 5% in 2016 and to zero in 2035 (when costs have fallen to €1,263/kW$_p$.[6] Suppose next that the R&D project, if successful, would lower current capacity costs by 1%, and that this would create a lower cost base from which future cost reductions are based (the most optimistic assumption), but that this innovation only diffuses through the entire global market (the largest possible market) with a time characteristic of 3 years and a starting value of $t = -10$.[7]

Suppose also that PV becomes competitive (given the right carbon price) in 2035, and that thereafter the PV costs stabilize but the value of electricity rises at 1% p.a. (because of the rising carbon price and the assumption that PV is displacing fossil generation, half of whose cost is CO_2. Future costs and benefits are discounted at 5% and the horizon is a century. The NPV of support cost reductions globally would be €336 million, and the effect of advancing the date of introduction through producing lower prices sooner would be worth €55 million, or €390 million in total, of which 86% is the saving in support costs. Lowering the discount rate to 4% increases total global benefits to €454 m, or by 16%, while increasing the discount rate to 6% reduces total global benefits to €343 m or by 13%.

If the EU is only responsible for 25% of global PV installations (it was about 50% in 2007) and if we only count the EU benefits in cost reduction, then the cost savings fall to €84 million, and if we only count the EU's current share of CO_2 of 16% in estimating its share of global benefits (and that share will fall) then the future social benefits are only €9 million, giving a total benefit of €93 million. If the project only succeeds with probability 10% the EU benefit falls to €9.3 million. It would be further reduced if PV is abandoned as a viable future commercializable choice, or if PV's future market share were lower, or if the current project has only a temporary

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[6] If other large scale commercialized generation technologies are experiencing learning by doing or cost reductions, then these rates of cost reduction should be interpreted as relative to their "background" rate, so by 2035 PV is effectively only enjoying the sector-wide rate of productivity increase or cost reduction.

[7] The market share at date t is $(1 + e^{-t/k})^{-1}$ where k is the time characteristic and date $t = 0$ is the date of 50% market share. The initial value also needs to be specified, and in this case is $t = -10$. With these parameters penetration reaches just over 25% in 7 years.

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impact on future cost reductions.

We can rerun the example making changes one at a time, but only looking at global benefits. Suppose first that rates of expansion only fall at 1% each year, so that ultimate PV penetration rises to nearly 10%, then the cost savings are worth €572 million and the advancing of social benefits €83, or €655 m in total, 68% higher than if the expansion rate slows more quickly. Interestingly, changing the ultimate cost limit from €1,250/kW$_p$ to €1,500/kW$_p$ has no effect on the project benefit (but a considerable effect on the costs of PV). The same is true of the load factor assumed (again, because the R&D project is assumed to lower costs per MWh by 1% regardless of how many kWh are produced per kW$_p$.

If we go back to the first expansion path but now suppose that cost reductions are 10% p.a. from 2016 on until 2035 instead of 5% p.a. then the global value of cost reductions falls to €189 m and the advancing of social benefits to €1 m, or €190 m in total, only half as much as the more pessimistic learning assumption. Raising the rate of learning for the first six years to 20% but then letting it fall to 5% has a smaller negative effect on benefits, which in total fall to €225 m. These apparently counterintuitive results of changing learning rates arises because the total costs of support are lower, and the benefits of lowering them 1% is also lower - clearly it would be better to have higher rates of learning both to reduce support costs and to advance the date of commercialization.

If the rate of diffusion is higher, for example if the start date of the process is $t = -8$, then the global total value increases to €525 m or by 34% and if the time constant $k = 4$ instead of 3 then total global benefits increase to €567 m or by a further 8%.

3   Conclusions

The numerical examples demonstrate that evaluating a low-carbon R&D project is fraught with difficulty, as its value will depend sensitively on a large range of parameters, almost all of which are very uncertain. The rate of capacity expansion is critical, not surprisingly as the power of compound growth over long periods is enormous, and some reality check on ultimate market penetration is clearly needed. Learning rates are important for determining total support costs and the date of commercialization, but higher future learning rates lower the value of a current R&D project that lowers costs today, assuming that leads to a lower cost base to which these learning effects are applied. Another way of putting the same point is that a given percent reduction in the initial cost base translates into a shorter period of time gained when exogenous learning rates are higher and hence is worth less. Discount rates have a predictably large effect on present values. So do diffusion rates, suggesting that IP policy will be important. That said, for many R&D projects the futures will be similar, even if all uncertain, and so the relative

ranking of these projects may be more robust than their absolute value. If the aim is to allocate a fixed sum of money, that ranking may be sufficient.

Finally, the project success rate, whether it will penetrate the global market, and whether it creates an enduring improvement that can be built on, all have powerful effects on its value, as does the generosity with which global rather than EU benefits are treated.

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ANNEX F: Industrial Council Meeting Summary

The question to be answered

How to fund innovation (RD&D) on low carbon energy systems[1] more efficiently[2] to meet on EU climate change policy goal(s)?

A potential answer at EU level

Completing the existing industrial initiatives on low carbon systems as described in the SET Plan will require novel public/private funding mechanisms, which go much beyond existing FP7 mechanisms, thanks in particular to more coordinated MS/EU activities.

Clarity improvements proposed for the report next version

The combination of all the SET Plan funding requirements (say 50 Billion € above what is already funded at MS and EU level over the next ten years) emphasises the needs to raise extra money (both public and private) if one wants to comply with the existing industrial initiatives demands. So far, most of the low carbon systems have coupled EC/MS and private funds coming from existing energy players. There is growing evidence that future support will require funding coming from non energy players, which in turn will require innovative financial measures.

The report must therefore clarify and pinpoint:

— the scope of the technology innovation cycle addressed, making sure to cover costly large scale demonstrations which are needed to scale up and to replicate successful solutions in the energy sector,
— the specific barriers which are faced by low carbon energy systems (infrastructure-legal-regulatory),
— market failures at MS and EU level which justify the needs for public intervention (which can be regulatory, financial, legal…),
— the sense of tax payers (subsidies) / customer (tariffs) / investor funding of climate change policies,
— the related IPR issues faced by low carbon system funding which can impede or accelerate the dissemination and use of the RD&D publicly funded projects: low carbon systems have a long lead time, with breakthrough concepts being originated quit often by start-ups or SMEs. They will need a strong IPR policy to avoid free riding from participating or non participating players.
— the potential sources of non energy funding sources (the example of British Telecom or Google committed to reduce the electricity demands from data management systems): they fund the RD&D to comply with their internal new requirements.

Another concept used in the initial report (maturity of technology) needs to be used with caution: a technology is said to be "mature" within a manufacturer when it has reached the development break even point. It might be therefore very much market dependent (for instance, several new power technologies are mature on the Chinese market; and not yet mature to be implemented in European systems since they need more development to fit European requirements).

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1   Technologies included are: hydrogen and fuel cells; wind energy; photovoltaics; carbon capture and storage; biofuels; smart grids and concentrating solar power.

2   The aggregated R&D spending towards selected non-nuclear SET-Plan priority technologies amounted to €2.38 billion in 2006/7, out of which €1.66 billion originate from corporate R&D investments in 2007, while €0.57 billion stem from public national R&D budgets in EU Member States in 2007 and €0.16 billion are financed through the European FP6 (see R&D investment in the priority technologies of the European strategic energy technology plan com(2009) 519)

Completeness improvements proposed for the report next version

The scope of the report must be extended to cover the following issues:

— the limited role of R&D intensity[3] as an indicator of innovation intensity: low carbon systems require system innovation with most of the value chain players involved in the innovation process,
— the past empirical experience on successes and failures at funding low carbon technologies[4] (the case of hydrogen), including the difficult transition between public and private funding,
— the apparent low innovation investments in the energy sector and an explanation per activities (generation, infrastructure, retail),
— the funding issues, and sometimes solutions, based on past experimental observations:
  – the innovative experience of OFGEM in the UK at funding electricity transmission and distribution operations,
  – the lack of scalable equity on low carbon technologies when comparing Europe versus USA-China
  – the adverse or favourable role of regulations in attracting innovation funding,
    - the ETS revenues and their potential impact on RD&D funding of low carbon technologies,
    - the NER 300 funding measures (based on outputs) and its possible expansion to non CCS technologies,
    - the role of consumer in financing directly innovation through adequate regulations

(see for instance the Third Energy Package recommendations to pay for innovation on transmission and distribution networks),
  - the importance of technology portfolio management[5] and funding measure portfolio: at EU level, at MS level, their interconnections (or lack of!).
  - the importance of service innovation around low carbon technologies (where more than 50% of the KWh costs come from peripherical services involved throughout the value chain over the whole life cycle) and the lack of funding for it at MS and EU level, a major anticipated market failure.

Coherence improvements proposed for the report next version

The following issues must be addressed to make the final report overall more coherent.

— What are the extra needs for statistical data about low carbon technology innovation to design funding schemes that make sense in Europe?
— What are the other EU policies which impact low carbon systems funding (for instance: agriculture policy for biomass, waste recycling for CHP development, regional infrastructure investments for electricity and heat networks) and their potential contribution to the funding of low carbon technologies?
— Is a mission oriented project selection and funding agency at EU level the appropriate instrument to reach a very low carbon economy by 2050 (see the DARPA Energy approach in the USA launched by President Obama)?
— What are the routes for innovation on energy

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3   "The Booz Allen Hamilton Global Innovation 1000: money isn't everything" B.Jaruzelski, K.Dehoff, R.Bordia (2006)
4   "Innovation and Transfer of Results of energy RTD in national and European Community's programmes: a comparative study of mechanisms, results and good practices" (2007) EC Contract N.: RTD/J1/CT-2005-25

5   "Portfolio analysis of European Community Non Nuclear Energy RTD projects in their overall EU context" Frost and Sullivan, April 2006

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regulations that can lead to private investments on low carbon innovation in Europe? (the early example of Japanese car manufacturing in Europe- a cap on the maximum Japanese cars that can be manufactured in Europe- pushing the European car industry to change its attitude toward innovation for cars – early 1990's).

Moreover, a coherent picture must be given about the relationship between public innovation support and IPR management, with a focus on dissemination activities in support of knowledge availability to non participants willing to deploy low carbon technologies.

ANNEX G: Comments by Project Advisors

Project Advisor:

Christian von Hirschhausen
Professor at TU Berlin
Submission date: October 2010

As one of the scientific advisors to Think on the report „Public Support for the Financing of RD&D Activities in New Clean Energy Technologies" I have participated both in the experts meeting (07 September 2010) and in the Scientific Committee (13 October 2010). In the following I report on the "V1"-version (October 2010).

Structure of the Report

The objective of the report is to investigate what are the most appropriate technology support tools at each stage of the innovation process. At present, the report consists of a full-fledged report, and two annexes by David Newbery, on a) modeling the optimal portfolio approach, and b) a case study on uncertainties in PV. My feeling is that the lessons from these two annexes should be better integrated in the main report.

This refers both to the issue of diversification, and the quantitative analysis of the PV sector (the data of which was suggested to be updated by Doerte Fouquet, who wanted to provide the relevant data). The cost-benefit analysis on PV should also serve to carry out other case studies of other technologies, such as CCTS, which is the second major case study. If these case studies can be integrated, for reasons of time, in the report, they should be carried out by graduate students in a follow-up activity.

The introduction should clearly point out that the task of the group was very limited, e.g. the early-stage RD&D activities in new clean technologies. Thus, neither demand-side aspects, nor the setting of standards at a later stage of development, are in the core of the report. However, this should be mentioned clearly at the outset of the report. It should also be mentioned that the focus was initially (terms of references) on technology push instruments applied to the research, development, and early demonstration stage of the innovation process; however, this would leave out a large number of issues.

The introduction neither makes clear who writes this report, in the context of which project (Think, with a specific distribution of tasks between the team leader and the research group), and whom it is addressed to.

Open Issues / Questions

I have three specific comments

A complex approach which is very generic, with an "easy" solution, but a certain disconnect to reality: I see a disconnection between the methodological results, as summarized by Table 2 ("Summary of the characteristics of technology push instruments") and the real-existing policy debate. The most elementary issue is the lacking link between the derivation of the "optimal" financial instruments, and the instru-

ments that are currently discussed both at the EU and the MS level. This becomes particularly clear in the case study on CCTS (carbon capture, transport, and storage), but also in the two other case studies (PV, electricity networks). One way out of this would be to feed the case studies with the relevant institutional details. A decision needs to be made whether the case studies should be "generic", or whether they should contain a proper assessment of the real situation by the team. The latter case is more demanding, but it would also assure a higher impact of the report.

Key Performance Indicators ("KPI") suggest precision of decisions, where in many cases there is "groping around in the dark" (von Mieses): I agree on the need of quantitative indicators, here described as Key Performance Indicators ("KPI"), Section 4.2 therefore logically defines the approach to high-resolution KPIs, e.g. in the tendering of projects or programmes, and for ex-post control. However, this instrument comes at a cost, too, i.e. the defining, monitoring, and other transaction costs. For example, the KPIs in the CCTS case study are much too detailed to be operationally applicable.

Another issue on quantification: it is not clear how the categories ("low-risk, high-risk", low cost, potentially profitable, etc.) could be operationalized in practice. This would require both a quantitative approach, such as outline by David Newbery in the annex, and, beyond that, a comparative analysis across sectors. Thus, the PV-case study could be complemented by similar applications to other sectors. Since this is a lot of work, one might consider to propose it as a topic of Master's Theses.

Message on IP unclear: It is my understanding that public support, in particular through the EU, would suggest that IP rights should NOT be privatized, but on the contrary rendered public, such that the diffu-

sion of knowledge be accelerated. Evidently, this is in contrast with incentives for investors that see appropriation as the way to proceed. The report is not clear on this issue, and I think there should be a more in-depth discussion of this issue, with clear-cut recommendations.

Case study on CCTS

I think the case study on CCTS is based on doubtful assumptions, and it does not make clear why CCTS really needs substantial public support. The assumption is that "The variables characterizing the innovation process will influence the choice of support mechanism. We assume that market conditions (critically, the future carbon price) are in place to guarantee the uptake of CCS plants once they reach maturity." [p. 29]. If this is the case, then do we need additional funding? In addition, there is a strong focus on capture, whereas transport and storage are widely ignored.

In general, I think it is unclear why the assumption that we "need" CCTS at all should be adopted without further consideration. There is currently a very controversial debate going on, about underestimation of costs and overestimation of the flexibility characteristics of CCTS. To my knowledge, none of the pilot projects supported under the European Economic Recovery Program (EERP) has advanced sufficiently, or has even seriously started. Given the underutilization of public support already provided to CCTS projects, in particular at European scale, spending further money on high-risk projects, e.g. through allocation parts of the 300 mn. Certificates from the New Entrant Reserve, seems inappropriate. Therefore, the case study seems quite theoretical, and not in tune with real world requirements in this sector.

Project Advisor: **Pantelis CAPROS**
Professor at NTUA – E3MLab/ICCS

Submission date: October 2010

As one of the scientific advisors to Think on the report "Public Support for the Financing of RD&D Activities in New Clean Energy Technologies" I attended the experts meeting on 7 September 2010 and the Scientific Committee on 13 October 2010.

Overview of the report

The report addresses the question of which financing support schemes are more appropriate for RD&D activities in new clean energy technologies. The support schemes are considered from the perspective of public policy. The new clean energy technologies are assumed to be those included in the EU's Strategic Energy Technology Plan. The report states that the design of public support schemes for financing RD&D has to induce socially optimal innovation.

The report concludes that without public financing support RD&D undertaking is not likely to deliver the targeted technology progress. The reasons mentioned include the weakness of the EU ETS price signal, the public good nature of the clean energy RD&D and the high uncertainty surrounding high potential return RD&D projects.

The report addresses the issue of RD&D projection selection on the basis of four criteria (page 8) by considering a "social value" of the project as a measurement of performance against all criteria. The report provides a calculation example (PV) and states that the estimation is difficult and involves many assumptions.

The report proposes an assessment of various policy instruments for public financing of RD&D against different goals aimed by the instruments (Table 2). Based on this a policy maker could select which instrument is more appropriate for a certain project

depending on its specific nature. Such application is illustrated by studying three cases, namely PV, CCS and innovative networks.

Clarity of presentation

The report addresses a certain subset of energy technologies, which mainly refer to power generation clean energy technologies, as listed in Table 1. For example, demand-side energy technologies are not covered, seemingly because they were not included in the terms of reference. This should be made clear in the introduction of the report, together with other boundary conditions. The introduction could also improve by including guidance about what are the outputs of the report and their practical usefulness.

The material covered in the two appendices prepared by David Newberry is an important contribution and deserve to be integrated in the main text of the report. The project selection issue and the estimation of social value are unclear in the main report (section 2.1.2 is not clear especially the paragraph in the beginning of page 11), although quite well elaborated in the PV example. Since this is an important component of the report's contribution, it would be of great value if the report could elaborate a practical guidance about how the social value of a project could be estimated in practical terms, instead of just mentioning in the conclusions that such a job is difficult.

The part of the report on financing instrument selection is well elaborated. The authors may consider moving the fine tuning 4.1 either to an Annex or merge with section 3, because of its length which makes the report unequally distributed among the various topics.

The part on Key Performance Indicators (4.2) is not very clear probably because it mixes KPI for project selection and KPI for project monitoring. It is unclear

whether the report just repeats commonly used KPIs or aims at adding something. If 4.1 merge with section 3, then 4.2 should also merge.

Section 4.3 on institutional issues is weak and deserves to be expanded, if possible.

Finally, conclusions must expand, become more practical in terms of recommendations and explicitly address the question posed by the Commission.

Major omissions

The report does not address the issue of distribution of financing and support effort between the Community-wide level and the country level, although it is mentioned that the CET requests for major contribution by the Member-States. Even if this request seems logical because of the size of the funds to be raised, there are risks of adverse effects and distributional effects from changing the balance between the EU-wide and the MS levels. Adverse effects can be identified for example for the internal EU market, the economies of scale and interoperability performance. Adverse distributional effects can be identified for example for the weaker and smaller Member-States. Questions about how national priorities are reconciled with EU-wide priorities could also be raised.

The report seems not addressing the issue of public funding as leverage of private funding. As the report over-emphasizes the need of public support for clean energy RD&D, it does not elaborate on how and under what conditions the choice of the level of public support and the choice of the appropriate policy instrument can maximize raising private funds on RD&D. For example such a feature is not included in Table 2, which is the major report's output regarding choice of policy instruments. It is not mentioned in the case studies. Looking at the list of technologies of Table 1, one can obviously identify different pos-

sibilities by technology in getting private funding as a result of public policy support. The degree of leveraging private funding differ depending on the stage of maturity of the technology, the potential dispersion of applications and the rate of uncertainty surrounding RD&D investment.

Specific Comments

Some of the statements included in the report are strong without adding substance to the reasoning. Examples are the statements: "research intensity in the electricity sector collapsed with the liberalization of electricity markets" on page 5; "the implemented EU emission trading scheme provides neither a sufficiently high current price nor a credible and adequate future carbon price.", on page 7; "without further public support, the level and timing of private investment in the development of new clean energy technologies will be socially suboptimal", on page 7. These statements should either be written in a moderate way or be justified with argument elaboration.

The public good nature of clean energy RD&D is justified in the report on the basis that, as other parts of the world also have to decarbonize, keeping strict IPR will have adverse effects on the public policy goal of global climate change mitigation. However today, energy technology innovations are widely diffused, through common industrial practices, without removing IPR. The Clean Development Mechanism seems to be an effective motivation for technology transfer, while keeping IPRs by the original developer of technology. Section 3.1.3 correctly mentions a seemingly trade-off between private RD&D motivation and global climate change actions, but does not seem to propose something for solving it.

The degree of uncertainty surrounding capital intensive RD&D activities in clean power generation technologies, resulting in a gap between private return

on capital and a social rate of return, as well as the positive externalities of technological progress may be sufficient reasons for justifying public support for financing RD&D. The weakness of ETS price signals may be added as an argument, but even if the signal was strong and certain, one could still argue in favor of public support. Similarly, the public good nature of RD&D could be less emphasized.

ANNEX H: Public Consultation Conclusions

Responsible: **Serge Galant**, Technofi
Submission date: January 2011

Overall paper background

The report must improve on the following background issues:

— The 2050 perspectives are being built at EU level for a first publication by Spring 2011: so far the only building performance and deadlines are 2020.

— 2050 ambitions can be dangerous: Projections up to 2050 might seem interesting from a theoretical point of view, but it would most probably be very arbitrary and essentially unreliable. Suggesting a ranking of projects on the basis of such a biased criterion does not seem to be a good idea: it would probably encourage project developers to overestimate their contribution to 2050 CO_2 reductions (which can not be measured anyway).

— A SET Plan funding line has been provided at EC level, but with no funds allocated. Clearly, the issue of having dedicated SET Plan funds must be addressed in the report since it is another option to motivate projects with high European added value.

— The SET Plan management is provided for by the EII teams: suggestions can be made according to

what EII teams have already published. This is especially true for the selection criteria of projects.

— Funding mechanisms must take into account the first FP8 trends, which have been described by the New Research Commissioner[6].

— The SET Plan roadmaps and implementation plans have been approved by the EC and Member States. Selecting priority actions at the beginning of three-year periods means to do it only 3 times in the 2010 – 2020 decade. This does not provide the flexibility required to ensure a proper implementation of roadmaps. In order to avoid this problem, annual Work Programmes will complement the Roadmaps' three-year Implementation Plans, so that every year experts in charge of implementing them will have the possibility to identify in details the actions to be funded (this is what is happening for the European Wind Initiative at least). This solution will allow a continuous adjustment of Roadmaps to ever-changing budgetary conditions, to the needs of the industry and to the results achieved by relevant R&D projects.

· The overarching goal of the SET Plan has not been enough underlined: it has been designed to increase coordination between EU and MS funding for energy research, and to focus it towards a low carbon economy based on priorities set by industries and R and D communities.

The optimal funding mechanisms for low cabon technology development

The report suggests to harmonize the funding approaches which is a political task.

Funding instruments are often used for making policy, gaining publicity by taking a nice picture with the developer and being able to claim the success.

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6   Innovation Union COM(2010) 546

The main virtue of this report is to underline that public grants allocating money to companies is the most appropriate mechanisms to support low carbon research: loans will restrict players to near to market technologies, private equity will impose a clear line about a product or a service.

Grants and contracts are by far the preferred policy instruments to fund clean energy innovation of any type. This is an extremely important point, which should be properly understood by public authorities at both EU and national level in order to ensure a proper implementation of the SET-Plan. Available resources should be directed to low-C R&D projects, since climate change represent the most urgent problem to tackle in this decade.

However, several sections in the report suggest that funding will mainly come from Member States and private players with a topping from the EC. This is clearly not acceptable since this report must emphasize the role EC money in support of technologies that have a high added value content.

Budget constraints should be solved not by reducing the budget of Roadmaps, which are needed for their implementation but by finding adequate sources of funding (e.g. radically increasing funding for low carbon energy in the FP8 and use new ETS resources to support low-C technologies.

The Japanese example

Nothing is said about Japanese approaches: the "top-runner" approach where innovation is driven by defining standards, not by exhaustive public support.

The funding of large scale research and demon-

strations using ETS funds

The proposed NER300 process description should be improved. The EU emission allowances (EUA) are monetised before the award decision for NER300 projects. Winners know exactly what their subsidy will be in Euros, 4 years before they need to begin operations. This allows project developers having enough time to prepare the projects. The main risk with the NER300 instrument lies in the capability to meet the scheduled CO_2 stored (output-based KPI).

Research funding of regulated operators

A dedicated section is needed in this topic, since transmission and distribution of electricity/gas are regulated activities. It is therefore needed to define a regulatory framework and a financing structure that ensures a long-term stable support for innovative multi annual projects through recognition in the tariffs of these costs. This is foreseen in the Third Energy Package approved by the Parliament and the Council in June 2010. Yet, there is a need to accelerate the regulation implementation at MS level to raise the funds for allocation according to RTD roadmap. A dedicated section on the topic introducing the OFGEM approach in the UK and the routes for network operators in continental Europe should help in speeding up regulatory changes. Likewise, the Italian regulator approved an additional 2% WACC on investments related to Smart Grids and Energy Efficiency Projects.

Moreover:

— Performance measurement on "enabling" technologies such as the electric Grid should be handled properly. These enabling technologies contribute only indirectly to the result the community is after. Their performance should be measured by measuring the progress of the work program, the resources used and the new technologies de-

livered and implemented. It should be explored if the hosting capacity of the grid for carbon free sources can be measured as well.

— Regulated companies have not the same incentives as the results of their innovation efforts will mostly fall to the customers of the network, without benefit to the shareholder of the regulated company. As long as this situation persists, Grants and R&D Contracts are most suitable instruments for regulated players to stimulate innovation.

— The efficiency of the grant awarding process plays an important role in the efficiency of the grid innovation process. It takes about 1.5 year from Call for proposal to the start of the project. in FP7. Compared to the time horizon of an EII implementation plan (3 years) or the duration of a project, it is far too long.

Intellectual property rights

This is a very critical issue, for which an analysis of FP7 rules (autonomous decision of the consortium based on an agreed exploitation plan) brings new perspectives and progresses. More attention ought to e paid to such rules and their impacts.

Interesting schemes are proposed in the report. For instance:

"In order to motivate efficient and well-directed RD&D, IP schemes should in general deliver returns to innovators that are largely proportional to the use, and therefore the level of success, of the technologies they contribute to develop. Hypothetically, clean energy IPR might provide geographical limitations on protected use. Thus, for example, patents issued could grant private entrepreneurs and companies exclusive rights that only apply to developed countries. In this case, developed countries should be able to import clean products even when they are subject to patents

under this limited geographic area restriction. Alternatively, a system of royalty payments could be created whereby the level of payments depends on the country where licensed technologies are used. Both a system of geographically differentiated royalty payments and one of geographically limited patents should probably be complemented by a centrally administered fund compensating innovators for foregone revenues in developing countries"

Beware that this might a false "good idea"

If companies should give away IP and / or rights to exploit that IP to the poorest countries (LDCs), then

— companies will give away their least valuable IP. It might also be of little value to the LDC

— Imagine the LDC benefits from a lot of foreign direct investment from, say, China, and it is a Chinese company that exploits that IP on behalf of the LDC.

Would the IP-ceding company be content with that situation given the potential for the IP which will be made relatively easy to diffuse into China?

This section should send warning signals about IPR management, list other experiences like the Spitzencluster Initiative in Germany, for example ("Solarvally mitteldeutschland"). It is advised to use a reference case box approach to illustrate the diversity of possible approaches.

Assessing available funding options

Public loans and guarantees must be addressed in a more in-depth fashion

— "Loans are less attractive to innovators than subsidies, since the amount of funds obtained must be paid back to the investor together with the agreed

interest rate": this is not necessary (see for instance http://www.euromoneyenergy.com/EventDocument.aspx?eventID=1114&DiscussionID=3640&SpeakerID=3879)

— "due to asymmetry of information, the public administration is better informed than private investors about the risks involved in an innovation process" only public administration has a greater appetite for risk

— "If the innovating entity is deemed to be able to pay back a loan with a high enough level of certainty, public loans turn out to be less expensive for the tax payer than any other form of direct support". It must be further substantiated, taking into account PPEP

— "Public guarantees for private loans, which involve the same allocation of risks as public loans, could have a lower public cost than public loans if the liquidity of the capital market is sufficiently high. In effect, the public sector may be able to borrow risky funds at lower cost as it has a wider cost base (the entire public budget, a significant fraction of GDP) to bear that risk. Against that, it may be less well-informed about the real success probability and more prone to optimism bias." This is incoherent with the above assertion about asymmetry of information.

Publicly Private Equity partnership

In 2010 the European Investment Bank set up an equity fund (so-called "Marguerite fund") to invest directly into smart grids and renewable energy projects. This is the first time that the EIB is investing in equity on its own, without going through other financial intermediaries. The expected role and impact of the "Marguerite fund" should therefore be mentioned in this section of the document

EERA role

The EERA is an alliance aiming at bringing R&D institutes resources together for implementing joint projects. However, the EERA as such does not contribute to the implementation of SET-Plan industrial initiatives, which are different programmes mainly led by the industry. EERA and EIIs should therefore not be confused. Otherwise the risk is to change the nature of industrial initiatives, which should not be shaped by R&D institutes (which typically have longer term research objectives, not always in line with the 2020 horizon of SET-Plan EIIs).

European added value of the projects

The table below recalls some basic principles.

> Occasions when European R&D collaboration is worthwhile
>
> — No single country can efficiently complete the R&D work on its own because its research teams lack crucial expertise that is to be found in one or more other European countries.
> — A project is too expensive for one Member State to tackle alone.
> — The collaboration provides an opportunity for researchers to pursue an R&D topic that perhaps is not a national priority but could become important if progress is made in the topic

It is possible also to argue that EU-funding of research is justified by considering the potential results of the project.

Output-related justifications for European R&D funding

— A project generates knowledge that is applicable in many Member States.
— A project yields a product, the cost-effective manufacture of which requires the involvement of companies in many European different countries.

Finally, the added value of EU-level action can be created and need not only be an inherent property of the research project. For example, the EU can choose to fund a particular project in an effort to stop Member States from needlessly duplicating R&D work. Especially in these fiscally austere times, this is a valuable service.

Joint programming and funding at SET Plan level

The report addresses indirectly the coherence of the whole set of initiatives in the SET Plan.

Joint programming represents one main obstacle against the proper implementation of the SET-Plan, which needs joint-programming to ensure that its budget requirements will be met. European Industrial Initiatives team, in charge of creating the conditions for this to happen, are and will play a key role to this respect. EII Teams are composed of industry, R&D community, EU and antional representatives: their role should therefore be mentioned in this document.

The way to increase joint-programming between the EU and Member States is to rely on the existing EII Teams, not to enhance the role and profile of the

EERA, which has sometimes different objectives in comparison to those of SET-Plan Industrial Initiatives.

Suggesting possible reallocation of funds between initiatives introduces the needs for funding coherent projects belonging to different initiatives and introducing interactions between them to avoid duplication of work. So far, it does not seem that funding reallocation has been allowed for. Moreover, the reallocation of public funds among sectors could raise distrust and competition among them: industry could become reluctant to invest in new projects. Clear rules and arguments defining reallocation will minimise uncertainty for investors.

Remain technology neutral in the report

The report must avoid statements about the performance (technological, economic, social) of the potential solutions, which have been tested in the past or are foreseen in the future. The acceptance conditions have indeed local features, which may make generic statements irrelevant. And public funding rules must be technology neutral , while relying on functional needs (like most of the Initiatives have set their R&D goals).

THINK

THINK is a project funded by the 7th Framework Programme. It provides knowledge support to policy making by the European Commission in the context of the Strategic Energy Technology Plan. The project is organized around a multidisciplinary group of 23 experts from 14 countries covering five dimensions of energy policy: science and technology, market and network economics, regulation, law, and policy implementation. Each semester, the permanent research team based in Florence works on two reports, going through the quality process of the THINK Tank. This includes an Expert Hearing to test the robustness of the work, a discussion meeting with the Scientific Council of the THINK Tank, and a Public Consultation to test the public acceptance of different policy options by involving the broader community.

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