Design and impact of
a harmonised policy for
renewable electricity in Europe

beyond 2020

D2.2 Report

Assessment criteria for identifying the main alternatives

- Advantages and drawbacks, synergies and conflicts

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The beyond*2020* project *at a glance*

With Directive 2009/28/EC the European Parliament and Council have laid the grounds for the policy framework for renewable energies until 2020. **Aim of this project** is to **look more closely** *beyond 2020* by designing and evaluating feasible pathways of a harmonised European policy framework for supporting an enhanced exploitation of renewable electricity in particular, and RES in general. Strategic objectives are to contribute to the forming of a European vision of a joint future RES policy framework in the mid- to long-term and to provide guidance on improving policy design.

The work will comprise a detailed elaboration of feasible policy approaches for a harmonisation of RES support in Europe, involving five different policy paths - i.e. uniform quota, quota with technology banding, fixed feed-in tariff, feed-in premium, no further dedicated RES support besides the ETS. A thorough impact assessment will be undertaken to assess and contrast different instruments as well as corresponding design elements. This involves a quantitative model-based analysis of future RES deployment and corresponding cost and expenditures based on the Green-X model and a detailed qualitative analysis, focussing on strategic impacts as well as political practicability and guidelines for juridical implementation. Aspects of policy design will be assessed in a broader context by deriving prerequisites for and trade-offs with the future European electricity market. The overall assessment will focus on the period beyond 2020, however also a closer look on the transition phase before 2020 will be taken.

The final outcome will be a fine-tailored policy package, offering a concise representation of key outcomes, a detailed comparison of pros and cons of each policy pathway and roadmaps for practical implementation. The project will be embedded in an intense and interactive dissemination framework consisting of regional and topical workshops, stakeholder consultation and a final conference.

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<u>This report</u> focuses on the definition of evaluation criteria for the subsequent impact assessment of feasible policy approaches for a harmonisation of RES(-E) support in Europe from a theoretical viewpoint, discussing and contrasting economic theory and practical applicability.

The assessment criteria proposed in this report are generally those considered in the assessments of environmental and energy policies. The identification of a priori relevant assessment criteria will draw on a literature review, including European Commission documents. This will provide a solid justification for the choice of those criteria, which will later prove their relevance within the empirical study as scheduled at a later stage within the beyond*2020* *project. In addition, the interactions between different assessment criteria need to be considered from a holistic perspective, involving an analysis of how they relate to each other (i.e. synergies and conflicts).*

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1 Introduction

This report represents the second outcome of the inception phase (work package 2) of the beyond*2020* project. The inception phase shall provide the conceptual basis for the detailed follow-up analysis in all subsequent work packages, comprising:

- the conceptual elaboration of feasible policy approaches for a harmonisation of RES(-E) support in Europe, involving several policy paths, which are defined according to different degrees of harmonisation and policy instruments.
- the definition of evaluation criteria for the subsequent impact assessment from a theoretical viewpoint, discussing and contrasting economic theory and practical applicability.

This report focuses on the second point. In order to evaluate the impacts of the aforementioned policy approaches, a set of evaluation criteria is required. Detailed reasoning for the selection of these criteria will be provided, integrating theoretical concepts and the practicability of the procedure for assessing these criteria. The assessment criteria proposed in this project are generally those considered in the assessments of environmental and energy policies. The identification of *a priori* relevant assessment criteria will draw on a literature review, including European Commission documents. This will provide a solid justification for the choice of those criteria, which will later prove their relevance within the empirical study as scheduled within WP6 of this project. In addition, the interactions between different assessment criteria need to be considered. This requires a holistic perspective on the criteria, involving an analysis of how they relate to each other (i.e. synergies and conflicts).

The following section briefly describes the methodology. Section 3 discusses the main insights from different streams of the relevant literature on the assessment of the functioning of RES-E support schemes and identifies the key assessment criteria to be drawn from those approaches. Section 4 further describes all of those criteria and justifies their usefulness. This includes also a listing of key indicators pertaining to those criteria. Finally, a discussion of the interactions between different criteria is provided in section 5.

2 Methodology

In order to identify relevant "*a priori*" criteria and their interactions, we draw heavily upon existing concepts from both the environmental economics and the innovation economics literatures, which are deemed relevant in the context of this project. This has been complemented with some insights from other streams of the literature, including the literature on learning effects, the political science literature, the empirical literature on RES-E policy support schemes and literature on EU harmonisation of RES-E support schemes. Commission documents have also been analysed in order to infer relevant criteria. Furthermore, guidelines in existing policy documents have been considered (Mitchell *et al* 2011, HMG 2011).

The aim at this stage is not to propose a definitive set of relevant criteria but rather to provide a filter: i.e., to reduce the range and quantity of possible criteria to something manageable. This would lead to a list of criteria whose relevance will be judged by stakeholders in the empirical research carried out in work package 6.

3 Theoretical background – Review of the literature

Different streams of the literature may provide relevant insights into the choice of specific criteria. This section provides a brief discussion of those approaches and identifies relevant criteria which are stressed in those approaches.

3.1 Traditional Environmental Economics[1]

Several theoretical approaches, including traditional environmental economics,[2] are based upon the linear model of innovation, which defends the view that technologies go through sequential stages, but without major interactions between them. In the environmental economics literature (see Jaffe *et al* 2002, Requate 2005 and del Río 2009 for a review) innovation is regarded as a "black box" – into which R&D inputs flow and out of which commercial technologies diffuse into the marketplace – to the neglect of the intermediary role for supply and demand interactions (Taylor 2008). The effects on the different stages of innovation are analysed separately. Assuming perfect economic rationality, decisions are based upon microeconomic optimisation behaviour which is triggered by price changes.[3] The treatment of technological change is either exogenous or assumed to respond automatically to changes in relative prices as a result of exogenous developments (such as environmental or energy policies).

In turn, embracing the linear model of innovation involves the recommendation of policies based upon R&D and commercialisation strategies, seeing the problem essentially in terms of a low level of R&D or low carbon prices in the energy sector. It is assumed that technologies, once created, are optimally deployed in response to whatever policy incentives may or may not be in place (Popp 2010). The main argument derives from the theory of induced innovation (Hicks 1932): changing relative prices induce innovations. Since the hypothesis is that the rate and direction of innovation are likely to respond to changes in relative prices, changing costs for energy use (for example, through the implementation of environmental or energy policies) are assumed to lead to incentives for future inventions and innovations (Jaffe *et al* 2002, Walz and Schleich 2009, Requate 2005).[4]

[1] This and the following three subsections heavily draw from del Río and Bleda (2011).

[2] Following Marechal (2007), we use the word "traditional" ("mainstream" or "orthodox" could also be used) to avoid the problems arising from the somewhat ambiguous use of the term "neoclassical", as shown in Colander (2000). By traditional economics, we refer to the Walrasian model of welfare economics, which can be defined as the theoretical synthesis of the Marshallian approach with marginal production theory and the rigorous precision of mechanical mathematics (Marechal 2007).

[3] A recent example of the conventional economics approach to dynamic efficiency is Popp (2010). The author claims to provide a review of the literature on environmental technological change, focusing on the implications of this research for climate policy. However, in reality he only considers the induced-innovation literature. His paper is an example of the linear approach to technological change, which can lead to an incomplete picture of the drivers and barriers to low-carbon technologies and, thus, to the mitigation policies that are needed in this context. The author claims that "[t]echnological change proceeds in three stages. At each stage, incentives, in the form of prices or regulations, affect the development and adoption of new technologies: invention, innovation and diffusion" (*op. cit.*, p.3). However, there is no mention of the interactions between stages. In addition, inertia is only mentioned in passing ("often times, a technology that appears to surpass competing technologies in performance and cost will not immediately be chosen over existing technologies").

[4] The environmental economics literature on induced innovation has focused on the role of environmental policy in stimulating innovation in environmentally-friendly technologies, including the effects of energy price changes and regulations on innovations in energy technologies, and the efficacy of market-based environmental policies relative to prescriptive regulation in inducing efficient innovation (Fischer

Contributions within this tradition normally analyse the cost-efficiency of RES-E deployment and support instruments by comparing them with CO2 mitigation instruments (Palmer and Burtraw 2005, and Fischer and Newell 2008). Indeed, there is a tendency among this literature to undermine the relevance of RES-E support schemes. The existence of a double externality is acknowledged: an environmental and a technological one. The former is internalised through a CO2 price and the latter through public R&D support (Newell 2008, Jaffe and Stavins 2005). No RES-E policy is as cost-effective as a cap-and-trade policy for achieving carbon emission reductions (e.g., Palmer and Burtraw 2005 and Fischer and Newell 2008). However, the time horizon considered is usually too short and the mitigation targets are modest. These limitations work against capital-intensive technologies (with a large cost-reduction potential), like renewables (IEA 2008a). The framework adopted is usually static, disregarding dynamics and the interdependencies between institutions, actors and technologies in complex systems, leading to inertia and lock-in. Furthermore, competitive pressure is regarded as the main (or exclusive) mechanism to reduce the costs of technologies, disregarding other dimensions of dynamic efficiency such as diversity. Generally, "technology-neutral" instruments are advocated.

Box 1 Main criteria and aspects highlighted by this approach (traditional environmental economics)

Criteria highlighted: effectiveness in reducing GHG emissions and promoting renewable energy sources, cost-effectiveness (static efficiency), and technological competition/neutrality.

Recently: some focus on dynamic efficiency (impacts on innovation process), less so on administrative and transaction costs and social acceptability issues.

3.2 Innovation studies

'Innovation studies' is a broad term encompassing various different theoretical approaches. However, a large stream of the literature based upon evolutionary economics deals with systems concepts and may complement or offer an alternative approach to traditional environmental economics. This is the 'systems of innovation' literature, which will be the focus of this subsection. These studies have emphasized that the interplay between existing institutional contexts and technology development is important for explaining the effectiveness (or failure) of specific promotional policies, such as RE policies (Mitchell *et al* 2011).

The systems of innovation (SI) approach (see Carlsson *et al* 2002 for an overview) stresses that innovations are not developed and implemented in isolation but within a technological and socio-cultural context. It focuses on the importance and interdependencies of actors, networks, institutions, cumulative learning processes and spatial and technological characteristics (Edquist 2005). It adopts an holistic perspective and considers phenomena such as path dependency, lock-in, interdependence, non-linearity and co-evolution (Edquist 2005, Markard and Truffer 2008). This approach can inform us about: how innovation occurs in relation to particular technologies, industrial sectors and specific national contexts; which system failures may be occurring; and how innovation may be influenced by incentives and policies (Foxon and Andersen 2009).

and Newell 2008). However, these studies have primarily focused on comparing emissions pricing policies, like emissions taxes and auctioned or grandfathered permits, rather than a more pragmatic, broader set of policies such as those using performance standards and supporting renewable energy (*op. cit.*).

Following Unruh (2000, p. 819), technological systems are defined as "inter-related components connected in a network or infrastructure that includes physical, social and informational elements". An innovation system consists of three elements (Malerba 2005, Woohthuis 2005): technology and related knowledge and skills; networks of actors; and institutions. Networks of actors develop and implement new knowledge and technology, within their institutional context[5]. For an innovation system to be successful in developing and implementing technologies, these three building blocks, which co-evolve in time, need to be aligned.

This approach has already been applied to analyse renewable energy systems (see Astrand and Neij 2006, Jacobsson and Bergek 2004, Foxon *et al* 2005, Jacobsson 2008, and Walz and Schleich 2009, among others). These papers stress that a shift to renewable energy technology systems is a complex process which involves changes in the aforementioned elements of an innovation system. They identify the system failures related to the development, commercialisation and diffusion of renewable energy technologies.

This perspective tries to cope with some of the drawbacks of the conventional perspective, which has been much criticised for its conceptualisation of technological change. These critiqus go in three directions. The systemic approach provides corrections to those criticisms and suggests policy implications which are different from (although not necessarily contradictory to) those derived from the conventional approach:

1) Feedbacks between stages. In particular, innovation and diffusion are not sequential phases, but learning and future innovations depend upon experiences made during market diffusion: i.e., the creation of a market for renewable technologies feeds back into investments in R&D**.**

2) Path dependency and lock-in. One drawback of studies based upon environmental economics is the fact that they do not look at system changes and interdependencies, although such system changes are necessary to reach long-term emission reduction goals (Rogge and Hoffman 2010). In contrast, the systemic perspective acknowledges that barriers to renewable energy are systemic (also termed 'system failures', see Nill and Kemp 2009). These systemic barriers lead to lock-in through a path-dependent process driven by technological and institutional internal returns to scale.

   Technologies are not only linked to other technologies, but are also inter-related with the cultural and institutional aspects of their environment (Marechal 2007). "Carbon lock-in" has been used to denominate the persistent dominance of high-carbon technologies (in spite of the existence of low-carbon ones).[6] Unruh (2000, p.817) defines carbon lock-in as the "interlocking technological, institutional and social forces that can create policy inertia towards the mitigation of global climate change". This lock-in occurs through a "path-dependent process driven by technological and institutional increasing returns to scale". Dynamic economies of scale and learning effects are a major source of lock-in. R&D investments and diffusion provide a source of improvement and cost reductions for existing technologies. The later effect takes place because diffusion allows technologies to benefit from learning effects and dynamic economies of scale. Emerging, more expensive technologies may fall into a vicious circle: they are not adopted because they are too expensive and they are too expensive because they are not adopted.

[5] These actors include: technology developers, technology end-users/owners, policy makers/government institutes, knowledge providers, entrepreneurs, service and maintenance providers, non-government organizations (NGOs), etc.

[6] An stream of the economic literature on climate change mitigation has applied an evolutionary approach with the aim of emphasizing the inertia in current technological systems (Kemp 1996, Unruh 2000 and 2002, Maréchal 2007, del Río and Unruh 2007, Rip and Kemp 1998, Foxon 2003).

3) Barriers to technological change are multifaceted and the price factor is only one of the factors affecting technological changes. Technological change is endogenous to an economic system in which there are both inducement and blocking mechanisms. Changes in relative prices are only one of the inducement mechanisms. In addition to the demand and technology factors, this approach underlines the importance of several factors (characteristics of innovation, actors, networks and institutions, including regulations) (Suurs and Hekkert 2010). These factors influence each other, highlighting the importance of feedback mechanisms and cumulative causation processes. Therefore, price signals are necessary, albeit not sufficient, conditions for the encouragement of innovation in new technological systems.

The implication for RES-E policy is that the inducement mechanisms need to be strong enough to overcome these interrelated barriers to RES-E and set in motion a process of cumulative causation which works in favour of the new technology.

Recently, the SI approach has been further developed along several avenues, namely by trying to integrate it with the multilevel approach of technological transitions (see Geels and Schot 2007), as done by Markard and Truffer (2008, 2009)[7] and by identifying the functions of an innovation system (see Hekkert and Negro 2009).[8] Regarding this last point, different innovation systems can be assessed and compared in terms of the functions they fulfil in order to derive policy recommendations to support the development of a specific technology (Hekkert *et al* 2007; Negro *et al* 2007). 'Functions' are emergent properties of the interplay between actors and institutions (Markard and Truffer 2008). The functions approach identifies those properties of a technological innovation system that are needed in order successfully to introduce sustainable energy technologies (see Hekkert and Negro 2009).[9]

Cumulative causation suggests that system functions may reinforce each other over time, thereby resulting in a virtuous cycle (Hekkert *et al* 2007, Jacobsson and Bergek 2004). The diffusion of renewable energy technologies into the incumbent energy system requires virtuous circles to be established between the different functions (Suurs and Hekkert 2010, Hekkert and Negro 2009). Similarly, Jacobsson and Johnson (2000) have argued that there are three central issues for the emergence of a new technological system based upon renewable energy technologies: variety in knowledge base increased by experimentation, institutional change aligned to the needs of renewable energy technology and the emergence of strong actors who can promote the new technology.

[7] Indeed, Markard and Truffer (2008, p.611) propose a definition of a "technological innovation system" (TIS) based upon the integration of the innovation systems approach and the multi-level framework. Under this interpretation, a TIS would be a set of networks of actors and institutions which jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or a new product.

[8] The assessment in terms of system functions is one of the main approaches of the systems of innovation literature (see Bergek *et al*. 2008). Other innovation system studies have placed more emphasis upon structural analyses (Carlsson *et al* 2002; Jacobsson and Johnson 2000). Currently, some authors are aiming at the integration of both approaches (e.g., see Markard and Truffer 2008).

[9] Walz and Scheich (2009) distinguish between the creation of new knowledge, creation of positive external economies through exchange of information, demand articulation, recognition of a growth potential (connected to the legitimacy of a new technology), facilitation of market formation, supply of resources and arenas for coalition building and organisation of interests. For Hekkert *et al* (2007) and Suurs and Hekkert (2010) these functions include entrepreneurial activities, knowledge development and diffusion, guidance of the search, market formation, resource mobilisation and support for advocacy coalitions. Jacobsson and Bergek (2004) mention the creation and diffusion of new knowledge, the guidance of the direction of search among users and suppliers of technology, the supply of resources, the creation of positive external economies and the formation of markets.

Such interactions may take place in a niche, which can be created by public policy through, for example, RES-E support instruments.[10] Niches allow technologies to progress and create a supportive institutional environment around it. Once they do so, technologies become a "technological regime", as it is the case of wind energy in many European countries.[11] The SI approach points to the importance of policy interventions which support all system elements—technology and cost development, as well as actor involvement—for the introduction and deployment of renewable energy technologies.

The formation of advocacy coalitions and the cumulative causation process have not been stressed by the traditional approach (2.1), but both are particularly relevant in the RES-E support realm. Although actors are embedded in an institutional context, they may also deliberately change or adapt existing institutions or create new ones (Edquist 2005). Radical innovations are often promoted by actor networks which show little overlap with prevailing actor structures in a sector or technological field (Markard and Truffer 2008). In turn, once advocacy coalitions have been formed, it is likely to organise lobbying for changes in public support funding, which feeds back into the deployment of the technology. For example, wind power actors, together with biogas stakeholders, lobby in favour of better feed-in payment conditions for renewable energy technologies (Markard *et al* 2009).

The formation of advocacy coalitions results from the sequential interaction between support, market creation, stages of technological change and actors (see Markard *et al* 2009). For example, the case of German wind power reveals how feedback loops may be generated from early market formation, via early entrants, to changes in the institutional framework beyond the formative phase (Jacobsson and Bergek 2004, Walz and Schleich 2009).[12] Jacobsson and Johnson (2000) have reached similar conclusions for wind energy in Denmark, Astrand and Neij (2006) for Sweden and del Río (2008) for Spain.

The formation of markets is thus a necessary requirement for setting in motion a learning process. Stimulating RES-E will create virtuous circles between actors and stages of technological change, providing further investment opportunities and expanding the market for key technologies (Lee *et al* 2009). This suggests the importance of implementing policies which result in cumulative causation processes leading to an effective deployment of RES-E in a long-term perspective.[13]

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[10] Niches represent the local level of the innovation process and are commonly referred to as protected spaces or incubation rooms, in which new technologies or socio-technical practices emerge and develop isolated from the selection pressures of 'normal' markets or regimes (Geels 2005; Kemp *et al*., 1998). "A niche can be defined as a discrete application domain (habitat) where actors are prepared to work with specific functionalities, accept such teething problems as higher costs, and are willing to invest in improvements of new technology and the development of new markets" (Hoogma *et al*., 2002; p. 4). Technological niches for photovoltaics have been created, for example, by governmental support programs in the form of investment subsidies or fixed feed-in tariffs **(**Markard and Truffer 2008).

[11] Whether a technological system (TS) is regime-like or niche-like certainly depends upon its maturity: i.e. an immature TS in an early, or formative, phase of development (cf. Bergek *et al*., 2005) is rather niche-like while a mature TS develops more and more of the features of a regime (cf. 'cumulative causation', Jacobsson and Bergek, 2004)(Markard and Truffer 2008). However, it is beyond the scope of this paper to analyse the overlaps between the concepts of technological system, regime and niche. See Markard and Truffer (2008) for further details.

[12] Likewise, in his analysis of wind energy deployment and policy in Denmark, Spain and Sweden, Meyer (2007) provides empirical evidence of the role of the coalition of forces to encourage wind energy in Spain.

[13] In their analysis of the comparative wind energy deployment and policy in the U.S. and Germany, Walz and Schleich (2009) use a 'systems of innovation' approach. The authors argue that, in the US, the primary policy was a subsidy in the form of a tax credit, introduced in 1992. However, it took almost 10 years before substantial deployment was observed. In addition to deficiencies in fulfilling the function of supplying resources, some of this delay can be explained by the lack of legitimacy of the technology because of reluctant environmental and climate policy. In contrast, in Germany, market formation on

Only public policy may break lock-in. However, not all policies are equally useful to encourage the emergence of new technologies. The systems of innovation approach stresses the difficulties that new technologies, which includes several RE technologies, experience in penetrating a market and competing with a dominant technology which has benefited from: economies of scale; learning effects; and the adaptation of the institutional environment to the existing technology. In order for renewable energy technologies to develop, the forces of inertia which prevail in the incumbent energy system have to be broken. We argue that different RES-E support instruments and design elements can exert significant influences upon the direction of technological development which a technological system takes.

Notwithstanding this, since the systemic perspective emphasises the wide array of barriers to RES-E, it suggests that deployment policies are only one of the factors (although a crucial one) to encourage RES-E. When this perspective has been applied to RES-E support, several barriers have been shown to constrain RES-E.[14] The complexity of stages and drivers influencing technological change makes it unlikely that a single policy instrument would be sufficient to trigger major technological changes (Skjaerseth and Christiansen 2006). Smits and Kuhlmann (2004) have argued that system innovation processes require "systemic instruments": i.e. those that support systems functions. Since RES-E support instruments cannot tackle all functions, they are not systemic instruments, although they can be made part of systemic policy packages.

In spite of the usefulness of this approach, there is a relatively paucity of studies using it. Walz and Schleich (2009) reviewed the empirical literature on RES-E support schemes and concluded that "these studies, by and large, do not analyse the effects on innovation within an integrated systems of innovation view".

Box 2 Main criteria highlighted by this approach (innovation studies)

Effectiveness (market creation, stability of regulation), dynamic efficiency (diversity of technologies, feed-back loops between stages of the innovation process), political feasibility and social acceptability. This view (implicitly) highlights that these criteria are interlinked.

3.3 The learning effects literature

A recent, albeit abundant, literature has stressed the role of learning effects in reducing the costs of technologies in general and renewable energy technologies in particular. However, this literature is not isolated from that discussed in 3.1 and 3.2 above, as many energy-economy models which incorporate induced technological change include some learning effects, and the literature on systems of innovation stresses the importance of these effects.

The specialised literature on learning emphasises two main components of technical change and energy costs: cumulative research, development and demonstration (RD&D); and cumulative installed capacity or learning-by-doing (see: Carraro *et al* 2003; Sagar and van der Zwaan

the supply side reinforced the organisation of common interests and the legitimacy of the technology. This was a prerequisite for aligning the conflicting interests when the electricity prices were increased by the fixed feed-in prices (Walz and Schleich 2009). In addition to key functions such as market formation and supply of resources, the rapid market growth of wind power was also made possible by creating vitruous cycles between the different functions of the innovation system which reinforced each other.

[14] The assessment of Astrand y Neij (2006) shows that early inflexible steering of technology and market development, together with a lack of comprehensive, long-term strategy, lack of continuity in policy interventions and weak combinations of policy programmes and measures have contributed to a very limited degree of wind power development in Sweden.

2006; Kobos *et al* 2008; IEA 2008b; and Kahouli-Brahmi 2008).[15] Whereas certain components of cost improve with R&D investment, others are likely to respond to increased deployment of the technology (Nemet and Baker 2010).

Learning assumes that a technology's performance improves as experience with the technology accumulates. Learning is an aggregate term that may involve many different mechanisms which all contribute to cost reduction over time in producing and deploying new technologies. This paper focuses upon those learning effects which are dynamic and have direct innovation effects:[16]

- *Learning-by-doing* (Arrow 1962) refers to the repetitious manufacturing of a product, which leads to improvements in the production process.
- *Learning-by-using* (Rosenberg 1982) refers to improvements in the technologies as a result of feedback from user experiences into the innovation process.
- *Learning-by-interacting* (Lundvall and Johnson 1994) takes place as a result of the network interactions between actors.

Often, combinations of these factors occur at each stage of the market diffusion process, and the contribution of each changes over time. The importance of those learning effects varies along the technological change pipeline and for different technologies.[17] In turn, each cost element (material costs, process costs and overhead costs) is affected by different mechanisms, as empirically shown by Kalowekamo and Baker (2009).

Cost reductions have been assessed through learning curves.[18] In learning curves, the experience gained with a given technology is expressed as a learning rate (percentage at which the unit cost decreases with every doubling of cumulative installed production)[19]. In the realm of

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[15] Learning-by-doing and learning-by-researching (cumulative R&D) mechanisms act as a virtuous cycle which reinforces itself (see Watanabe *et al* 2000). A major question in the technological learning literature (in spite of the two-factor learning curves) is still to what extent learning can be attributable to the R&D expenditures.

[16] This is the more traditional categorisation of learning effects (i.e., Junginger *et al* 2005). But other authors define other shapes of learning. For example, Sagar and van der Zwaan (2006) distinguish between learning-by-manufacturing, learning-by-copying, learning-by-operating and learning-by-implementing.

[17] For example, Junginger *et al* (2006) showed that for technologies developed on a local level (e.g. biogas plants), learning-by-using and learning-by-interacting are important learning mechanisms, while for CHP plants utilizing fluidized bed boilers, upscaling is probably one of the main mechanisms behind cost reductions. Nemet and Baker (2010) have shown that certain components of the costs of solar PV improved with R&D investment, while others responded to increased deployment of the technology.

[18] Some authors have stressed the difficulties in building learning curves for some renewable energy technologies. For example, Junginger *et al* (2006) acknowledged that the case studies revealed large difficulties in devising empirical experience curves for investment costs of biomass-fuelled power plants. Other authors have criticised the learning curve model itself, but this is beyond the scope of this paper (see Nemet 2006 and Kahouli-Brahmi 2008). One key problem is that the learning approach may underestimate the real costs of innovation because it assumes 100% success and makes no allowance for the costs of false starts or failures. For example, in the field of car technologies, many options have been tried in the past three decades, but only very few have survived (IEA 2008b).

[19] More specifically, learning curves describe how the specific investment costs of a given technology are reduced through one or more factors representing the accumulation of knowledge and experience related to R&D expenditures, and the production and use of that technology. These factors are the cumulative installed capacity or production of a certain technology in the so-called one-factor learning curve, as well as the cumulative R&D expenditures or knowledge stock with regard to that technology in the two-factor learning curve (Kahouli-Brahmi 2008).

energy technologies, the IEA (2000) and McDonald and Schrattenholzer (2001) were the first to estimate learning rates.[20]

These learning effects have been incorporated into energy-economy models (for an overview, see Kahouli-Brahmi 2008). A key message from these models is that policy needs explicitly to consider the learning potential associated with investments and accelerate abatement in order to induce cost reductions (Grubb and Ulph 2002). Endogenisation of technological learning induces early investments in initially expensive technologies, since future revenues offset the short-run additional investments (Kahouli-Brahmi 2008).

The extent to which instruments and design elements are able to encourage those learning effects is a major aspect of RES-E support. Obviously, learning effects only take place when deployment is increased, suggesting that there is a clear synergy between the effectiveness of an RES-E support instrument and learning effects. For socio-technical systems like the wind power system, where an important barrier to market introduction and expansion is high investment costs, policy instruments should support and accelerate the learning process (Astrand and Neij 2006).

Box 3 Main criteria highlighted by this approach (learning effects literature)

Effectiveness, dynamic efficiency (long-term cost reductions).

3.4 Insights from the political science literature

Insights from the political science literature are similar to the systems of innovation perspective, in the sense that they focus increasingly upon understanding the interplay between governments and other societal actors, and the implications of this for the success of policy implementation. Indeed, some political scientists argue that policy action is more effective and efficient when it includes non-State actors, networks and coalitions in building guiding visions, and formulating and implementing public policy (Rotmans *et al*., 2001; van den Bergh and Bruinsma, 2008; Mitchell *et al* 2011). Therefore, the focus of this approach is upon political feasibility as directly influenced by social acceptability. Social acceptability is directly related to the creation of advocacy coalitions which support the new technology. Indeed, this and the literature on innovation studies stress that new technologies and the institutional framework in which they are embedded co-evolve. This means that the new technology helps to create supporting institutions which contribute to the legitimacy (and, thus, social acceptability) of the new technology.

Box 4 Main criteria highlighted by this approach (political science literature)

Political feasibility, social acceptability.

3.5 Empirical literature on RES-E support schemes

The empirical literature on RES-E support schemes generally use one of the previous approaches and use three types of methodology: econometric modelling, model simulations and case studies. Criteria are usually discussed implicitly (normally in case studies), and generally only effectiveness and cost-effectiveness are considered in the evaluation of the functioning

[20] For a recent analysis of (observed) learning rates for various electricity supply technologies, see IEA (2008b) and Kahouli-Brahmi (2008), among others.

of instruments in specific countries. However, some studies also provide a list of multiple criteria according to which RES-E support schemes are assessed (for a description of these studies, see the Annex to this paper).

Several of these studies include: Bohm and Russell, 1985; Huber *et al*., 2004; Sawin, 2004; del Río and Unruh 2007; Gupta *et al*., 2007; Ragwitz *et al* 2007; Bergek and Jacobsson, 2010; European Commission, 2008; Verbruggen 2009; Mitchell *et al* 2006; Kaberger etal.,2004; del Rio and Gual, 2007; Mitchell *et al* 2011; Klessmann 2009; Oikonomou and Jepma 2008; Madlener and Stagl 2005; Groenenberg and de Coninck 2008; Konidari and Mavrakis 2007; Jacobsson and Lauber 2006; and Gan *et al* 2007.

Some of these case studies have recently stressed the role of social acceptance. For example, Mendonça *et al*. (2010) found that steady, sustainable growth of RES would require policies that ensure diverse ownership structures and broad support for RES. Social acceptance will become more and more important in the future as the number of RES-E projects increases (due to NIMBY effects) and the rising penetration of RES-E in the electricity mix will also increase the bill for consumers. This is supported by studies in New Zealand and elsewhere (Barry and Chapman 2009). The magnitude of the necessary changes will require public consent to a variety of policies, which in turn implies increased efforts to raise public awareness of renewable energy (Mitchell *et al* 2011).

Box 5 Main criteria highlighted by this approach (empirical literature)

Econometric studies: effectiveness.

Model simulations: effectiveness, cost-efficiency (minimum generation costs, consumer costs), dynamic efficiency (diversity of technologies).

Case studies: in addition to effectiveness, some pay attention to static efficiency, some to social acceptability/political feasibility.

3.6 The literature on harmonisation of RES-E support schemes

To the different streams of the literature which have assessed RES-E support schemes we should add studies which deal more explicitly with harmonisation of RES-E support in the EU. Some of these studies have been carried out in EU-funded projects (Uyterlinde *et al* 2003; Huber *et al* 2004; Resch *et al* 2007; Bergmann *et al* 2008; Arentsen *et al* 2007),[21] although others are not (Guillon 2010; Ragwitz *et al* 2006; del Río 2005; Pflüger *et al* 2005; Muñoz *et al* 2007). In addition, there are official documents (European Commission documents) from which we can infer relevant criteria for the assessment of harmonisation of support (European Commission 2005, 2008). Finally, the two Directives themselves may provide relevant criteria.

For example, recital (12) to Directive 77/2001/EC defines several criteria which a support framework at EU level would have to fulfil. It should: contribute to the achievement of the national indicative targets; be compatible with the principles of the internal electricity market; and take into account the characteristics of the different sources of renewable energy, together with the different technologies and geographical differences. It should also promote the use of renewable energy sources in an effective way, and be simple and at the same time as efficient as possible, particularly in terms of cost, and include sufficient transitional periods of at least seven years, maintain investors' confidence and avoid stranded costs. This framework would enable electricity from renewable energy sources to compete with electric-

[21] For an overview of the pre-2008 literature on harmonisation, see Bergmann *et al* (2008).

ity produced from non-renewable energy sources and limit the cost to the consumer, while, in the medium term, reducing the need for public support.

In Directive 28/2009/EC, such criteria are spread across the Directive. Apart from mandatory targets being achieved (effectiveness), other criteria are mentioned. Important terms and expressions in the recitals to the Directive include: “cost-effectiveness”; “reducing the cost of achieving the targets laid down in this Directive”; innovation; the continuous development of technologies which generate energy from all types of renewable sources; the opportunities for growth and employment that investment in regional and local production of energy from renewable sources should bring about in the Member States and their regions.

Box 6 Criteria and sub-criteria (literature on harmonisation)

Source: Guillon (2010).

C1 – Target achievement

- *Ensure target achievement using a diverse portfolio of RES-E*

C2 – Average remuneration

- *Minimise average generation costs*
- *Minimise average producer surplus*

C3 – Average costs external to remuneration

- *Minimise average transaction costs (public authorities, grid operators)*
- *Minimise average costs for balancing services (grid operators, electricity retailers)*
- *Minimise average costs for grid extension (grid operators)*

C4 – Compatibility with the principles of the internal electricity market

- *Maximise the market experience of RES-E producers*
- *Minimise market dominance (concentration, vertical integration)*
- *Ensure equal rights for all market players*
- *Ensure sufficient cross-border trade of RES-E*
- *Maximise competition between technologies and sub-technologies*

C5 – National acceptance of EU legislation

- *Maximise the autonomy of Member States*
- *Minimise the collapse of existing local RES-E markets*
- *Minimise the creation of hotspots*

C6 – Operability

- *Ensure a clear distribution of functional responsibility*
- *Minimise the number of authorities involved*
- *Minimise the complexity of rules and regulations*
- *Maximise fraud-resistance*
- *Maximise transparency*

C7 – Systems integration

- *Maximise demand orientation of RES-E generation*
- *Maximise quality of load forecasts*
- *Maximise the share of RES-E available as operating reserve*
- *Minimise intermittency of total RES-E load*

Regarding the literature on harmonisation, a major contribution is made by Guillou (2010), who has provided a very complete list of criteria and sub-criteria (Box).

Similarly, Pflüger *et al*. (2005) explicitly considered several criteria, including: the stimulation of RES-E generation (effectiveness); certainty of target achievement; regulatory certainty after the introduction of support mechanisms; the level of end-user electricity prices; the occurrence of over-stimulation (windfall profits); the impact on technology cost-reduction and innovation; technology diversity; and suitability for EU-wide application.

In contrast, Bergmann *et al* (2008) did not explicitly provide a list of criteria, although these are mentioned throughout the text and include: the achievement of targets; creating a common power market (liberalising the EU internal electricity market); cost effectiveness/efficiency; political acceptance; and compatibility with European primary legislation. The authors use the term "policy objectives" rather than "criteria", and include: achievement of national and European targets; cost savings; increased efficiency of RES-E support; reduction of distortions, especially in cross-border trade; and compatibility of support systems with each other and with the internal electricity market. In addition, the authors have some concerns or "remarks concerning harmonisation", which include: parallels to the EU-ETS; reduction of distortions, political necessity / judicial legitimation; political opposition; efficiency; effectiveness; and time frame. In addition, the authors consider several "impacts" (geographic distribution of a RES-E industry, electricity generation in conventional power plants, the price of power on the market, the price of power for consumers, the trade of power between MS, administrative (transaction) costs and CO2 emissions and the price of emissions allowances in the EU ETS) and "barriers" (opposition due to neglected policy objectives, opposition due to expected high costs for a MS, opposition due to path dependencies and opposition due to local resistance). These aspects are all relevant when considering the criteria to be used to assess different harmonisation options.

A major question remains: how does this literature add to the other streams? In other words, does this literature provide criteria additional to those already mentioned? The answer is 'yes and no'. Since the aforementioned literature is usually restricted to the analysis of RES-E support schemes either theoretically or at country level, and given that the EU adds an international dimension, some criteria could be argued to be additional to those considered by the other streams (such as compatibility with the internal electricity market).

However, we have to take into account that we have two dimensions here: the criteria and the national/international territorial scopes. In reality, however, the second dimension can be included in the first one: i.e., the first dimension provides a wider, overarching framework. Of course, the benefits and costs according to certain criteria may fall on the national or EU level. However, the second dimension and, more importantly, the specific EU criteria, should be explicitly taken into account within the first one.

Box 7 Main criteria highlighted by this approach (literature on harmonisation)

Effectiveness, efficiency in deployment of RES-E across Europe, distortions between MS, benefits and costs for stakeholders in MS (acceptability), compatibility with the principles of the internal electricity market.

3.7 Summary

There is no inherently superior approach to the analysis of innovation processes in renewable energy technologies and to the assessment of RES-E support schemes. They all provide relevant insights which help us better to understand the crucial aspects involved. Furthermore, some of the above approaches overlap with each other. This is particularly the case with regard to the innovation studies approach, which takes a broader view of the innovation process, thus encompassing technological, socio-economic and political aspects. In other words, when analysing the innovation process in renewable energy technologies, innovation studies include insights from both political science and environmental economics. It thus provides a more comprehensive perspective. In addition, the empirical literature overlaps with other approaches: i.e., empirical studies are based upon the use of theoretical/methodological frameworks.

4 Identification of assessment criteria

Taking into account the aforementioned literature, we are able to identify key criteria for the assessment of RES-E support schemes. This section defines those criteria and justifies their relevance.[22]

4.1 Effectiveness

One main criterion on which to judge the success of RES-E support schemes is obviously the extent to which instruments are effective in triggering deployment. An instrument is said to be effective if it is able to achieve a significant RES-E deployment or a certain RES-E target. Reaching the target depends upon the level of support as well as the stability (continuity) and the degree of security associated with the support scheme. The latter contributes to keeping investment risks for investors at a low level.

Effectiveness may refer either to increased generation or increased capacity. Trends and rankings of countries in one or the other may differ, since capacity factors may differ significantly across countries. Furthermore, the relatively low capacity factor of some renewables and their intermittent character may lead to significant oscillations in renewable generation for a given capacity.

Effectiveness can also be defined in relative terms: i.e., as a percentage of total electricity or energy consumption (as set in the previous Directive 77/2001/EC and in the current Directive 28/2009/EC, respectively). In the latter case, the evolution of electricity or energy demand should be taken into account, and this suggests significant interactions between energy efficiency and renewable energy targets and policies.

On the other hand, when assessing the effectiveness of a support scheme the renewable energy potentials of countries should be taken into account and the increase in deployment adjusted accordingly. This is done in the OPTRES, futures-E and RE-Shaping projects, in which the effectiveness of a policy scheme for the promotion of renewable electricity is measured as the increase in normalised electricity generation due to this policy compared to the additional available renewable electricity generation potential or the gross electricity consumption (Ragwitz *et al* 2007). More specifically, the effectiveness of a Member State's policy is interpreted as the ratio of the change in the normalised electricity generation over a given period of time and the additional realisable mid-term potential until 2020 for a specific technology, where the exact definition of effectiveness reads as follows:

$$E_n^i = \frac{G_n^i - G_{n-1}^i}{ADD-POT_{n-1}^i}$$

E_n^i Effectiveness Indicator for RES technology i for the year n

G_n^i Electricity generation potential by RES technology i in year n

$ADD-POT_n^i$ Additional generation potential of RES technology i in year n until 2020

[22] These criteria are common in declarations of the goals of climate and energy regulations and instruments in Europe. An example is the recent European Climate and Energy Package. Konidari and Mavrakis (2007) provide a complete overview of the criteria used in the literature on climate policy.

This definition of effectiveness has the advantage of giving an unbiased indicator with regard to the available potentials of a specific country for individual technologies. Member States need to develop specific RES-E sources proportionally to the given potential to show the comparable effectiveness of their instruments (Ragwitz *et al* 2007).

However, another, and not mutually exclusive, definition of effectiveness has proven relevant in the context of the EU. This concerns target attainment: i.e. the extent to which targets for the penetration of renewable energy are fulfilled and the trend towards the fulfilment of those targets over time (as in the interim targets in the current EU RES Directive).

Finally, when assessing the effectiveness of RES-E support, we should be aware that support schemes are only one possible influence on effectiveness (although probably the most important one). Others factors include (*inter alia*) administrative procedures or grid access. So, a given variation in deployment in a country cannot be attributed entirely to the support scheme.

Box 8 Main indicators (effectiveness)

- *Ratio of the change in the normalised electricity generation during a given period of time and the additional realisable mid-term potential until 2020 for a specific technology for each pathway.*
- *Target fulfilment (interim and final targets).*

4.2 Cost-effectiveness

Cost-effectiveness generally refers to the achievement of a given RES-E target at the lowest possible cost to society. Environmental Economics sets a clear criterion for cost-effectiveness in reaching a target: i.e. the equimarginality principle. This refers to static efficiency and welfare gains. Cost-effectiveness is attained when an instrument encourages proportionally greater RES-E deployment by those firms and installations with lower RES-E deployment costs, and lower RES-E deployment by companies with higher deployment costs,. This leads to an equalisation of marginal costs across firms/plants (equimarginality). The extent to which an instrument encourages the choice of technologies, sizes and places which minimise generation costs is thus a key aspect. This would lead to a minimisation of generation costs across firms/countries.

The costs of RES-E generation can be grouped into several categories:

- *Investment costs.* These include the costs of: the technology (i.e., turbines or PV panels, as well as the transportation of these to the site and their installation); land, grid connection (cables, sub-station, connection); civil engineering works (foundations, roads, buildings); and other costs (engineering, licensing, permitting, environmental assessments, monitoring equipment, consultancy and structured finance) (Wiser et al 2011, Rathmann et al 2011).
- *Capital costs.* This consists predominantly of the weighted average cost of capital (WACC), determined by the interest rate for debt and equity needed to cover the investment cost and the debt-equity ratio (Rathmann et al 2011).
- *Variable costs.* These include: fuel (only for biomass) and maintenance costs; insurance; taxes; management and forecasting services; and variable costs related to the maintenance and repair of equipment, including spare parts (Wiser et al 2011).

With these variables, one can calculate the levelised generation cost, which is defined as "the ratio of total lifetime expenses versus total expected outputs, expressed in terms of the present value equivalent" (IEA, 2005, p.174). LCOE therefore captures the full costs of an energy conversion installation and allocates these costs over the energy output during its lifetime. It is affected by six primary factors: annual energy production; investment costs; O&M (operation and maintenance) costs; financing (capital) costs; and the assumed economic life of the plant.

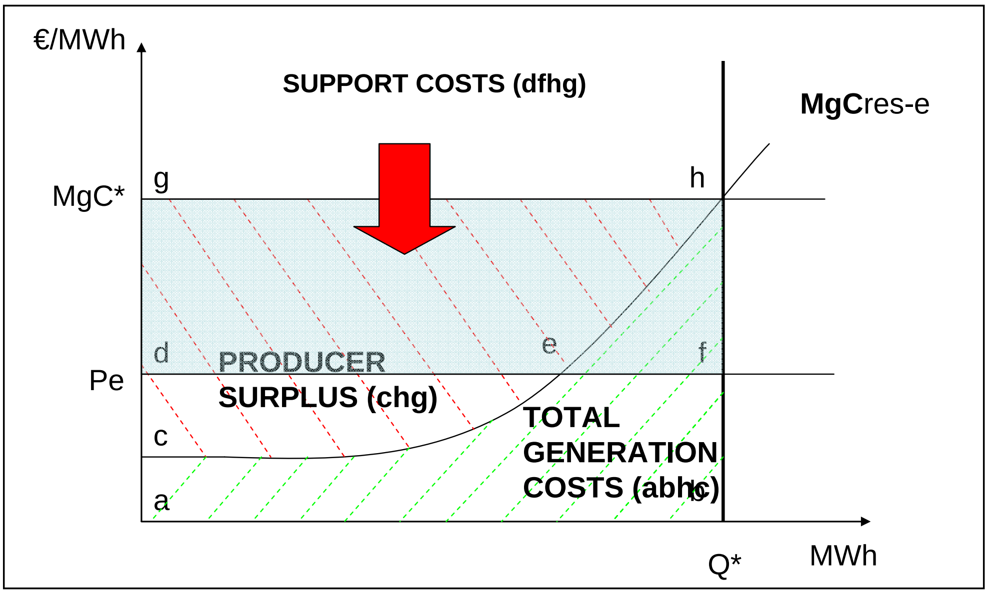

Figure 1 Illustrating different cost concepts

Source: Huber *et al* (2004) and Resch *et al* (2009). Note: Q* = Quota or target; MgC* = Marginal costs of the last technology needed to comply with the RES-E target/quota. Pe = Wholesale price of electricity. MgCres-e = Marginal cost curve of RES-E generation.

Since renewable energy has higher generation costs than traditional power generation technologies, they need public support to penetrate the market, which is ultimately paid by consumers and/or taxpayers. While part of the literature has focused on the minimisation of the generation costs and, in fact, only these costs are taken into account in several recent papers on the economics of renewable energy,[23] some have argued about the need to reduce the overall policy costs for consumers or taxpayers (Huber *et al* 2004, Ragwitz *et al* 2007, Steinhilber *et al* 2011, EC 2008, IEA 2008, IEA 2011). Thus, the costs of support should also be taken into account. Except for the case of investment subsidies and tax incentives, which are generally covered by the public budget, RES-E support is, in the end. paid by electricity consumers in their electricity bill. Therefore, cost-effectiveness has been interpreted in this context as supporting a given amount of RES-E at the lowest possible consumer costs.[24] In this

[23] See, e.g., Schmalensse (2011), Green and Yatchew (2012), Borestein (2011), Heal (2010). For example, Schmalensee (2011) argues that "The notion of ex-post efficiency, explored in this section and the next, involves taking detailed policy goals as given and asking whether they are likely to be attained at minimum cost or anything close to it. In the case of renewable energy this mainly requires production at the best sites, given the technologies required or allowed to be employed … . Ex post efficiency as regards the top-line twenty percent target requires E.U.-wide equalization of the marginal cost of producing electricity from renewable energy". There are other authors which take the other extreme, i.e., they only look at the costs of support and disregard the minimisation of generation costs (i.e., Verbruggen and Lauber 2012), including the very influential IPCC report on renewables (Mitchell *et al* 2011).

[24] See, e.g., Huber *et al* 2004, EC 2008, Ragwitz *et al* 2007, IEA 2008, IEA 2011, Mitchell *et al* 2011, among others.

case, the aim should be to minimise the revenues for producers (to sufficient and appropriate levels)[25]. Thus, instruments should be designed in a way which ensures that transfers of payments from consumers to producers are minimised. This would imply a reduction in the producer surplus. Figure 1 (above) illustrates the different cost elements.

Attempting simultaneously to minimise support costs *and* generation costs may be in conflict. In other words, an instrument may lead to the minimisation of generation costs while simultaneously leading to such large transfers from consumers to producers that the cost to consumers becomes unacceptable. Minimisation of generation costs means that the targets should be attained with the same marginal generation cost across countries (equimarginality) with a single EU support price at such equimarginality. However, a single support price would lead to windfall profits: i.e. too much support for the low-cost technologies. Indeed, a technology-neutral instrument may lead to minimum generation costs at the expense of high consumer costs, since it would lead to a single support level, leading to excessive support for the most mature and cheapest technologies and absence of support (i.e., no deployment) for the least mature, more expensive ones.[26] This has been shown by Verbruggen (2009), Bergek and Jacobsson (2010) and Toke (2010), for the cases of a quota with TGC instruments in Belgium, Sweden and the U.K.

The transaction costs related to the implementation and functioning of an RES-E support scheme should also be included in the definition of cost-effectiveness. An instrument satisfying the equimarginality rule or leading to low consumer costs may not be cost-effective if it involves high transaction costs. We should distinguish between system installation, system operation and system adjustment (Madlener and Stagl 2005). Transaction costs may fall on the public administration or on companies. The former are usually called "administrative costs".

Finally, other costs of RES-E deployment should be taken into account, namely **transmission and distribution costs** and **back-up costs**. **Transmission and distribution costs** refer to the costs of transmitting the power generated in RES-E plants to customers, which may require significant investments. RES-E plants, such as wind farms, may be located far from where electricity is needed. Thus, the deployment of wind requires investments in grid capacity: either grid extensions or grid upgrades.[27] Transmission costs for connection to the grid are generally not included in levelised cost estimates, in part because they are so idiosyncratic to any given project (Borenstein 2011).

In addition, the **costs of back-up capacity** should also be included. Some renewables are intermittent and thus, in order to address this issue, renewables have to be supplemented by fossil fuels: i.e. backup capacity is needed for when the sun does not shine or the wind does not blow. There is a social cost associated with the use of an intermittent power source: this is the cost of constructing capacity to replace the power source when it is not operating, or alternatively the cost of leaving demand unsatisfied at such times. This is not an externality in the classical sense, but it emphasises the fact that there is a system-wide cost linked to the use of intermittent power sources (Heal 2010).

[25] Costs for consumers due to RES-E support are defined as transfers from consumers to producers due to RES-E support with respect to the consumer costs due to the purchase of conventional electricity.

[26] Under an unbanded quota with TGC scheme those technologies whose long-term marginal costs are above the TGC price would not receive support. With very stringent quotas, some relatively expensive technologies might be supported (relatively high TGC prices), but not all (for example, not solar PV).

[27] For example, in the US, the best wind power sites in the United States are mainly in the centre of the country (Heal 2010), which is also the least populated area.

System costs include: technology costs (investment costs, capital costs, O&M costs and, in the case of biomass, fuel costs); transmission costs; and back-up costs. System plus policy costs plus transaction (administrative) costs would lead to total costs, as illustrated in Figure 2.

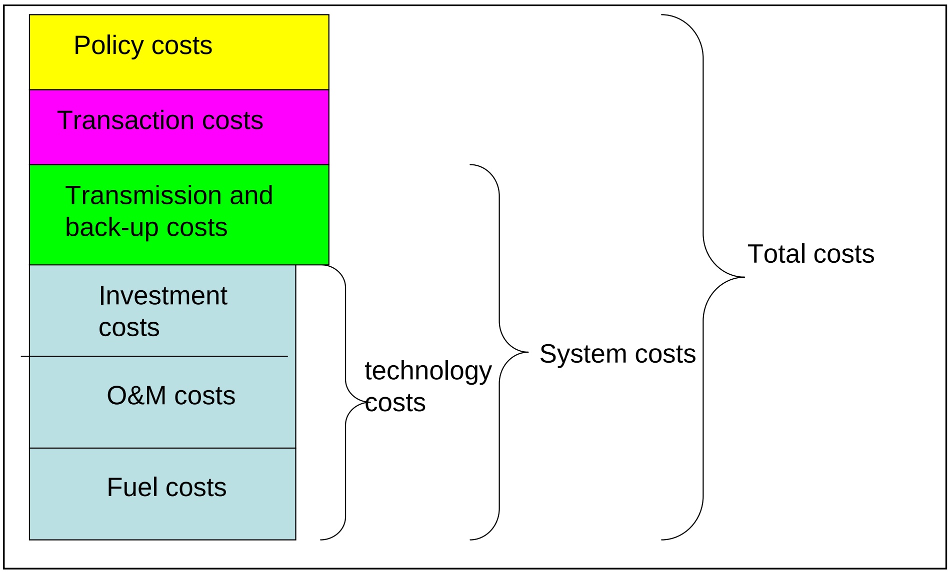

Figure 2 Illustrating the different categories of costs

Box 9 Main indicators (cost-effectiveness)

Total cost

System costs:

- *Generation costs (investment costs, capital costs, O&M costs and fuel costs for biomass).*
- *Transmission costs (costs of grid reinforcement and extension).*
- *Back-up costs.*

- *Policy support costs*
- *Transaction (incl. administrative) costs*

4.3 Dynamic efficiency

Dynamic efficiency refers to the ability of an instrument to generate a continuous incentive for technical improvements and costs reductions in renewable energy technologies: i.e. an incentive positively to influence technological change processes in the medium and long term. This is a key benefit of investing now in renewable energy technologies because, while RES-E is not a cost-effective means of reducing CO_2 emissions today, it may be so in the future if investments are made now to accelerate its development. In contrast to the cost-effectiveness criteria, which are much more concerned with the short term, dynamic efficiency is key in a problem with long-term horizons such as climate change. Future targets regarding GHG emissions and renewable energy are unlikely to be less ambitious than today and, thus, technological change will continue to be a key element in both realms.[28]

Those RES-E support instruments which favour the commercialisation of expensive technologies in niches tend to lead to quality improvements and cost reductions; this will allow us to have renewable energy technologies in the future to comply with more ambitious renewable energy and emissions reduction targets at reasonable costs. If currently expensive mitigation technologies have a large cost reduction potential with increased diffusion (as shown by several studies for energy technologies, see for example IEA 2008), then supporting them today would lead to welfare benefits in terms of intertemporal mitigation efficiency (i.e. cost-effectiveness in the short, medium and long term). In contrast to cost-effectiveness, dynamic efficiency has an intertemporal perspective on costs.

Several authors have emphasised the implications of the path-dependent character of technological change on climate policy (see, for example: Rip and Kemp 1998; Unruh 2000; and Marechal 2007). If currently expensive technologies with significant potential for quality improvement and costs reduction are not supported today, a vicious circle may ensue: they will remain expensive because they have not been adopted, and they will not be adopted because their high costs make them unattractive for potential adopters.[29]

The impact of RES-E support schemes upon innovation in renewable energy technologies has several aspects or "dimensions": diversity; R+D; learning effects; and competition (del Río 2012). Some are related to other criteria.[30]

4.3.1 Technological diversity

Dynamic efficiency refers to the promotion of technological diversity: i.e. encouraging the development and adoption of a basket of technological alternatives, including those which are currently more expensive. If they are not supported in the short term, the low-cost technologies which will be necessary to reach the future targets cost-effectively will not be available, and target attainment will be more expensive than it would be otherwise. As stressed by Sanden and Azar (2005), the aim would be to broaden the range of viable technologies, not simply to choose from those technologies already available.

Both the "options approach" (Buckman and Diesendorf 2010) and model simulations (Huber *et al* 2004, 2007) have consistently shown that ambitious RES-E deployment targets can only be attained cost-effectively from an intertemporal perspective by *simultaneously* (and not sequentially) promoting different technologies (Ragwitz *et al* 2007, IEA 2008a, Resch *et al* 2009). The SI approach has also stressed the need to invest in a broad variety of technological options in order to avoid lock-in to technologies with limited potential or negative conse-

[28] The need for a large-scale deployment of renewables to reduce CO_2 emissions is common in the projections made with simulation models. For example, according to projections made by IEA in its 2008 report on energy technology perspectives, by 2050 the increased use of renewables would contribute 21% to CO_2 emission reductions in the BLUE map scenario (the one compatible with 450ppm concentration levels) with respect to the reference scenario.

[29] The importance of these dynamic efficiency effects is shown by both renewable energy models and climate change models (see, e.g., Stern, N. 2006. *Stern Review on the economics of climate change* (Cambridge University Press, Cambridge, UK)).

[30] One of the "sources" of technological change (spillovers from activities undertaken in unrelated sectors) is not included in this paper because, as argued by Clarke *et al* (2008), a substantial component of spillover effects is exogenous from the perspective of the home industry. Thus, RES-E support instruments are largely ineffective to trigger these effects. Other factors contributing to reductions in technology costs – such as economies of scale, greater size and economies of scope – have also not explicitly been included, although, since economies of scale are related to effectiveness in support, they are implicitly treated under the "learning effects" dimension, which basically depends upon effectiveness in deployment (see section 5).

quences (Markard and Truffer 2008). Lack of support for immature technologies with a large cost-reduction potential would lead to higher costs in the long term, because these technologies will not be sufficiently developed when they will be needed to comply with more ambitious targets.

Diversity is about supporting different technologies, but also different actors, since vested interests are a barrier to a transition to renewable energy technology systems (van den Berg and Kemp 2008). New energy technologies are often developed outside the established energy systems and engage non-traditional energy actors (Lund 2010, Astrand and Neij 2006). Actors, networks and institutions involved in radical innovation processes are not identical to those performing activities that sustain an established system (Markard and Truffer 2008). The SI approach has stressed the need for new firms to enter into an emerging technological system (see Woolthuis *et al* 2005, Bergek *et al* 2008, Markard and Truffer 2008 and Astrand and Neij 2006, among others).

Building advocacy coalitions is crucial to support technological diversity, gradually breaking the institutional lock-in which is required for the emergence of a new techno-economic system (Jacobsson and Bergek 2004) and building the social acceptability and political feasibility of RES-E promotion (Hvelplund 2005, Verbruggen 2009, Agnolucci 2008).[31] Therefore, RES-E support should contribute to this variety by promoting technologies with different maturity levels: i.e. through niche creation. Increasing the diversity of actors reduces long-term policy risks (i.e. the risks created by policy), since the wider the range of types of actors and technologies participating, the greater the social and political legitimacy of RES-E support policies, which should ensure the continuation of public support for such policies in the future.[32]

Risks related to public support are problematic for diversity. The costs of renewable energy technologies are highly dependent upon the cost of capital and are affected by price, volume and balancing risks. In turn, they are all affected by policy risk (Beaudoin *et al* 2009, Jacobsson 2008). Given their greater capital intensity and reliance upon public support, immature technologies are more affected by risks. In turn, it is more difficult for small generators to cope with greater risks. Different design elements result in different degrees of policy risk.

Finally, if many technologies are supported, available funds may be spread over too many alternatives at the same time, without resulting in significant progress in any technology.

4.3.2 Private RD&D investments

As with other technologies, energy technology innovation is characterised by research, development and demonstration (RD&D), deployment, and the presence of multiple dynamic feedbacks between these phases (Figure 3).

Empirical studies have shown that private RD&D investments are an important side-effect of deployment policies (Rogge *et al* 2010, Lee *et al* 2009, Watanabe *et al* 2000, Johnstone *et al* 2010), in a context of relatively modest and stagnant direct public RD&D support in renewable energy technologies (IEA 2008b, Ek and Soderholm 2010).[33] Indeed, private RD&D seems

[31] For example, in the case of German wind power, new entrants (manufacturers and generators) increased the political power of the advocates of wind energy so that they could defend a favourable institutional framework (Bergek *et al* 2008).

[32] An example is Germany, where one-third of wind power is owned by over 200,000 local landowners and residents. 45 percent of wind projects in Germany are locally owned. In Denmark, 83 percent of wind projects are owned by individuals or local cooperatives (Farrell 2009).

[33] In the last 35 years, total public sector energy RD&D budgets have declined in real terms, while the relative share of energy in total RD&D has also declined from 12% in 1981 to 4% in 2008 (Kerr 2010). According to OECD (2011), public spending in renewable energy-related RD&D in OECD countries repre-

to contribute the main share of total RD&D in the RES-E sectors.[34] Deployment support is no substitute for public RD&D support, however. Rather, they are complements to each other and should be coordinated (Popp 2010).

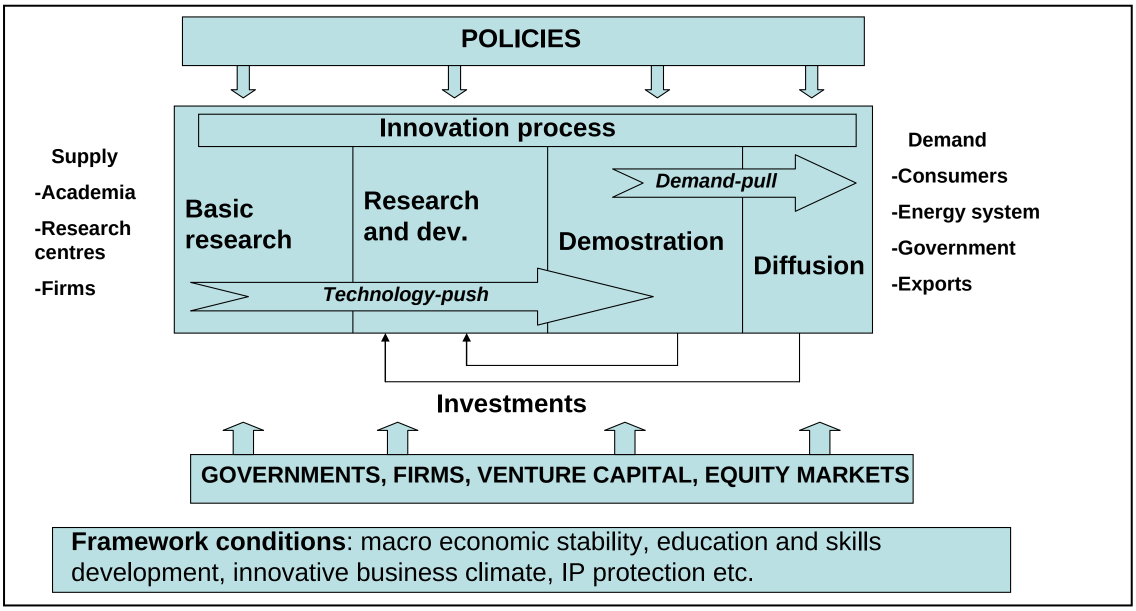

Figure 3 The innovation process

Source: Adapted from IEA (2008).

Deployment feeds back into RD&D as a result of two interrelated factors: the existence of a stable market for renewable energy technologies (demand-pull); and the existence of a surplus for RES-E generators which they can invest in RD&D (supply-push). The supply push influence is argued by Menanteau *et al* (2003) on theoretical grounds and empirically shown by Butler and Neuhoff (2008) for the U.K. and German cases. However, the surpluses which are likely to be reinvested in RD&D are those obtained by investors in immature technologies, since the scope for improvements is greater for these technologies. In contrast, greater profits for mature technologies are unlikely to be reinvested in radical technologies and more likely to lead to windfall profits (Lauber 2008). Obviously, policy risks negatively affect this dimension, since both the aforementioned demand-pull and supply-push influences are constrained.

4.3.3 Learning effects

Diffusion allows cost reductions and improvements in the technologies over time through learning effects. Policy instruments can contribute to learning effects by creating niches, especially for immature technologies. In contrast, policy risks have negative effects upon the effectiveness of support and, thus, upon learning effects. Only a reliable and stable mass market would allow technologies to advance along their learning curves.

sented, in 2007, 25% of total public energy technology RD&D. Thus, with this it remained at the same level as in 2000.

[34] Criqui *et al* (2000) report that, over the last 25 years (1974–1999), private RD&D expenditures for wind energy might have been approximately 75% higher than public RD&D expenditures. IEA (2008b) notes that private-sector RD&D spending on energy technologies today is at $40 to 60 billion per year, about four to six times the amount of government RD&D.

Learning effects suggest that it might be cheaper to provide significant investment early on in order to drive renewable technologies rapidly along their experience curves and reduce costs quickly, rather than to reduce the costs of technologies relatively slowly through more gradual introduction (Rickerson *et al* 2007). This is supported by model simulations (Huber *et al* 2007).

The SI literature suggests that, in particular, the interaction of the actors involved should be supported (learning by interacting). When the connectivity and interactions between elements of the innovation system are poor, fruitful cycles of learning and innovation are prevented (Woolthuis *et al* 2005). Learning mechanisms are largely based upon the networking of suppliers and users (Tsoutsos and Stamboulis 2005). In particular, the competitiveness of generators is dependent to a large extent upon their collaboration with equipment suppliers, with whom they have formed long-lasting networks of technological interaction and interdependence. This is confirmed by analysis of the Danish wind energy support scheme (Buen 2006, Astrand and Neij 2006).

4.3.4 Technological competition

A wealth of literature exists attesting to the positive relationship between market competition and cost-reducing innovation (Egenhofer and Jansen 2006). This innovation dimension stresses competition between RES-E generators and between equipment manufacturers as a source of innovation. Strong incentives are passed from RES-E generators to equipment suppliers to seek revenue-enhancing or cost-reducing innovations. RES-E generators may increase their profits by purchasing more efficient (greater revenues) or cheaper (lower costs) technologies from equipment manufacturers. Thus, competition between manufacturers to provide those technologies is ensured, regardless of the type of RES-E support scheme used.[35]

Competition depends upon an attractive investment climate, which in turn is contingent on policy stability. However, a guarantee of total revenue certainty eliminates the incentive to improve efficiency (Lesser and Su 2008) and reduces competitive pressures.

4.3.5 Total consumer costs; Cost-containment

Technological change is instrumental in achieving dynamic efficiency. But, obviously, the overall costs of supporting technologies, which take place in the short, medium and long term, should also be considered in any analysis of dynamic efficiency.

To put it graphically, with dynamic efficiency (and in contrast to static efficiency) we are watching a movie, not looking at a picture. Simulations suggest that promoting technological changes may be costly in the short term, but cheaper in the long-term.[36] If currently expensive technologies with a significant cost-reduction potential as a result of learning effects are not promoted today, the overall costs of attaining long-term targets would be higher because underdeveloped expensive technologies will be needed at a later date to meet those targets.

Maintaining a balance between short-term and long-term promotion costs is a crucial challenge for policy-makers. Indeed, dedicating large sums of support in the short term does not ensure dynamic efficiency. We could have technologies which are currently expensive, and

[35] Indeed, a FIT facilitates the implementation of high quality components, as the objective of the investor is not only the minimisation of generation costs, but also the maximisation of revenues gained from the tariff over the entire period (Huber *et al* 2004).

[36] Huber *et al* (2007) have shown that, due to learning effects, a 2010 target of 15% rather than 13.2% generates lower costs for society over the whole period 2006–2020, but higher costs for the RES-E strategy over the period 2006–2010. The 15% target implies that higher cost technologies are developed earlier.

yet relatively cheap in the long term, which carry significant economic baggage because they have received too much or inappropriate support in the past. For example, the large amount of support for deployment of solar PV in Spain may have been more cost-effectively invested in improving the technologies through direct RD&D investments.

Finally, the relationship between costs and risks is straightforward: lower policy risks reduce the level of support needed. Lower risks reduce capital costs, making RES-E projects cheaper and easier to finance. In the opposite direction, high and/or increasing support levels may lead to a political backlash that could reduce the legitimacy of support and lead to long-term policy instability (as with PV in Spain).

Figure 4 (below) illustrates the impact of RES-E support upon costs when a dynamic efficiency perspective is adopted. Marginal cost curves for renewable energy technologies would shift down and to the right over time as some of the aforementioned dimensions (R&D and learning) are activated as a result of RES-E support.

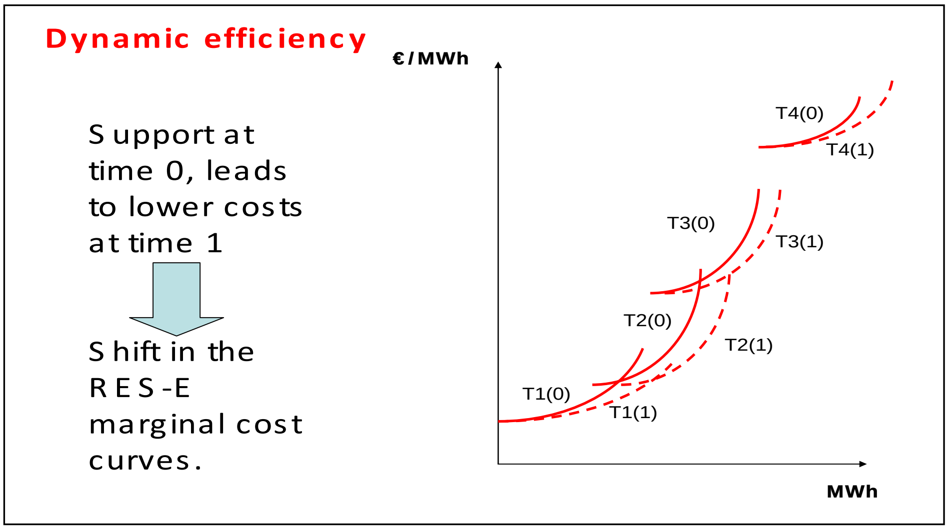

Figure 4 Illustrating the impact of RES-E support schemes upon dynamic efficiency
Source: Own elaboration.

Finally, when the larger picture concerning innovation effects is considered, the negative impacts of RES-E support schemes upon other technologies and sectors should also be considered. RES-E support drains financial resources from the whole economic system and this may have a negative impact upon productive and R&D investments elsewhere in the economy.

Box 10 Main indicators (dynamic efficiency)

- *Technological diversity (degree of deployment of more expensive or relatively immature technologies, measured as percentage deployment of different technologies with respect to potentials by country).*
- *Development of investment costs over time (€/kW).*

4.4 Equity

Even if an instrument leads to net benefits for society as a whole, there will be winners and losers. The distributive impacts upon consumers, citizens, sectors, firms or countries should be considered when designing climate policies at any level (global, European, national or regional). The social acceptance of a given policy depends to some extent upon how those distributive impacts are handled. In the context of this project, distributive concerns are mostly related to winners and losers at the national level (countries): i.e. who pays for and who benefits from a given instrument or design element. In particular, it should be identified whether a given instrument leads to a concentration of the costs of RES-E promotion in a limited number of countries. While minimisation of the total costs of complying with RES-E targets is part of the cost-effectiveness criterion, compliance costs may fall disproportionally upon countries with lower GDP per capita. As argued by Capros *et al* (2008) for the case of compliance with EU GHG targets, this result was considered by the European Commission to be inconsistent with the equity and fairness criteria which have been set as basic policy principles by the EU.

Box 11 Main indicators (equity)

- *Total policy cost for a Member-State per unit of GDP (or GDP per capita). Minimisation of variation of criterion value across the Member-States*

4.5 Environmental and economic effects

The deployment of RES-E projects may bring positive effects for the countries where they are located, as well as to the EU as a whole. Here, we take into account two of those potential positive effects of RES-E deployment at the EU level: environmental and economic effects. The former refers to reduction in GHG emissions and local pollutants, while the latter concerns avoided fossil fuel consumption, which positively affects the trade balance (exports minus imports). While other co-benefits are likely (including: net job creation; industry creation; and exports of renewable energy technology equipment) they cannot be quantified within this project. Finally, it is important to take into account that environmental impacts are not necessarily positive, but may also be negative (visual, land use). However, we only focus on the former here.

Box 12 Main indicators (environmental and economic effects)

- *Environmental indicators in different pathways:*
  - *GHG emissions*
  - *Air pollution*
- *Reduction of fossil fuel imports in different pathways: trade balance affected (avoided fossil fuel consumption from Green-X).*

4.6 Socio-political feasibility

Related to the equity concerns, which may result in significant conflicts with (or within) specific countries or interest groups, is the social acceptability (and, thus, political feasibility) of a given instrument. The implementation of a system which meets all of the aforementioned criteria may still not be socially acceptable. Social rejection may be of a general nature (i.e., civil society is against the deployment of renewables or against deployment support) or it may have a local character (the so-called 'NIMBY' syndrome).

Likewise, social acceptability is related to the existence of real or perceived local benefits for specific Member States (MSs) or regions. The local benefits of RES-E would be especially valuable in the case of countries depending to a large extent upon primary energy imports or those creating a local RES-E equipment industry. Indeed, the reduction of fossil fuel use (imports) has a positive effect upon a country's trade balance. In addition, RES-E deployment would be very attractive as a development alternative for rural regions, given the few available options in this regard apart from the traditional and declining agricultural activity. Finally, the local environmental impacts are also very relevant, leading to reductions in GHG emissions or air pollution in general.

In turn, social acceptability may be related to other criteria. For example, an expensive support scheme is unlikely to be socially acceptable to the general population (consumers). Countries may be willing to make local generation of RES-E a policy priority, because of its local benefits (socioeconomic and environmental) and not care so much about reaching the RES-E targets cost-effectively via international cooperation, which would involve encouraging RES-E generation abroad. Citizens would have a low acceptability (and, thus, low willingness to pay) for RES-E generation when they do not enjoy the local benefits Thus, they may not care so much about reaching the RES-E targets cost-effectively via international cooperation, because such *local* benefits would be concentrated abroad, since that is where the RES-E generation would occur. A system would thus be considered superior in this criterion if it stimulated the local deployment of renewable electricity projects.

Mendonça *et al*. (2010) found that steady, sustainable growth of RE would require policies which ensured diverse ownership structures and broad support for RE, and they argued that local acceptance will become increasingly important as RE technologies continue to grow in both size and number (Mendonça *et al*., 2010). This is supported by studies in New Zealand and elsewhere (Barry and Chapman, 2009). The magnitude of the changes needed will require public consent to a variety of policies, which in turn implies increased efforts to raise public awareness of renewable energy (Mitchell *et al* 2011).

The (perceived) social acceptability of RES-E policies at the MS level can be assumed to translate into a preference of national policy-makers for a specific pathway (or combination of pathways). Indeed, the political feasibility of a given instrument is related to equity concerns, environmental and economic effects and social acceptability, which may result in significant conflicts with specific countries or interest groups. Although the European Commission makes legislative proposals, the Member States and the elected representatives of their populations, in the Council and European Parliament respectively, get to vote on those proposals, and it is ultimately a question whether the required majority can be achieved.

Thus, political feasibility – within the legislative procedures of the European Union, as well as at national level – deserves separate consideration. The history of environmental policy in general is full of instruments which score highly on the previous criteria but which are not implemented, mostly because they are not attractive to policy-makers (since they are rejected by societal actors at large or by highly influential stakeholders). Therefore, it is necessary to consider this criterion in order to propose policy measures which have a chance of being implemented in the real world. In turn, political feasibility depends upon: the distribution of the costs of reaching the targets; and awareness of potential local benefits.

The assessment takes place in two steps: first, one has to look at the role which MSs play in the relevant legislative procedure for each policy pathway. Unanimous decisions are harder to achieve than voting under a qualified majority rule, for example. Then, and based upon the role of the MSs, one can ask whether there are "historic" or other preferences among policy-makers in the Member States which may influence their vote on the measure.

Box 13 Main indicators (socio-political feasibility)

- *Revealed preference of (national) policy-makers for a specific pathway. What is your preferred pathway, taking into account the benefits for your country and the perceived social acceptability of the electorate? (Likert scale, in favour/balanced views/opposed). (Survey to policy-makers).*
- *Procedures for adoption of the respective policy pathway and role of the MS (unanimity decision or qualified majority), etc., to reflect the actual "say" that MSs have)*
- *Political consensus in MSs with coalition governments on specific pathways (review coalition programmes).*
- *In MSs where RE policy is devolved (e.g. UK, BE), political consensus between devolved governments on specific pathways.*

4.7 Legal feasibility

The criterion of legal feasibility has two aspects: legislative competence; and compatibility with other EU primary and secondary law.

With regard to the first aspect, the EU only has the competence conferred upon it by the Treaties. This has not changed after the entry into force of the Lisbon Treaty, and Article 5(2) of the Treaty on the European Union (TEU) accordingly still provides: "Under the principle of conferral, the Union shall act only within the limits of the competences conferred upon it by the Member States in the Treaties to attain the objectives set out therein. Competences not conferred upon the Union in the Treaties remain with the Member States." This provision plays a crucial role in the relationship between the EU and the Member States and is the reason why, for every legislative action taken by the EU, an appropriate legal basis needs to be found (i.e. a provision which confers the competence to legislate upon the Union, rather than leaving it as a topic for Member State legislation.

The legislative competence of the European Union in the field of energy is specifically addressed by Article 194 of the Treaty on the Functioning of the European Union (TFEU), as introduced by the Lisbon Treaty. According to Article 3(2)(i) TFEU, the European Union and the Member States share competence on energy issues, meaning that they can both legislate; however, Member States are competent where the European Union has not (yet) exercised its competence (Article 2(2) TFEU).

Article 194 TFEU in this regard specifically provides:

> "1. In the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, Union policy on energy shall aim, in a spirit of solidarity between Member States, to:
>
> > (a) ensure the functioning of the energy market;
> >
> > (b) ensure security of energy supply in the Union;
> >
> > (c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and
> >
> > (d) promote the interconnection of energy networks.
>
> 2. Without prejudice to the application of other provisions of the Treaties, the European Parliament and the Council, acting in accordance with the ordinary legislative procedure, shall establish the measures necessary to achieve the objectives in

paragraph 1. Such measures shall be adopted after consultation of the Economic and Social Committee and the Committee of the Regions. Such measures shall not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply, without prejudice to Article 192(2)(c).

3. By way of derogation from paragraph 2, the Council, acting in accordance with a special legislative procedure, shall unanimously and after consulting the European Parliament, establish the measures referred to therein when they are primarily of a fiscal nature."

In addition to the question of whether the Union is competent, the second aspect of "legal feasibility" is partly referred to in Article 7 of the Treaty on the Functioning of the European Union: "The Union shall ensure consistency between its policies and activities, taking all of its objectives into account and in accordance with the principle of conferral of powers." Also, and according to long-standing case-law of the European Court of Justice "as the European Union is based on the rule of law, neither its Member States nor its institutions can avoid review of the conformity of their acts …" (e.g. Cases C-402 and 415/05 *Kadi* [2008] ECR I-6351) Thus, all measures need to be compliant with EU law and they need to be coherent with existing policies.

Accordingly, the assessment of the legal feasibility criterion falls into two parts.

- First, one has to examine whether the Union has competence to legislate with regard to each specific pathway to be examined, and which provision could be an appropriate legal basis for such legislation. Of particular importance in this assessment will be the "new" energy competence created by Article 194 TFEU. This first step will result in the definition of a legal basis, or the conclusion that there is no legal basis: i.e. in a clear "yes or no" answer to the question whether the pathway is, *prima facie*, legally feasible.
- In a second step, all of the provisions of EU primary and secondary law which could be affected have to be listed and the compliance of each respective pathway has to be assessed. So far as EU primary law is concerned, those would be (for example) the rules of the internal market, in particular on free movement of goods and competition (including State aid). For EU secondary law, one needs to look at the existing secondary legislation on the internal energy market.

It should be noted that, for the different RES-E pathways, different provisions of EU primary and secondary law may be triggered. With regard to results, the second evaluation step may lead to a clear answer as regards legal feasibility as well: if the policy pathway does not comply with EU primary and secondary law, then the respective pathway could not be adopted. However, since – depending upon the policy pathway in question – different provisions of EU primary and secondary law may be triggered, and for some policy pathways more (or at least more intensively or strongly) than for others, this evaluation step will additionally involve a "ranging exercise": some policy pathways may be classified as being "more feasible" than others from a legal perspective.

Box 14 Main indicators (legal feasibility)

- *Does the EU have competence to legislate the specific pathway (legal basis / lack of legal basis)? (Yes/No answer)*
- *Does the policy pathway comply with EU primary and secondary law? (Likert scale).*

4.8 Summary

Table 1 summarises the different criteria.

Table 1 Brief characterisation of the criteria

Criteria	Brief characterisation
Effectiveness	Increase in RES-E generation adjusted by national potentials. Attainment of RES-E targets
Cost-effectiveness	Minimisation of generation costs and minimisation of policy support costs. Transaction costs (whether they fall on private or public entities) and other costs (costs of grid reinforcement and extension and back-up costs) should also be taken into account.
Dynamic efficiency	This criteria refers to the impact of RES-E support instruments, which are mostly "diffusion", market-pull instruments, on previous stages of the innovation process in renewable energy technologies.
Equity	RES-E support instruments have distributive impacts. A pathway may have less beneficial effects on certain countries and there will certainly be winners. Within countries, distributive impacts between producers and consumers are also a major concern. Share of the market between different RES-E producers (independent power producers vs. large utilities) is also important in this respect.
Environmental and economic effects	RES-E deployment triggered by RES-E policy has unavoidable local impacts of a different nature: socio-economic, environmental and otherwise.
Socio-political acceptability	RES-E support policies may not be socially acceptable and may be rejected by the population. Social rejection may be a general aspect (i.e., civil society is against the deployment of renewables or against deployment support) or may have a local character (the NIMBY syndrome). Social acceptability and political feasibility go hand-in-hand. Political feasibility refers to the attractiveness for policy makers of a given RES-E support instrument or pathway and it is critically affected by equity, environmental and economic effects and social acceptability.
Legal feasibility	This criterion refers to whether the EU has competence to legislate a given pathway (legal basis) and whether the policy pathway complies with EU primary and secondary law.

5 Interactions between criteria

In the literature on renewable electricity support schemes, criteria have traditionally been proposed as a checklist, and thus have been represented and assessed independently of each other. In reality, however, criteria are interrelated. Thus, the interactions between different assessment criteria may need to be considered. The aim is to identify possible synergies and conflicts between them.

The criteria established above do involve various overlaps *inter se*. This is unavoidable, since there are mutual interactions between criteria. There is no way in which we can remove one criterion and/or integrate several of them without losing relevant perspectives for the assessment of pathways. Criteria are inclusive of all relevant aspects even if this means that one is partially (but never totally) included in others. For example, high consumer costs (cost-effectiveness) affect social acceptability. But social acceptability also depends upon the local benefits of deployment and upon how costs and benefits are distributed among different socio-economic actors (equity). In turn, the existence of local benefits depends upon effectiveness in deployment, which overlaps with dynamic efficiency to create a national industry upstream from the innovation process in renewable energy technologies. Finally, political feasibility depends, on the one hand, upon the interaction between social acceptability, cost-effectiveness, local benefits and equity, and, on the other hand, upon the juridical criteria.

Criteria may certainly be in conflict with each other. For example, a greater level of local benefits may come at the expense of cost-effectiveness in meeting EU targets. This means that if national policy-makers are interested in the local benefits of renewable electricity, deployment may not occur in those places with a better renewable resource potential in the EU. Another example of a conflict is between consumer costs and dynamic efficiency. Lower profit margins for renewable generators would lead to a lower cost for consumers. But it could also lead to lower incentives for innovation, if innovation results from reinvesting the profit that is obtained by renewable generators into new technologies (developed by equipment producers), although the evidence from the German and Spanish solar PV industry is not so clear in this regard. In general, a conflict between static and dynamic efficiency could occur if existing, cheaper technologies lock out promising technologies with a large cost-reduction potential.

But, on the other hand, there might also be synergies. For example, effectiveness in the deployment of different technologies would encourage dynamic efficiency by facilitating technological diversity and allowing technologies to advance along their learning curves. Furthermore, the existence of a market feeds back into the R&D stage and, thus, deployment triggers R&D investments.

Another example of a synergy between criteria is between static efficiency and political feasibility, insofar as low consumer costs enhance social acceptability and, thus, political feasibility. In contrast, windfall profits undermine cost-effectiveness, equity, social acceptability and political feasibility. Equity and political feasibility are also obviously interrelated. Note that, in this section we have separated the criteria concerning socio-political feasibility into two sub-criteria (social acceptability and political feasibility) to grasp relevant interactions between them and other criteria. However, it is very difficult to disentangle both sub-criteria. A socially unacceptable pathway will also almost certainly be politically infeasible.

It may come as a surprise that static efficiency (consumer costs) and effectiveness are positively related through lower investment risks (see Mitchell *et al* 2006, Ragwitz *et al* 2007). This is so if an RES-E support scheme which is effective in deployment (because it provides a stable flow of revenues) would be regarded as less risky. In turn, lower risks obviously entail a lower risk premium and, thus, lower levels of support would be required, which involves lower consumer costs.

Therefore, a holistic perspective on the criteria is required, whereby their mutual relations (synergies and conflicts) are made explicit. This may help to build a hierarchy of criteria, whereby criteria and sub-criteria are related and some are shown to be instrumental in achieving others. The aim is to produce a figure identifying those interactions. Figure 5 and Table 2 picture and summarise those interactions. Further details are provided below.

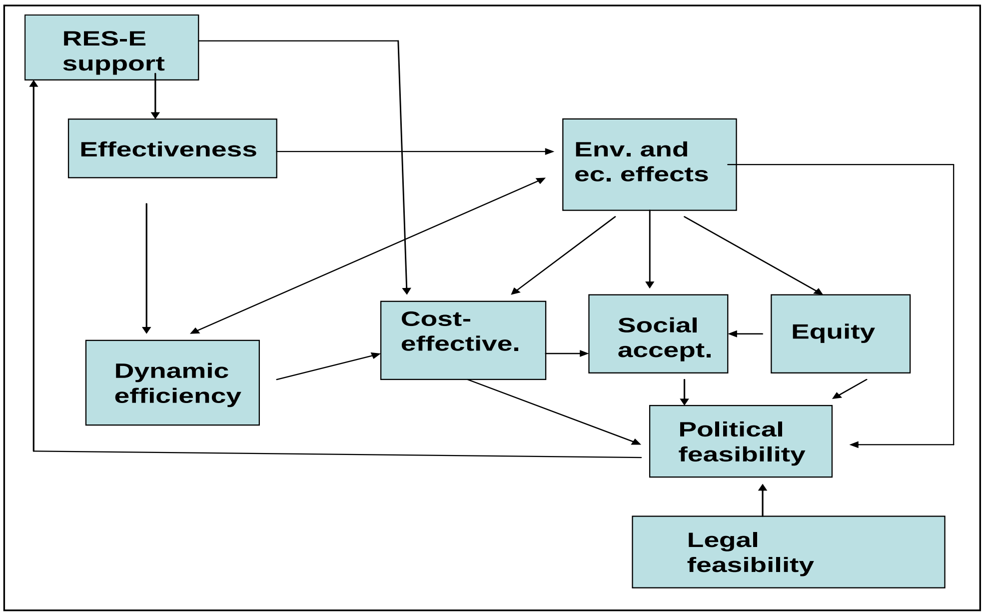

Figure 5 Picturing the interactions between criteria

Source: Own elaboration.

Table 2 Illustrating the interactions between criteria

From (columns) /to (rows)	Effectiveness	Cost-effectiveness	Dynamic efficiency	Equity	Local impacts	Social acceptance	Political feasibility	Legal feasibility
Effectiveness						(indirect effect through political feasibility)	Regulatory stability as a result of political feasibility favours deployment	
Cost-effectiveness			Innovation positively influences cost-effectiveness (techno-cost reductions)				Regulatory stability results in lower risk premium	
Dynamic efficiency	Market creation leading to learning effects and private R&D							
Equity					Local impacts have equity effects some of which are difficult to predict			
Local impacts	Deployment leads to local impacts		Creation of a local industry and impacts upstream the innovation process (technology diversity).				Indirectly through impact of political feasibility on effectiveness	
Social acceptance		Greater consumer costs reduce social acceptance		Distributive impacts of the support scheme affects social acceptance	Benefits of RES-E deployment results in social acceptance			
Political feasibility		High consumer costs make continuation of support scheme unlikely		Inequitable schemes are politically unfeasible in the long-term	Greater local benefits make the continuation of support politically feasible	Social acceptance is a crucial element of political feasibility		If the instrument is not legally feasible it can not be political feasibility. Not the other way around.
Legal feasibility								

An obviously crucial link is between RES-E support schemes and effectiveness. The upper part of the figure suggests that key aspects of support schemes subsequently trigger a set of relevant effects (profit margins, risks, competition between technologies and between actors, transaction and administrative costs or the equimarginality rule) which have an impact upon the effectiveness and cost-effectiveness of RES-E support. Several key aspects and features of support schemes are relevant in this context. The type of support scheme is obviously one, while the specific design elements of the instruments form another.

The type of instrument and its design elements obviously affect the transaction costs of the instruments and their administrative costs, although not much empirical research has been undertaken in the RES-E support literature on this topic. Both transaction and administrative costs affect the total costs of an instrument (i.e. static efficiency) but transaction costs also have an impact upon the effectiveness and diversity of actors and technologies, since they fall disproportionately upon the smaller actors (given their large fixed-cost component). The type of support scheme and design element, targets and support levels affect profit margins, risk and the level of competition. This has a bearing upon effectiveness in deployment and on the cost-effectiveness of the scheme, in this later case through their impact upon policy costs. However, they may also have a direct influence upon cost-effectiveness through their impact upon the equimarginality rule, which leads to a minimisation of generation costs.

Effectiveness (market creation) is a crucial criterion which is clearly instrumental in achieving many of the others, since it triggers multiple effects. Two are worth mentioning: local benefits and dynamic efficiency. Regarding the former, it is well known that renewable energy deployment has significant local/national impacts. Some may be negative (i.e. negative externalities in the form of visual impacts, soil occupancy, or negative impact upon grid stability), while others are positive (including job creation, rural and regional development opportunities and diversification of energy supplies). These local benefits are crucial to the acceptability of the RES-E support scheme by the general population of a country and, thus, for its political feasibility (see below). In turn, one crucial local benefit is the creation of a local industry. This leads to the existence of domestic suppliers of the technology which, in turn, affect policies and, particularly, support levels (lobbies). Building a constituency behind the new technology (advocacy coalitions) has positive effects upon several criteria (social acceptability, R&D in dynamic efficiency), but may also lead to regulatory capture, rent seeking and, thus, negative effects upon cost-effectiveness.

There are feedback loops from diffusion to the previous stages of the innovation process. As shown in section 4.3 above, private R&D can be influenced by RES-E support instruments in the form of deployment incentives, although it is certainly not the only source of R&D, the other being public investments in R&D in the form of direct subsidies, tax incentives, tax credits, etc. Indeed, the innovation literature has often stressed the complementary role of private and public R&D in the innovation process, although their relative importance may vary along the different stages.[37] As mentioned in sub-section 4.3.2., the link between RES-E (deployment) support and private R&D investments takes place through two mechanisms: profit margins and the existence of a market. The profit margins which are particularly relevant for R&D investments are those obtained by those immature technologies with a greater improvement potential through R&D, whereas excessive profit margins to mature technologies are more likely to result in windfall profits and not in private R&D investments.[38] Private R&D also benefits from the existence of a local manufacturing industry which, in turn, is highly dependent upon the effectiveness of the support scheme.

A second major source of dynamic efficiency is the activation of the different types of learning effects, which generally takes place as a result of effectiveness in deployment. Note that private R&D

[37] Public support for R&D is particularly necessary where a market failure in the innovation process is more likely to occur: i.e. in basic R&D, whereas it becomes less relevant as we move towards later stages.

[38] Windfall profits may occur both in mature and immature technologies. However, high profit margins in immature technologies are more likely to be reinvested in R&D than is the case with mature technologies.

and learning effects interact (Watanabe *et al* 2000). A lower cost for technologies as a result of R&D: makes them more attractive for potential adopters; increases their diffusion; and allows them to advance faster along their learning curve. On the other hand, learning reduces costs and promotes diffusion. In turn, market creation makes RD&D investments in those technologies more attractive. Therefore, it becomes obvious from this analysis that effectiveness (market creation) is instrumental in successfully meeting the dynamic efficiency criterion (both regarding R&D and learning effects).

From long-term perspective, dynamic efficiency relates to other relevant criteria and affects crucial aspects of the support scheme. For example, better and/or cheaper technologies as a result of R&D investments would allow the setting of more stringent RES-E targets in the future or the reduction of support levels over time. A particularly relevant effect of dynamic efficiency is the impact upon the cost-effectiveness of the scheme in the longer-term.

Finally, the social acceptability of renewable electricity deployment and public support for this deployment is a crucial criterion, mostly stressed by the systems of innovation perspective and the political science literature, and confirmed by several empirical studies. It is closely linked to political feasibility since, in democratic systems, policy-makers seeking re-election should avoid major conflicts with social constituencies related to RES-E deployment and support. The continuation over time of the support scheme, and the support levels themselves, depend upon social acceptability and political feasibility.

Social acceptability is directly affected by three criteria: cost-effectiveness (mostly consumer costs); local benefits; and the way in which the costs and benefits are distributed among the population and between countries (equity). High (or, more importantly, significantly increasing) consumer costs as a result of a RES-E policy is likely to trigger a backlash against the instrument and maybe against RES-E deployment itself, as has recently been shown by the case of solar PV promotion in Spain. Countries experiencing a disproportionate cost in a given pathway compared to other countries would reject this pathway as socially unacceptable and politically unfeasible.

On the other hand, social acceptability is enhanced by the existence of local benefits stemming from RES-E deployment and, particularly, the more visible ones: industry creation and jobs. In reality, the creation of a market (effectiveness), local impacts (leading to the creation of a local industry) and social acceptability interact with each other and are likely to generate a reinforcing effect with positive feedbacks, mostly due to advocacy coalitions.

Of course, there might also be negative local impacts in the form of negative environmental externalities due to the concentration of RES-E projects, which may negatively affect the social legitimacy of RES-E support (see, for example, Bergmann *et al* 2006 for the case of the U.K.). Deployment (effectiveness) and social acceptability (NIMBY) may be negatively related at high RES-E penetration levels. Thus, social acceptability becomes proportionally more important with increasing RES-E penetration due to NIMBY and greater costs.

Social acceptability influences political feasibility, which is also directly affected by the cost-effectiveness of support, where high-costs of support are politically non-acceptable. The juridical criteria (legal feasibility) also affect political feasibility. It is obvious that a legally infeasible pathway is also politically unfeasible.

Finally, it is worth mentioning that political feasibility feeds back to RES-E support. Governments may need to fine-tune the RES-E support scheme (either targets, instruments or design elements) as a result of identified drawbacks in the scheme or due to pressures from socio-economic actors (lobbies, advocacy coalitions). This change in the support scheme would have influences upon the criteria in successive time periods. Thus, Figure 5 (above) provides a picture of circular flows, and suggests an inherent dynamic perspective on the interactions between criteria with changes over time.

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