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METHODS

Sustainability-guided promotion of renewable electricity generation☆

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Abstract

In recent years, the threat of global climate change, high fuel import dependence, and rapidly rising electricity demand levels have intensified the quest for more sustainable energy systems. This in turn has increased the need for policy makers to promote electricity generation from renewable energy sources. Guaranteed prices coupled with a buy-back obligation for electricity fed into the grid is a popular renewables promotion instrument, especially in Europe. More recently, driven mainly by electricity market liberalisation efforts, quota targets for the share of renewables in combination with tradable 'green' certificates (TGC) have received considerable attention. TGC offer a greater theoretical potential for economic efficiency gains, due to price competition and the greater flexibility assigned to the obliged parties. While guaranteed prices and TGC schemes support the operation of renewable energy technology systems, bidding schemes for renewable energy generation capacity are used to raise economic efficiency on the plant construction side. All of these policy instruments suffer from the shortcoming that they do not explicitly account for the often widely varying environmental, social and economic impacts of the technologies concerned. In this paper, we propose a methodology for the design of renewable energy policy instruments that is based on integrated assessment. In particular, we argue that using participatory multicriteria evaluation as part of the design of renewable energy promotion policies would make it possible: (1) to differentiate the level of promotion in a systematic and transparent manner according to their socio-ecological economic impact, and (2) to explicitly account for the preferences of stakeholders. A further problem of existing TGC and bidding schemes is that diversity of supply could be severely diminished, if few low-cost technologies were allowed to dominate the renewable energy market. To ensure a certain diversity of technologies, our scheme suggests the use of different technology bands for technologies that are relatively homogeneous with respect to their maturity.

Keywords: Renewable energy; Guaranteed feed-in tariffs; Tradable green certificates; RPS; Integrated assessment; Multicriteria evaluation; PROMETHEE; GEMIS

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1. Introduction

The promotion of renewable energy technologies (RET) for a more sustainable development has become one of the primary goals of energy policy makers in many countries (European Commission, 1999; UNDP/UNDESA/WEC, 2000; IPCC, 2001; IEA, 2004a). Policy makers increasingly assign high priority to promote RET because they contribute to the mitigation of climate change and local environmental pollution, stretch-out of the non-renewable resource base, decrease of import dependence, increase of (local) employment, and the support of remote and rural communities. Furthermore, they can be useful to increase energy supply diversity, improve of the national balance of trade, and because most of them are less prone to terrorist attacks than, say, nuclear power stations or oil and gas supply infrastructure (the obvious exception being large dams for hydropower generation). Besides, the RET manufacturing and services sector is increasingly seen as an important domestic industry that is able to create new jobs and exports.

In 2002, renewables accounted for some 14% of total primary energy supply worldwide, while 18% of global electricity was generated by use of renewable sources. By far the largest renewable energy source is still biomass (two-thirds of which is used traditionally for cooking and heating), followed by hydropower. Over the next 30 years, in the absence of major technological breakthroughs, incisive policy action will be needed to increase the share of renewables in the future primary energy mix and to "steer the global energy system onto a more sustainable path" (IEA, 2004b). Reasons are that many countries, especially developing ones, switch from traditional biomass to more 'modern' (usually fossil) fuels in their attempt to satisfy rapidly growing energy demand, and that 'new' (i.e., non-hydro) RET only start from a very low base. Renewable energy promotion instruments[1] are in place in many countries, because higher generation cost and/or capital intensity would hinder the transition to an increased use of RET. Typically, such promotion schemes create sub-markets, which are protected from competition against conventional technologies, a feature that can be undesirable in the longer term when RET are more mature and have gained substantial market shares. Clearly, instruments that create protected and subsidised sub-markets are 'second-best' solutions, compared to the most obvious solution, namely to make energy consumers pay for the full costs that arise from energy supply by means of a Pigovian tax (Hall, 1992).

Mostly two instruments have been used to promote the generation of electricity from renewable energy sources: (1) guaranteed feed-in tariffs and (2) quota targets combined with tradable 'green' certificates (TGC) for renewable electricity fed into the grid (also referred to as Renewable Portfolio Standards, RPS). Feed-in tariffs provide certainty about the achievable per unit revenues from selling renewable electricity to the grid and allow for 'planned' technology diversity, but cannot ensure that a certain amount of renewable electricity is actually provided. In contrast, TGC are based on competitive market principles. Typically, with few exceptions, they feature mandatory quota targets and involve certificate trading and cost minimisation. Therefore, while the amount of renewable electricity can be safeguarded, the certificate price is variable, creating uncertainty about the profitability of the RET investments.

In Europe, in particular, guaranteed feed-in tariffs have been used widely to support the generation of electricity from renewable energy sources (RES-E) directly.[2] With growing market shares of RES-E, however, the distortionary effects and the cost burden of fixed feed-in tariffs (the latter is either put on taxpayers via the fiscal budget, or on utilities who pass it on to electricity consumers) become increasingly problematic. At the same time, TGC schemes with prescribed quotas for the amount of renewable energy in overall energy supply were praised for their potential to raise economic efficiency and introduced in several countries since the late 1990s (e.g.,

[1] Commonly, these are either investment subsidies or subsidies for the operation of a plant, or may come in the form of tax grants (e.g., Wohlgemuth and Madlener, 2000). Note that typically other policy instruments, such as information campaigns, RD&D programmes, and often also commercial strategies (e.g., the marketing of 'green' power), complement economic (incentive-based) policy instruments.

[2] Because of the worldwide wave of electricity market liberalisation, the main emphasis of energy policy makers in recent years has been on the renewable electricity market.

Madlener and Fouquet, 1999; Berry, 2002; Menanteau et al., 2003; Nielsen and Jeppesen, 2003; among many others).

The substitution of renewable energy sources for fossil and/or nuclear fuels is no panacea either. Extensive use of renewable energy sources can lead to important adverse environmental and social impacts. These impacts differ widely across renewable energy sources and the technologies concerned (e.g., Abbasi and Abbasi, 2000; Tsoutsos et al., 2005). When designing policy instruments for more sustainable energy futures, therefore, the aim from a sustainability point of view ought to be to generate the lowest possible adverse socio-ecological economic (SEE) impact per unit of electricity generated, while ensuring a certain degree of economic efficiency. Both of these also depend on local conditions and other project-specific circumstances, which of course create some fuzziness and ask for a maximum possible local adaptation of the instruments used. The SEE impact can be assessed by an array of sustainability criteria and with data based on life-cycle analysis. Building on Bossel (1996), we aim to derive sustainability criteria such that they represent the main system functions; the second key criterion is data availability. The relevant impacts are the net impacts that arise when RET substitute for conventional energy technologies (while our approach can be extended in this way, a comprehensive discussion of this dimension is beyond the scope of this paper). A widely applied method to compare and rank options by a large number of criteria is multicriteria evaluation (MCE). MCE provides policy makers with information which is not forthcoming from other 'valuation' instruments (Munda, 1996).

Besides the multiple dimensions of SEE impacts, the diversity of technology options is essential for the adaptiveness of an energy system. In view of uncertainty about potentials and SEE impacts of technologies, and the danger of negative long-term consequences of lock-in effects, renewables promotion schemes also need to foster RET diversity (on the issues of flexibility, risk, and diversity of energy supply systems see also Hall and Thomas, 1984).

Given these two main goals – minimal SEE impact and a certain degree of diversity among the renewable energy sources used – TGC have two important shortcomings. On the one hand, all renewable energy sources are treated as homogeneous in their environmental and socio-economic impacts. On the other hand, ordinary TGC schemes fail to meet the goal of assuring diversity. In this paper, therefore, we suggest a methodology for adapting the policy instruments for the promotion of RES-E such that they can overcome these two shortcomings.[3] Note that while our approach allows to assess and rank RET according to their SEE impacts, it is the policy makers who have to decide by how much feed-in tariff levels, or the number of certificates issued, are varied for different RET.

The remainder of the article is organised as follows: Section 2 contains a concise literature review on the use of MCE methods in energy studies. Section 3 outlines the conceptual framework on which we base our analysis. An overview of the institutional framework related to the promotion of commercially available RES-E follows in Section 4. Section 5 critically reviews the different policy instruments for direct price support of RES-E, and Section 6 introduces the basic design of a multicriteria-based participatory scheme to evaluate different RET along sustainability criteria, and shows how it can be applied for redesigning conventional renewable energy policy instruments. Section 7 concludes.

2. Literature review on multicriteria evaluation of (renewable) energy use

MCE is widely used in electricity generation planning and energy policy design. Applications include the construction of indices summarising the environmental performance of energy systems for accounting, managerial or planning purposes (Stewart and Horowitz, 1991; Mirasgedis and Diakoulaki, 1997); construction of sustainability indices at the energy conversion plant level (Afgan et al., 2000; Afgan and Carvalho, 2002); transmission and distribution system planning (Weedy, 1989; Ramirez-Rosado and Adams, 1991); supply-capacity planning

[3] Obviously, by doing so, we deviate from the assumption made in standard economics that the problem of optimal renewable energy supply can simply be defined as 'finding the trade-off between marginal benefits of renewable energy generation and its marginal external (or abatement) costs'.

(Kavrakoglu and Kiziltan, 1983; Quaddus and Goh, 1985; Lootsma et al., 1990); generation systems operation (Muslu and Anderson, 1989; Maekawa et al., 1992; Gandibleux, 1999); integrated resource planning incl. demand-side management (Hanson et al., 1991; Hobbs and Horn, 1997; Schmutz et al., 2002); project selection in a resource bidding context (Siskos and Humbert, 1983; Goumas and Lygerou, 2000a; Mavrotas et al., 2003); national energy policy planning (Keeney et al., 1987; Linares and Romero, 2000; Stagl, forthcoming); and regional energy policy planning (Schulz and Stehfest, 1984; Georgopoulou et al., 1997; Kablan, 1997). For a review of the use of MCE in energy decision making, see also Hobbs and Meier (2000).

From a methodological point of view, these studies apply two main types of MCE methods: continuous methods and discrete methods. *Continuous methods* are used for elucidating the range and the consequences of feasible actions, for illustrating trade-offs between environmental, social and economic parameters, and for assisting in the selection of a compromise solution. *Discrete methods*, in contrast, are applied for the evaluation of a given number of energy alternatives (technologies or scenarios) with respect to multiple criteria and for helping to address the conflicts associated with energy decisions.

Most applications in the energy field focus on the technical aspects of the planning process. Like in other fields of application, one can observe also in energy studies a trend towards increased stakeholder involvement for enhancing validation and ownership of the planning process, and as a means for addressing uncertainty (e.g., Haralambopoulos and Polatidis, 2003; Greening and Bernow, 2004; Stagl, forthcoming).

The studies mentioned in this section are either case studies or works that develop a decision support framework, but none of them integrates MCE and participatory processes into the design of energy policy instruments; this is a contribution which we aim to make with our article.

3. Theoretical framework

Sustainability requires minimising adverse biophysical impacts from human action, while fulfilling other goals like maintenance of human well-being and minimising the waste of economic resources. Two main groups of economic policy instruments aim to reduce the biophysical impact of our economies. They are *quantity-based instruments*, like standards and tradable permits (certificates), on the one hand, and *price-based instruments*, like taxes (or subsidies) and fees, on the other hand (for comparisons, see Bohm and Russell, 1985; Tietenberg, 1990; Requate, 1998; Denicolò, 1999; Dietz and Vollebergh, 1999). Both types of instruments are cost effective, but they differ in what is fixed and what is variable. For permits, the quantitative target is fixed, which provides a straightforward measure of environmental progress as well as compliance, and the price of the permits is variable (Tietenberg, 1985; Koutstaal, 1999). For the price-based instruments (e.g., taxes for 'bads' or subsidies for 'goods'), the monetary incentive is fixed for a certain period of time, reducing uncertainty for investors, but taxes/subsidies offer no guarantee that the environmental impact will be limited to a certain level (Bovenberg and De Mooij, 1994), or a certain amount of RET used. When making extremely simplifying assumptions, we could calculate optimal solutions and both types of policy instruments would lead to the same result. In reality, uncertainty about reduction costs (present and future), uncontrolled environmental consequences of production, interdependencies of impacts, and responses of economic actors may lead to different outcomes from the two types of instruments. Weitzman (1974) for example showed that uncertainty about control costs leads to a preference for quantity-based regulation, because the risk of missing the reduction target is higher in the case of price-based regulation (for a more recent application to climate change, see Pizer, 1997). While these comparisons are extremely important for decisions about environmental policy, the focus of this paper is on the need for amendments of existing instruments, and on the possibilities to design these amendments such that they better account for known problems relevant to sustainability-oriented policy making. The issues that we discuss below apply to both types of instruments.

Policies for sustainability are the result of a constant search of balance in the face of shifting background conditions. Socio-economic and biophysical systems are *complex adaptive systems* (Allen, 2001; Berkes and Folke, 2003; Giampietro, 2004). Important characteristics of such systems, such as sustained change, irreversible change, unpredictability, qualitative change and disequilibrium make the design and data collection for instruments for sustainability-oriented policies a challenging task. Moreover, due to multiple interdependencies, these systems are *co-evolving*. Economic development is therefore seen as a process, which results in, and at the same time is driven by, changes of knowledge, technologies and social organisation over time (Gowdy, 1994; Norgaard, 1994).

The models most widely used to design environmental policy instruments are static optimisation models, which have been heavily criticised. Difficulties in finding optimal solutions are attributable to *behavioural limitations* (Simon, 1979; Nelson and Winter, 1982; Hodgson, 1988) and *limits on effective computability*, either due to the complex nature of socio-economic systems (Goodwin, 1990; Day, 1994; Arthur et al., 1997; DeCanio, 1999; Rosser, 1999; Foster, 2000) or due to the uncertainty about the consequences of an action (Dosi and Egidi, 1991; Perrings, 1991; Wynne, 1992). In sustainability-oriented policy design, uncertainty is particularly relevant due to the long time horizons and the socio-ecological economic interactions involved (Faucheux et al., 1997).

Martinez-Alier et al. (1998) argued that in co-evolving systems we can only *hope for weak comparability of values*, i.e., that there is an irreducible conflict between non-equivalent perspectives and interests of different groups when deciding what common comparative term should be used to measure and eventually rank alternative actions (here: technologies). This acknowledges that different stakeholders can exhibit different 'rational choices' when facing the same specific situation (Vatn, 2004). Therefore, we need to design sustainability-guided policy instruments that (1) account for the impacts along all sustainability dimensions, and (2) allow different stakeholders to have an input.

Due to the complex nature of the relevant systems and the long-term perspective, measuring the *impacts* from the use of RET (e.g., climate change, loss of habitat or biodiversity, noise, visual intrusion, pollutant emission; employment and income creation) as well as the *consequences* of these impacts within the biophysical and socio-economic systems (e.g., economic cost and benefits, social cohesion, stability of biosystems) are subject to *large uncertainties*. Uncertainty can refer to the nature, incidence, magnitude, and/or timing of possible biophysical and socio-economic consequences. Under uncertainty it is impossible to identify an 'optimal' technology mix for any set of goals. To deal with situations where decisions need to be made despite uncertainty, Funtowicz and Ravetz (1991) suggest the inclusion of various stakeholders (laypersons) in participatory processes in decisions between different (technology) options. Another reason for incorporating stakeholders and decision makers into the process of instrument design is that sustainability of complex adaptive systems is an inherently dynamic, indefinite and contested concept. Therefore, sustainable development must be seen as an unending process—defined not by fixed goals or the specific means of achieving them, but by an approach to creating change through continuous learning and adaptation (Mog, 2004). Policy making for sustainability is an ongoing social learning process.

Environmental and socio-economic systems face sustained and often irreversible change. By this, we mean that some unique, historical and path-dependent process takes place (Bergh and Gowdy, 2000). At any given moment, technological progress can proceed along a variety of paths. But historical events, in combination with positive feedback mechanisms (e.g., scale economies, R&D commitments, complementary investments, increasing consumer acceptance) following a technology choice, may lock society onto a possibly sub-optimal path (Goodstein, 1995; Liebowitz and Margolis, 1995). While the definitions of *path dependence* differ somewhat in the literature (David, 1986), they all try to explain the difficulty of switching to an alternative path in cases where long-term marginal costs of the alternative technology turn out to be lower (Arthur, 1989). More generally, evolving systems can get locked onto given paths of development, excluding a host of other, perhaps more desirable possibilities (Hodgson, 1993). In this sense, path dependence is related to particular kinds of inflexibility in socio-economic processes. Under conditions of path dependence, maintaining options and/or facilitating a shift from one path to a socially preferred one requires active policy making, i.e., the support of a variety of technologies.

We conclude from this discussion about uncertainty and path dependence that a certain level of diversity of technologies needs to be maintained. Diverse technological systems that provide a range of responses to new selective pressures, e.g., due to an occasionally harsh environmental surprise, facilitate the adaptation to long-term environmental change (Low et al., 2003). Because many of the electricity generating technologies using renewable energy sources are still infant technologies, and because a large part of the conventional fuels are still being subsidised (lack of a level playing field, see, e.g., IEA, 1999; Pershing and Mackenzie, 2004), RET need at least for a limited time protection from competition with established technologies. In addition to fostering a variety of different technologies for the use of renewable resources, also *different organisational types of energy production* (e.g., centralised vs. decentralised electricity generation—see Watson, 2004, among others) and the temporal variation in the value of the electricity generated (e.g. peak vs. off-peak power, see Walton and Hall, 1990) need support.

In sum, energy analysts must *properly account for qualitative differences* in environmental effects, numerical uncertainties, and a variety of social goals (Holdren, 1982). From the discussion in this section, we derive four principal criteria for the design of sustainability-guided promotion policy instruments aimed at renewables:

- consideration of the impact of renewable energy use along all sustainability dimensions;
- reduction of adverse environmental and social impacts and increase in short-term economic efficiency;
- development and promotion of a variety of technologies; and
- use of participatory processes.

After this discussion of the theoretical framework in which we are acting, we now turn to the renewable energy promotion instruments that we aim to improve.

4. Instruments for the promotion of renewable electricity

4.1. Guaranteed feed-in tariff schemes

Guaranteed feed-in tariffs (or buy-back rates) are regulated prices for renewable electricity fed into the grid, set by law for a certain period of time, and typically set higher than the achievable market prices. They can be seen as subsidies granted for electricity generation that provides benefits to society otherwise unaccounted for. They imply that utilities (or, alternatively, final consumers) are subject to a purchase obligation for electricity produced from certain eligible renewable energy sources, and have to pay a certain guaranteed (minimum) price per kilowatt-hour of electricity supplied. Typically, special ordinances accompanying the respective law specify the renewable sources and technologies covered, and the tariffs offered, in great detail.

A potential problem with existing feed-in tariff schemes is that it is not always clear why a certain feed-in tariff is granted for a particular technology, and by what factors the relative differences in the tariffs across technologies are motivated. While policy makers would argue that estimated electricity generation costs were used as a yardstick, it can safely be assumed that in practice certain national interests, lobbying skills, and other factors also play a role. In Austria, for example, before harmonising the feed-in tariffs nationwide by the 2002 Renewable Electricity Act (Ökostromgesetz, 2002), the averages of these varied among the nine federal provinces by a factor of 5.34 for solid and liquid biofuels, 3.53 for biogas, 2.68 for wind power, 22.22(!) for photovoltaics, and 2.54 for geothermal power (see Cerveny, 2000, for a detailed overview). Likewise, considerable differences in the levels of feed-in tariffs paid for one and the same technology can also be found across Europe.

Guaranteed feed-in tariff schemes, such as in Austria, Denmark, Germany and Spain, have proven to be very effective in promoting the deployment of renewable energy sources (especially in Denmark, Germany and Spain in the case of wind power), and cause relatively minor regulatory and administrative costs. However, in cases of high volumes of RES-E fed into the grid and where the government takes responsibility for paying (part or all of) the guaranteed price, there may be a lot of pressure on the public budget. For example, Denmark abolished the feed-in tariff system after the rapid growth of wind power (Meyer and Koefoed, 2003). Moreover, due to the purchase obligation, a major disadvantage is that those electric utility companies tend to be penalised which happen to operate in regions with large renewable energy potentials. As a consequence, the obligation can lead to potentially large distortionary effects among competing operators, unless precautionary measures are taken (e.g., equalisation funds). Another major disadvantage of guaranteed (or fixed) feed-in tariffs lies in the sometimes insufficient incentive for investors to drive down costs by means of adopting technological innovation and/or improvement of operations. Also, it is very difficult to find (and from time to time adjust) optimal tariff levels for each of the RET included in a scheme that enables to avoid excessive profit margins, enhance at least some degree of economic efficiency, and promote all technologies in the way and to the desired extent. In recent years, analysts and policy makers have learned much about fine-tuning of feed-in tariffs, and experience has shown that especially in cases where feed-in tariffs decrease over time or competition exists in the technology manufacturing sector, substantial cost reductions can arise even under a guaranteed price regime (e.g., Goodstein, 1995). Moreover, there seems to be a substantial benefit arising from stable framework conditions for investors, facilitating rapid technology diffusion and thus the exploitation of learning curve and scale effects, as well as the establishment of domestic industries.

With regard to enhancing static and dynamic cost efficiency (i.e., provision of incentives to minimise cost as a one-time or continuous process), the recently amended German Renewable Energy Act (EEG, 2000, 2004) is worth mentioning. The aim of the EEG, 2004 Act is twofold: (1) to enable sustainable energy supply, reduce social cost by accounting for long-term external effects, avoid conflicts connected to fossil energy resources, and to foster the development of RET; and (2) to raise the share of RES-E to at least 12.5% by 2010 and at least 20% by 2020. An interesting feature of the German regulation, which due to its effectiveness serves as a model for many other countries in Europe and elsewhere (e.g., China), is an annual reduction of the guaranteed feed-in tariffs for certain technologies, in order to reflect cost reduction potentials due to technological progress, learning effects, and economies of scale and scope—and thus to avoid excessive profits as mentioned above. Besides, the tariff system is funded by a levy on electricity consumption, thus avoiding public budgeting.

In sum, in the case of guaranteed feed-in tariffs, it is basically in the hands of the policy makers (and their skills and motivations) to allow for at least some degree of economic efficiency (i.e., by reducing the tariffs over time according to the expected cost reductions), to steer the diversity of technologies employed (i.e., by widening or narrowing the range of eligible RET), and to have an influence on the environmental and social impact of the RET mix (i.e., by deliberately under- or oversubsidising certain technologies). A disadvantage is that with a price-driven instrument particular quantity targets cannot be achieved with certainty, and that regulated prices may lead to certain inefficiencies that could possibly be avoided by more competition-oriented instruments, such as those described in the following two subsections.

4.2. Tradable green certificates

In a TGC system, renewable electricity is sold just like conventional electricity at market prices. The additional costs incurred in producing RES-E are covered by the sale of certificates in a separate market for certificates. These are demanded by the obliged parties (e.g., electricity suppliers or, alternatively, the consumers), who must purchase a certain amount of certificates according to a quota, or fixed percentage, of their total annual electricity sales (or consumption in the alternative case). The principal idea of a TGC system is to sell the environmentally and socially beneficial characteristics of using renewables separately from the electricity itself, and to introduce competition among the sellers and buyers of both the renewable electricity and the certificates. The total price achieved by producers of RES-E is composed of the market price of electricity and the price of the certificates.

The main advantage of a tradable certificate scheme is that it enhances both static and dynamic efficiency. Low-cost producers have better chances to sell their certificates in the certificate market. Hence, in the longer term, the market determines which renewable plants to build, where, and for what price. This leads to the positive effect that regionally operating distribution companies are no longer restricted by resource availability and technical possibilities in their own region. For obvious reasons, a 'weakness' of such schemes is that lower cost (and maybe in the long run less promising) options might push higher cost (but in the long run more promising) options out of the market (Kühn et al., 1999; Schaeffer et al., 1999). The functioning of this mechanism, however, is based on the assumption of existing excess RET capacity, which itself is dependent on the quota imposed. By 'excess capacity,' we understand in this context any renewable electricity capacity that could be made available that is beyond the politically imposed (and in principle arbitrarily chosen) quota target.

There are several examples of existing tradable renewable electricity schemes. The Netherlands introduced in 1996 (with revisions in 1998) a pioneering 'Green Label' system, which has received much attention (Boots, 2003; Dinica and Arentsen, 2003). Based on a trading market and combined with a voluntary commitment by Dutch utility companies to reach a set renewable energy target, the system has produced mixed results, partly due to the lack of binding targets (and settlement payments) until the end of 1999. The Dutch experience has shown (1) that the government needs to set clear intermediate and long-term targets (policy predictability); (2) that green certificates should be valid for more than one period (flexibility to allow for 'banking' and 'borrowing' of certificates); and (3) that internationalisation is necessary to enhance the stability and liquidity of the market (Drillisch, 2001).

Other countries who have introduced tradable renewable electricity certificates comprise a number of US states (since 1998; Berry and Jaccard, 2001), Italy (since 2002; Lorenzoni, 2003), the UK (since 2002; Connor, 2003), Belgium (Flanders, since 2002; Verbruggen, 2004), Australia (since 2001; Walsh, 2002), and Sweden (since 2003; Caycedo, 2003). Several countries have postponed or abandoned TGC schemes, such as Austria (Madlener and Drillisch, 2002) or Denmark (Meyer and Koefoed, 2003).

If TGC schemes are not only understood as a means of reflecting external costs and benefits, but also as mechanisms for supporting the commercialisation of emerging technologies and diversity of supply, separate *bands* would be needed for different RET. This way crowding out of at least some of the more expensive and/or less developed technologies could be avoided (Grubb and Vigotti, 1997). While maintaining the least-cost mechanism inherent in such systems, a problem with this approach is that the liquidity of the certificates market diminishes, as instead of one single certificate traded in one single certificate market there would be separate certificates for electricity generated from wind (solid, liquid or gaseous), biomass, photovoltaics, and others. Selection of the technologies competing with each other in the various technology bands is eventually a political decision. In principle, it can be thought of that relatively more expensive technologies with a relatively low socio-ecological-economic impact are included, whereas without banding, these would not be able to compete successfully. This would not only increase the diversity of supply as a function of the number of bands allowed for, but also decrease the adverse overall impacts of the energy system on the economy, society, and nature.

In sum, conventional TGC schemes tend to favour low-cost technologies, a problem that can only be partly ameliorated by introducing technology bands of (almost) equally competitive technologies. The major aim is to increase economic efficiency and achieve a given RES-E quota, whereas diversity of supply and a reduction of the adverse environmental and social impacts are not explicitly aimed at. Achievement of the latter two goals depends on which and how many of the technologies can successfully compete in the market, and whether or not the lowest cost technologies are in fact those with the least adverse environmental and/or most socially beneficial impact, respectively.

4.3. Bidding or tender-based systems

Bidding or tender-based systems for renewable electricity capacity feature elements both of feed-in tariff systems (guaranteed prices) and tradable certificate systems (competition, quota targets), and have been introduced in the past in the United Kingdom[4], in France, and in Ireland. Mainly independent power producers compete on price for contracts to supply RES-E within a certain limited capacity quota. Usually the regulator invites bids for each technology band. Bids received are ranked in order of price by the authority in charge. The lowest bids within each technology band are accepted in preference. The marginal bid (in a Vickery auction the (losing) extra-marginal bid) is therefore most expensive and sets the final price paid for the whole band (Mitchell, 1995, 1999).

The most widely studied bidding scheme for RET is the Non-Fossil Fuel Obligation (NFFO) system in England and Wales (1990–2001, Mitchell and Connor, 2004), which has been successful in lowering the cost of RES-E generation. More mature technologies and learning, and the related reduction in the perceived risk (which lowers the risk premium and thus the cost of finance), have contributed to this success. However, their impact on the total amount of RES-E generated has been limited. Also, the costs of preparing bids to NFFO have been relatively high, which tends to promote larger companies as the main bidders instead of small and local ones (Kühn et al., 1999). Finally, evaluating the bids has been a relatively cumbersome and bureaucratic process (Grubb and Vigotti, 1997).

Potential investors in a bidding system are also faced with several uncertainties. First, the chance of winning a bid is rather low. Second, planning permission problems and local resistance against the construction of RES-E generation plants have made realisation impossible in several cases. Third, for each of the NFFO-rounds, it has been unclear which share of the total funds will be available for RET (Mitchell, 1995, 1999).

Summing up, bidding or tender-based systems have helped to increase economic efficiency. Similarly to the case of the guaranteed feed-in tariffs, the policy makers primarily determine the diversity of supply. The only (more theoretical) difference is that if a technology is economically very unattractive, it might still be included in a tariff scheme, whereas it can probably not successfully compete in a bidding scheme. In terms of environmental and social impacts, the comment made for tradable certificates applies: higher economic efficiency of a particular technology does not necessarily correspond with a lower adverse environmental and social impact.

Table 1 compares and contrasts some of the main features of the renewable electricity promotion instruments just reviewed.

4.4. Green electricity schemes

Electricity market liberalisation opens up the possibility to differentiate electricity products according to certain, typically environmental, characteristics (e.g., Bird et al., 2002). Marketing of such 'green power' is a means to create a private market for renewable electricity that is driven by consumers' demand for green products (Wiser, 1998). A variety of labelling schemes exist (Truffer et al., 2001; Patterson and Rowlands, 2002). The multicriteria-based assessment method for the impacts of renewable electricity, which we suggest in this paper, could also be applied to green electricity labelling in a straightforward manner. Due to space restrictions, however, this discussion is beyond the scope of our paper, as is a similar discussion on the applicability of our method to bidding schemes.

5. Institutional framework

In this section, we introduce some aspects concerning the institutional framework for the increased use and promotion of RES-E, primarily from a European perspective. As Midttun and Koefoed (2003) have noted, the 'greening' of the electricity industry in Europe is characterised "by a multiplicity of challenges and contradictory patterns", including (1) a mixture of global, regional and local environmental problems; competition between national and EU-based regulation to solve them; (3) additional rivalry between public regulatory and private commercial initiatives for shaping and providing green electricity; and (4) rivalry between specialised niche-oriented and broader price-based commercial approaches (Midttun and Koefoed, 2003: 677). Furthermore, it is clear that given the current wave

[4] The UK has switched from a bidding system to a system of tradable certificates in 2002 (see Mitchell and Connor, 2004).

Table 1
Summary of main features of the RES-E promotion instruments discussed (theoretical assessment)

Feature	Feed-in tariffs	Quotas/TGC	Bidding schemes
Policy target	RES-E generation (amount fed into the grid)	RES-E generation (amount fed into the grid)	Investment in RET capacity
Preset variable	Price	Quantity (RES-E share)	Quantity (RES-E capacity)
Possibility to control technology diversity	Yes (direct)	Yes (via technology bands)	Yes (via technology bands)
Possibility to control SEE impact	Yes (direct)	Yes (indirect, technology bands)	Yes (direct)
Administrative effort—system installation	Low	High	Low
Administrative effort—system operation	Low	Medium (e.g., regarding market monitoring)	High (e.g., regarding tender preparation and conduct)
Administrative effort—system adjustments	Low (but optimal tariff studies can be costly!)	Medium (e.g., fine-tuning)	Low
Achievement of specific quantity target	No (only indirect control)	Yes (if functioning market; direct control)	Yes (if functioning market; direct control)
Economic incentive for RES-E producer	Profit maximisation (constant revenues minus minimised cost; not forced)	Cost minimisation (forced)	Cost minimisation (forced)
Investor risk	Low (electricity prices guaranteed over certain period of time)	High (due to revenue uncertainty, both regarding certificates and RES-E sales)	High in the initial phase (due to uncertainties regarding winning a contract and obtaining planning permission), low after starting RES-E generation

of liberalisation, policy makers are under strong pressure to introduce more market-compatible policy instruments.

The development in the European Union provides a good example for the development of renewable electricity promotion. In line with the need for common rules in the European internal market for electricity, as stipulated in the EU-Directive 96/92/EC on electricity market liberalisation (European Commission, 1996),[5] the European Commission has aimed at harmonising the different support schemes for renewables[6] in order to reduce market distortions and trade limitations. Article 8(3) of the Directive permits Member States to require renewable electricity preference in dispatching. Moreover, an accelerated penetration of RES-E generation is recognised as a major potential area for action to meet the commitments made both under the Kyoto Protocol and the targets set in the EC White Paper on renewables (European Commission, 1997). Particularly, the 1997 White Paper states that renewable energy sources still make an unacceptably low contribution to the Community's energy balance, as compared to the technical potential available, and suggests a doubling of the share of renewable energy sources in the EU overall gross inland energy consumption from 6 to 12% by 2010.

The Commission's 1998 draft 'Directive on access of electricity from renewable energy sources to the internal market in electricity' (European Commission, 1998) stipulated that the share of electricity generated from renewable sources should be at least 5% by the end of 2005. Moreover, it suggested to allow direct price control schemes only until 2005 and to promote both competition between different RET and international trade of regenerative electricity. This version of the Directive also favoured standardised certification of origin of RES-E.

[5] Note that in 2003, this Directive has been repealed by Directive 2003/54/EC (European Commission, 2003).

[6] In the Renewables Directive 2001/77/EC the European Commission defines renewable energy sources as "... renewable non-fossil energy sources (wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases", and electricity from renewable energy sources as "electricity produced by plants using only renewable energy sources, as well as the proportion of electricity produced from renewable energy sources in hybrid plants also using conventional sources and including renewable electricity used for filling storage systems, and excluding electricity produced as a result of storage systems." (European Commission, 2001, Art. 2).

In April 1999, the European Commission presented an important Working Paper (European Commission, 1999), in which the advantages and disadvantages of different support mechanisms were discussed. Its main objective apparently was to serve as a basis for further discussions and consensus finding. Moreover, it signalled more flexibility regarding transitory regimes from non-competitive fixed price to competitive market-based schemes, indicating that the transition to the new system may not be without difficulties.

The eventually approved Directive 2001/EC/77 of the European Commission on the promotion of electricity from renewable energy sources in the internal electricity market (European Commission, 2001) is in many respects more moderate than earlier versions. On the one hand, it repeatedly stresses the importance of the subsidiarity principle and the role of periodical reporting (and monitoring), while on the other hand it emphasises that more time is needed to develop an appropriate EU-wide scheme for the direct promotion of RES-E (e.g., by learning from the experience made in the member countries with the various national schemes and expert groups). The Commission has further indicated that it will make a proposal for a Community framework with regard to RES-E support schemes, which

"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, . . ., maintain investors' confidence and avoid stranded costs" (European Commission, 2001, Art. 16).

Indicative targets for the member countries, and the EU as a whole, have been calculated based on an updated scenario for electricity consumption, and the overall target of a 12% share of total renewable energy sources in gross inland energy consumption stipulated in the EU White Paper on renewables. For a more in-depth discussion of the issues, main conflicts and compromises that arose during the development of the European Renewables Directive see, e.g., Rowlands (2005), and for a recent overview on renewable electricity policies in European Union member countries see, e.g., Vries et al. (2003).

In the United States, the Renewables Portfolio Standard (RPS) has been promoted by the American Wind Energy Association (AWEA) in the mid-1990s (Rader and Norgaard, 1996; Rader, 2000) as a market-based concept for the promotion of RES-E. Several US states have since then adopted RPS schemes (e.g., Berry and Jaccard, 2001; Berry, 2002; Langniss and Wiser, 2003). Moreover, RPS have also been included in several federal restructuring bills.

6. Towards an operational concept

In order to move from these theoretical and institutional considerations towards an operational concept, we need to address the question how the differences in the biophysical and socio-economic impacts of the different RET can be accounted for. We refer to them as 'socio-ecological-economic' or 'SEE' impacts. In order to distinguish different electricity generation technologies by their SEE impact, the options must be compared by a number of criteria. Criteria can be measured with indicators, using data collected by statistical offices and science labs, socio-economic studies, or simulations calculated by environmental scientists.

Table 1 depicts an illustrative scheme of an impact matrix for RET. To establish such a matrix, each of the RET considered needs to be evaluated by each of the criteria listed. Note that we deliberately excluded short-term economic efficiency criteria from the list, as these are already at work in the support mechanisms themselves. Before using the impact matrix for calculating a ranking of alternative RET, decisions need to be made about the extent to which benign impacts (e.g., net employment creation) can outweigh adverse impacts (e.g., net pollutant emission). The definition of minimum (or maximum) values for individual criteria can do this. In terms of notation used, a 'high SEE impact' stands for a relatively less desirable technology and 'low SEE impact' for a relatively more desirable technology.

Fig. 1 summarises the set-up of the evaluation as an iterative learning process. While the first part of the evaluation process (institutional analysis regarding policy formulation, RET options, and stakeholder involvement) provides the basis, the second part deals with the MCE, together resulting in the formulation of sustainability-guided policy recommendations. At each stage, the results gained are interpreted and, if necessary, may lead to a readjustment of previous steps taken. The set-up makes the evaluation process dynamic and judgements regarding the political relevance of actions or impacts are frequently re-considered. This procedure responds to the need for policy analysis to be flexible and adaptive in nature.

To show the practical applicability of our method, we use life-cycle analysis data from the GEMIS[7] database (Fritsche and Schmidt, 2003) for 14 RET used in Germany and compare them by an array of 24 environmental and economic criteria (see Appendix A; a description of the RET covered by this illustrative example can be obtained from the authors upon request). GEMIS is one of the most comprehensive life-cycle-based process databases, which also contains a large number of energy conversion technology processes. As such, unfortunately, GEMIS only contains few economic and hardly any social impacts (although recently some employment figures for Germany for a range of bioenergy technologies have been added). From the list in Table 1, we only found consistent data for the criteria marked with a star, so that the results do not account for the main dimensions of sustainability, and hence must be interpreted with great care.

In impact studies of the type indicated here, 'illusory precision' should clearly be avoided. By this we mean that *variations* (i.e., predictable differences in locational and operating conditions) and *uncertainties* (i.e., imperfect knowledge about the exact performance of a technology and the linkage to SEE consequences) can allow for a wide range of values for the impacts, which should neither be veiled by the presentation of decimal values (e.g., GEMIS data come with many decimals, and thus should be rounded before use) nor a missing statement about the real range of possible impacts (see also Holdren, 1982).

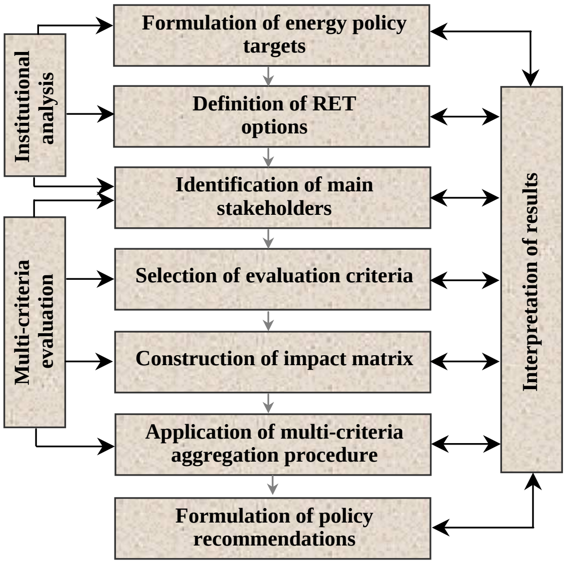


Fig. 1. Set-up of the (participatory) RET evaluation process. Source: Based on De Marchi et al. (2000).

For taking an array of non-additive criteria into account, the question of aggregation of indicators in different units arises. For such problems, MCE methods were developed over the last three decades. They enable to rank a finite number of alternatives, while considering several, sometimes conflicting criteria. PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) is a widely used multicriteria evaluation method (Brans et al., 1986). With this method, alternatives are compared in pairs for each criterion. A number in the interval [0; 1] (zero for no preference or indifference, unity for strict preference) expresses the preference level. A multicriteria preference index is formed for each pair of alternatives as a weighted average of the corresponding preferences computed in the last step for each criterion. The index $\Pi(\alpha, \beta)$ (in the interval [0; 1]) expresses the preference of alternative α over alternative β considering all criteria. The weighting factors express the relative importance assigned to each criterion. Alternative actions can be ranked by a positive or a negative flow. The 'leaving flow' $\phi^{+}(\alpha)$ is the sum of indices $\Pi(\alpha, i)$ indicating preference of action A (here: RET n) over all the other actions (here: other RET). It shows how 'good' alternative α is; the alternative with the higher leaving flow is superior. The 'entering flow' $\phi^{-}(\alpha)$ is the sum of indices $\Pi(i, \alpha)$ indicating

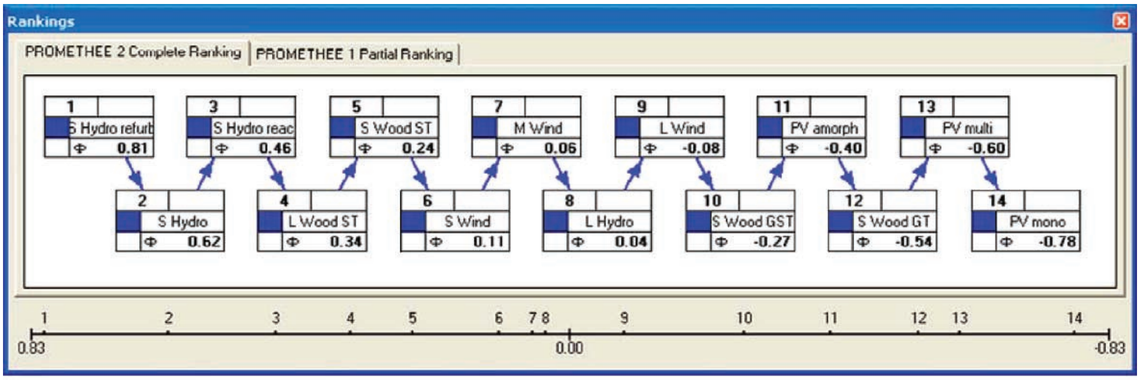
[7] GEMIS—Global Emission Model for Integrated Systems.

preference of all other actions compared to α. It shows how much alternative α is 'inferior'; the alternative with the lower entering flow is superior. PROMETHEE II ranks actions according to their net flow, i.e., the difference of 'leaving flow' minus 'entering flow' (Fig. 2). PROMETHEE I bases its calculations on the same information, but points out incomparability of actions in case the 'leaving flow' indicates that α is better than β, while the 'entering flow' indicates the reverse (or vice versa).

Since most projects dealing with sustainable development in general, and energy problems in particular, carry the problem of inaccuracy in the data due to uncertainty, the method to be applied needs to be able to address this. For example, Munda's (1995) method, NAIADE, which is also based on outranking flows, addresses uncertainty in data by use of fuzzy numbers. More recently, Goumas and Lygerou (2000b) have extended PROMETHEE to also deal with fuzzy input data.

Almost all multicriteria ranking methods require *weights*. They allow the users to distinguish between more and less important criteria. Two basically different approaches for finding out about the weights are usually distinguished: (a) direct weighting and (b) trade-off between criteria. Experiments with planners and stakeholders show that many decision makers are distinctly uncomfortable with trade-off questions. This may lead to answers which are not meaningful and, as a result, decision makers may have little confidence in the outcome (for further discussion see, e.g., Choo et al., 1999; Hämäläinen and Salo, 1997).

(a) Weight = 1 for each criterion



(b) Weight = 1 for each category of criteria
(i.e. GHG; air emissions; CEI; CMI; solid residues; water pollution; land use; economic cost)

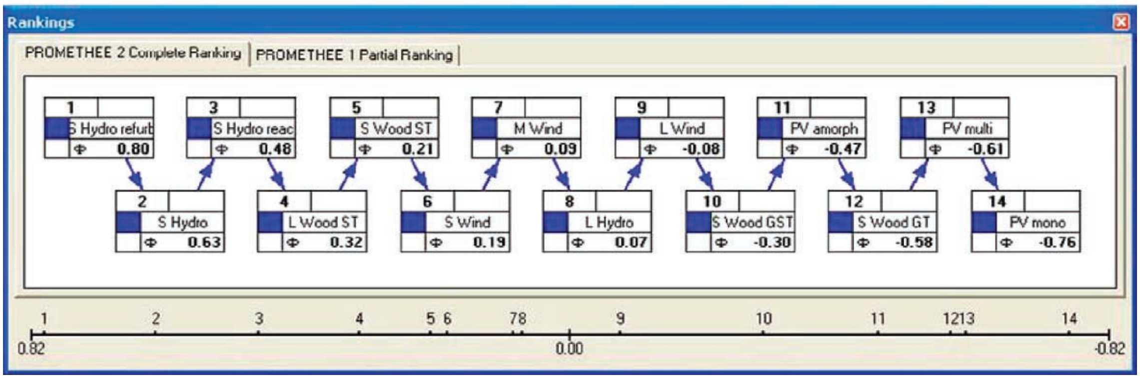


Fig. 2. Complete ranking of alternative technologies (PROMETHEE II; linear preferences; equal weights).

Also it is good practice to devise a procedure such that it allows for substantial learning of the decision makers to take place during the weighing (Roy, 1990).

In our illustrative example, we assume equal weights for each criterion, which of course is a colossal simplification. This approach has been motivated by arguing that criteria represent values of different stakeholders and that each actor should have equal importance (i.e., weight) (Munda, 1995; De Marchi et al., 2000), it has the disadvantage that the results are very sensitive to the number of criteria included in the evaluation. In order to extend and refine the data to be used for the impact matrix (especially data on social impacts), and to apply the proposed method under real world conditions, we started the project ARTEMIS (http://www.project-artemis.net) in June 2003, a 3-year research project that is funded by the Austrian Science Council. For this project, decision makers are defined as representatives of those decision-making bodies, which are by law responsible for energy policy, and additional stakeholders representing various interests within society (for a discussion of different ways to select representatives, see O'Neill, 2001). In deliberative workshops weights will be derived through a mix of group activities and tested for outliers in individual interviews. We chose the PROMETHEE method here instead of the current version of NAIADE, which is probably better known to readers of this journal, (a) because PROMETHEE will allow us to incorporate the different weights derived from the deliberative workshops and interviews and (b) because it also calculates complete rankings (for a comparison of different MCE methods, including NAIADE and PROMETHEE, see e.g., De Montis et al., 2005).

The illustrative depicted in Fig. 2 results indicate how a ranking of RET can be calculated by taking an array of criteria into account. Due to data limitations and lack of input from stakeholders in the derivation of weights (for simplicity, we have used equal weights), they should not be considered as results directly usable for policy recommendations.

The net flows of the complete ranking can be used as indicators for the relative desirability of the respective RET. The higher the net flow of positive and negative outranking flows, the more desirable the alternative. Given the uncertainties discussed earlier, however, the net flows should only be used for guidance and as a tool for a more transparent and reasoned political debate about a more sustainability-guided design of renewable energy promotion instruments. For example, for the decision process about how to design a 'SEE tradable electricity certificate' scheme the net flows (ϕ values) can help decision makers to set the number of certificates allowed to be issued per a certain amount of kilowatt-hour generated with the one compared to another technology. If the minimum and the maximum amounts of certificates are decided, the intermediate ones could be easily calculated with the information given above.

As a next step, we now describe how the 'traditional' direct price support mechanisms discussed in Section 5 can be modified in order to redress the existing imbalance towards short-term economic performance goals and to achieve a more balanced approach of simultaneously targeting SEE criteria (as set out in Table 2). While it is certainly not an easy task to determine the different degrees of SEE impact of the various technologies, we find the sole reference to economic criteria – maybe supplemented by CO_2 emissions avoidance criteria – in the design of renewables promotion schemes to be insufficient (for example, Drillisch, 1999 made such an attempt, suggesting to regulate the number of certificates issued by means of CO_2 equivalents). For reasons of space, we restrict the following discussion to guaranteed feed-in tariffs and tradable certificates. The arguments made, however, can be extended to bidding or voluntary systems in an analogous way.

6.1. SEE-differentiated tradable green certificates

To avoid the important drawback of tradable green certificate schemes, i.e., that they tend to reduce technological diversity by cornering higher cost options, at least two options can be thought of: (1) to introduce technology bands in order to provide for a certain degree of technological diversity; or (2) to vary the number of certificates issued according to the SEE impact of the technology in question.

The major difference between RES-E and electricity produced from conventional sources is the intrinsic lesser SEE impact, which, however, differs from technology to technology. From an ecological economics point of view, it is therefore desirable to distinguish the technologies by their SEE impact.

Table 2
SEE impact matrix (illustrative example)

Criteria	Renewable energy technology *n* (*n*=1,…,*N*)					
	RET 1	RET 2	RET 3	RET 4	RET…	RET *N*
Biophysical dimension						
Inputs needed for production						
■ Land resources (e.g., in ha)[a]	…	…	…	…	…	…
■ Water resources (e.g., in litres)[a]	…	…	…	…	…	…
■ Materials requirements (e.g., scarce or heavy; scale 1–10)[a]	…	…	…	…	…	…
■ Indirect energy requirements (e.g., in MJ)[a]	…	…	…	…	…	…
Potential consequences of production						
■ Impact on natural biota, habitats and wildlife (e.g., scale 1–10)	…	…	…	…	…	…
■ Environmental risks (e.g., groundwater contamination; scale 1–10)	…	…	…	…	…	…
■ Visual intrusion (e.g., linguistic scale)	…	…	…	…	…	…
■ Impact on microclimate (e.g., scale 1–10)	…	…	…	…	…	…
■ Impact on soil productivity (e.g., scale 1–10)	…	…	…	…	…	…
■ Impact of resettlements (e.g., scale 1–10)	…	…	…	…	…	…
Potential consequences in energy conversion and use						
■ Air pollution (e.g., SO_x, NO_x, CO_2, VOC, particulate matter; scale 1–10)[a]	…	…	…	…	…	…
■ Organic emissions (e.g., dioxin hydrocarbons, toxic irritants, carcinogenic compounds; scale 1–10)	…	…	…	…	…	…
■ Generation of solid wastes (e.g., bottom ash; scale 1–10)[a]	…	…	…	…	…	…
■ Water pollution (e.g., scale 1–10)[a]	…	…	…	…	…	…
■ Pressure on land[a] and water resources (e.g., scale 1–10)	…	…	…	…	…	…
■ Other hazards (e.g., accidental fires, exposure to toxic chemicals; scale 1–10)	…	…	…	…	…	…
Socio-economic dimension						
■ Employment (e.g., number of jobs created)[b]	…	…	…	…	…	…
■ Occupational hazards (e.g., scale 1–10)	…	…	…	…	…	…
■ Noise (e.g., in db)	…	…	…	…	…	…
■ Impact on local poverty (e.g., scale 1–10)	…	…	…	…	…	…
■ Household income disparity (e.g., scale 1–10)	…	…	…	…	…	…
■ Democratic control over markets (e.g., scale 1–10)	…	…	…	…	…	…
■ Safety of power supply (e.g., linguistic scale)	…	…	…	…	…	…
■ Impact on balance of trade (e.g., scale 1–10)	…	…	…	…	…	…
■ Long-term economic viability (e.g., scale 1–10)	…	…	…	…	…	…
■ Local net value added (e.g., in €)	…	…	…	…	…	…
■ Economic risk to ratepayers (e.g., in €)	…	…	…	…	…	…
■ Impact on flexibility of supply (e.g., scale 1–10)	…	…	…	…	…	…

For criteria measured by a scale from 1 to 10, 1 stands for the least negative impact and 10 for the maximum negative impact.
[a] Depicts those criteria that are covered to a certain extent by the GEMIS database.
[b] Depicts criteria that GEMIS currently only covers for a very limited number of RET—i.e., in the case of employment for bioenergy technologies—which were thus not included.

Technologies with a high SEE impact are subsidised to a lesser extent than technologies with a low SEE impact. Analogous to the method suggested by Drillisch (1999), this can be achieved by issuing different numbers of certificates depending on the SEE impact of a particular technology. The decision on the exact variation in the number of certificates issued per amount of electricity generated, or fed into the grid, ultimately lies in the political realm. The major advantage of this method is, as compared to one based on technology bands, that only one market for certificates and only one quota is needed. Hence liquidity of the certificates market will be higher, while achieving the same diversification and SEE impact minimisation.

6.2. SEE-differentiated feed-in tariffs

In the case of guaranteed feed-in tariffs, schemes are usually driven by certain economic motives (e.g., avoidance of excessive profits without choking the introduction of the technologies desired) and political considerations (e.g., diversity of supply, promotion of some local industry). In principle, it is straightforward to adjust an existing tariff scheme according to more SEE-driven criteria simply by adjusting the tariffs appropriately (again the exact adjustment lies in the political domain). Because the socio-economic ecologically most preferable energy technology will in general not be the most economical technology, however, political acceptance could in many cases be much more difficult to realise. Besides, due to the uncertainty inherent in the assessment of certain criteria, the need for readjustments can be higher than under conventional feed-in tariff systems, which can significantly increase investors' planning uncertainties (and hence the risk premia applied) as well as regulatory and administrative costs.

The main critique put forward against guaranteed feed-in tariffs, however, cannot be eliminated by designing a scheme justified on socio-economic-ecological grounds: the lack of incentives to increase static and dynamic economic efficiency and that the achievement of certain quantity targets cannot be safeguarded. Nonetheless, technologies with highly adverse SEE impacts can be prevented from receiving unjustifiably high guaranteed prices.

7. Conclusions

This paper focuses on the improvement of renewable energy promotion schemes, such as guaranteed feed-in tariff, tradable green certificate, and generation capacity bidding systems, in a way that they allow for a dynamic and targeted attempt to promote sustainable development. The consideration of life-cycle-based SEE impact factors in the design of such policy instruments allows for the achievement of better environmental and social quality, the avoidance of lock-in in less (or un-) sustainable technologies, and the provision of incentives to lower short-term costs. Some inherent differences between the two types of instruments remain, though. By the use of 'SEE differentiated feed-in tariffs' it will be easier to ensure the maintenance of technological diversity. By use of 'SEE differentiated tradable electricity permits' instead, the achievement of a certain quota of electricity generated from renewable energy sources can be safeguarded.

We find that a differentiation of support by SEE impact can strongly increase gains achievable from using such instruments. The choice between the instruments will then depend on whether the maintenance of a range of technologies in use or the guarantee of a particular quota achievement is considered more important. Hence the participatory approach we suggest here only supplements the political process of designing an appropriate renewable energy promotion scheme, and cannot guarantee *per se* that robust valuation results are gained from the participatory process (neither across different communities or regions nor over time).

With the integrated and participatory methodology for renewables promotion instruments suggested, we aim to respond to the need for an approach which is in line with the principles of complex adaptive systems and operational at the same time. Governance of complex adaptive systems needs constant adjustment, which requires room for innovation and experimentation, while trying to fulfil more immediate goals to the extent possible. Hence, the participatory MCE process forms an integral part of the approach, and is intended as a learning process for stakeholders and researchers, i.e., as a social learning process. Also the presented approach addresses uncertainty in three different ways: (1) by involving stakeholders in the decision making about priorities of different goals; (2) by choosing a multicriteria evaluation method, which can address uncertainty in the data by allowing for fuzzy numbers; and (3) by emphasising the avoidance of 'illusory hyper-precision' in data use.

The approach presented in this paper may be extended to the promotion of renewable heat and/or combined-heat-and-power generation from renewable sources on the one hand, and the promotion of renewable energy sources by means of investment cost (rather than operating cost) support schemes on the other hand.[8]

From a policy-making point of view, it is clear that our approach is driven by the SEE impact of

[8] For a discussion of the merits of investment vs. operating cost subsidies for promoting RET see, for example, Wohlgemuth and Madlener (2000), and references therein.

certain RET only, and hence does neither account for national industrial competencies and commercial strategies nor national resource endowments and differences with respect to what conventional technologies are actually replaced by RET. Besides, for practical implementation of our method, there is a clear need for compiling sufficiently reliable and comprehensive (i.e., covering the three main dimensions of sustainable development) life-cycle analyses data for characterising the RET considered. Tackling some of these issues provides plenty of scope for further research.

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Appendix A. Impact criteria considered for illustrative empirical study (in total 24, incl. subcategories)

1. Air pollutants (ozone precursors-eq.*; SO_2-eq.; dust particles; in g/kWh)
2. Greenhouse gases (CO_2-eq.; in g/kWh)
3. Cumulated energy input (CEI) (non-renewable; renewable; others; in kWh/kWh)
4. Cumulated material input (CMI) (non-renewable; renewable; others; in g/kWh)
5. Solid residues (ashes; SO_2 scrubber residues; sewage sludge; production wastes; rubble; highly active nuclear waste; in g/kWh)
6. Waste water pollutants (P; N; AOX; CSB; BSB5; inorganic salts; in g/kWh)
7. Land requirement (in m^2/kWh)
8. Economic cost (investment and current fixed costs; in €/TJ)

*In GEMIS, ozone precursor equivalents are the quantitative expression of the tropospheric ozone precursor potential (TOPP) and are calculated from the relative ozone formation rates of the air emissions CO, NMVOC and NO_X and the greenhouse gas CH_4. The more ozone precursor equivalents, the higher is the possibility for summer smog.

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