Methods for Evaluation of Technology and Market Development of Wind Power

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ABSTRACT

The evaluation of Governmental policy programmes aiming at stimulation of technology and market development of renewable energy technologies requires systematic evaluation strategies and systemic utilisation of assessment criteria for accelerated development. The purpose of this paper is to analyse approaches to evaluations of Swedish wind power programmes. The analysis is focusing on the methods of evaluation and criteria used for assessment of technology and market changes. The analysis shows that a clear, systemic strategy for evaluation of wind power programmes have been lacking. Not all programmes have been evaluated with regard to technology and market development and to changes induced by the programmes. Few have been evaluated with a systems approach; addressing the interactions between technology, market actors and public policy programmes. It is concluded that current evaluation methods for assessment of programmes for stimulation of renewable energy systems should be further improved and developed for a better understanding the effects of policy on barriers to and drivers of technology and market development.

Introduction

Evaluating policy instruments is an important tool for obtaining knowledge regarding the results, effects and impacts of policy interventions on the development of new energy technologies. Such knowledge can contribute to an enhanced understanding of the mechanisms behind the market introduction and diffusion of new energy technologies, such as wind power. In turn, the understanding of barriers to and drivers of technology and market development can be helpful in designing policy programmes. A profound understanding of the specific dynamics of the development of a renewable energy technology can also assist in future policymaking.

The aim of this paper is to analyse strategies, methods and assessment criteria for the evaluation of programmes aimed at technology and market development of renewable energy technologies. The study is limited to evaluations of policy interventions for wind power in Sweden between 1975 and 2001.

The analysis is based on the notion that evaluation of technology and market development would benefit from a systemic *socio-technological systems* approach; i.e. an approach focused on the technological energy system including the actors, institutions and organisations that build, drive and utilise it and the economic and legal framework that regulates it. A system approach permits close monitoring of changes in the market over time − changes that can explain whether policy instruments have created the intended effects or not, and why. Moreover, a systemic

evaluation approach can point to where further public policy interventions are required and where they are less necessary. Not only is it important to understand the combined effects and influence of policy on market development, on technology development and on the actors within a system. It is also useful to assess the specific characteristics of an energy system for an accelerated technology and market development of new energy technologies. Thus, a systemic evaluation requires the use of assessment criteria that capture the specific changes in technology and market development and the different effects of these changes.

The study is based on an ongoing research project entitled *Efficient Use of Policy Programmes to Drive the Development of Energy System*s, a transdisciplinary project, conducted together with senior researcher Dr. Lena Neij at the department of Environmental and Energy Systems Studies at Lund University, Sweden, and financed by the Swedish National Energy Administration (STEM). The aim of the project is to develop systemic evaluation methods to be used to devise effective policy options for different technologies within different energy systems. However, developing enhanced evaluation methods requires an analysis of previous evaluation approaches. In this study, the merits and shortcomings of evaluations of Swedish government wind power programmes between 1975 and 2001 are discussed and analysed in relation to the notion of a systemic evaluation approach. In a previous study of the development of Swedish wind power, costs, prices, and actors' behaviour and commitment to market development, along with technology development, such as turbine design and size, were identified as particularly important characteristics of the wind power system (Åstrand & Neij 2003). Thus, the assessment criteria used for evaluation of technology development, costs and actors are given special attention. First, however, Swedish wind power policy and policy instruments are introduced.

Introduction to Wind Power Policy in Sweden 1975 - 2000[1]

In 1975 wind power became an issue on the political agenda in Sweden. The aim of energy policy during the 1970s was first and foremost to reduce the oil dependency. However, the focus of the energy policy soon changed to the issue of compensating a reduction in nuclear power in the late 1970s.[2]

Since the 1990s, national energy policy has been focused on securing long- and short-term supplies of energy under internationally competitive conditions, and to develop a sustainable energy system, mainly through supports for increased supply of renewable energy, through energy efficiency and a cost-effective domestic energy supply (Swedish Government 1991; Swedish Government 1997). The 1991 energy policy bill contained an overall programme for the transition of the Swedish energy system, which in turn consisted of three major sub-programmes:

[1] For further reading of Swedish wind energy policy and policy interventions see Åstrand & Neij (2003) (in Swedish). An English version is to be published later this year.

[2] In 1980 Sweden had a referendum which led to the decision that nuclear power should be phased out by 2010. Nuclear power accounts for nearly half the electricity production and hydro power for the other half in Sweden - In 2001 nuclear power contributed 44% to the Swedish electricity production (STEM 2002). Together, these two energy sources represent together almost half of the total energy supply in Sweden. On November 30, 1999 the first of Sweden's twelve nuclear reactors (Barsebäck I) was closed down. The resolution to close the second reactor (Barsebäck II) has been deferred.

An investment subsidy programme, an energy efficiency programme and an Energy Technology Fund for support of demonstration projects and applied technology development. The energy policy bill from 1997 strengthened the 1991 energy policy. Long-term and short-term goals for renewable energy sources were introduced. The long-term goals required that power generation from renewable energy sources should increase considerably through RD&D efforts (STEM 2000). A short-term goal for wind power generation dictated that wind energy generation should increase by 0.5 TWh/year until 2002 (Ministry of Industry, Employment and Communications 2000a). Despite the short-term goal from 1997, the goals specified in Sweden's wind power policy have been characterized for nearly three decades by soft formulations stating that wind power shall be introduced and spread in the Swedish energy system, without explicitly stating when and how much.

Policy Instrument for Stimulation of Wind Power Development in Sweden

Over the years, several policy instruments have been designed to support the development of wind power, as illustrated in Figure 1. The policy instruments for wind power changed focus over time; from technology development to a more general focus on market development and production of wind power.

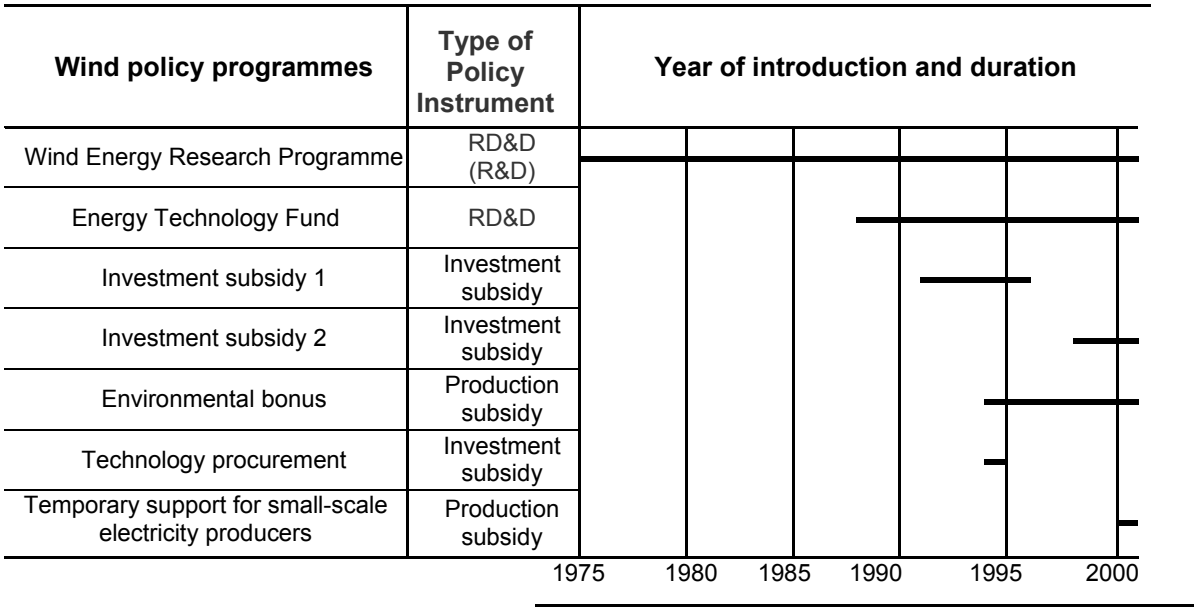

Figure 1. Year of introduction and duration of policy instruments targeting wind power development and market expansion, implemented in Sweden between 1975 and 2000

Wind power research has been supported and secured by two extensive programmes: the *Wind Energy Research Programme* and the *Energy Technology Fund*. In the 1970s, the first target of the policy interventions was to develop wind turbine technology, which was obvious since no turbines were yet available on the market. Since the 1970s, research, development and demonstration (RD&D) measures have come to support first and foremost the development of large-scale wind turbines and non-conventional turbine technology; non-conventional in the sense that the technology differs from that used in smaller, horizontal, three bladed turbines with a gear box, which dominate the wind power market internationally. There has been no market for the turbine technology developed in Sweden, in Sweden or internationally (Åstrand & Neij 2003).[3]

The early RD&D programmes not only steered development towards two-bladed design and large-scale wind technology, but also to a certain kind of market – a market supposedly driven and developed by the large utilities. The focus of these measures was limited to actors from the industry sector, research organisations, utilities and energy authorities. These bodies developed into an indirect wind power market. However, the utilities' commitment to expansion of the market fro wind power was limited until the mid 1990s. Other instruments for stimulation of market development did not exist during the 1970s and 1980s (Åstrand & Neij 2003).

A broader set of policy instruments were introduced to stimulate the development of new energy technologies, including wind power, in 1991 (Ministry of Industry, Employment and Communications 2000a). The new policy instruments were an investment subsidy,[4] followed by the environmental bonus, introduced in 1994,[5] and the temporary support for small-scale electricity introduced in 2000.[6] The introduction of the investment subsidies and the environmental bonus was a change in focus from actors involved in wind turbine development to actors involved in wind electricity production. The change in policy increased the diversity of actors involved in the development process. These policy instruments strengthened the market expansion for international standard turbines but had no effect on the demand for the wind power turbines developed with Swedish RD&D funds (Åstrand & Neij 2003).

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[3] The exception is the commercial production of small wind turbines, with an effect of 20 kW or less. A few Swedish companies have produced wind turbines for remote areas and battery chargers, both for a Swedish and an international market (Statens energiverk 1985; Ruin 2001). These companies have not received governmental support for their activities (Statens energiverk 1985; Åstrand & Neij 2003).

[4] During the first period of investment subsidy, between 1991 and 1996, wind turbines with a rated capacity over 60 kW qualified for a subsidy of 25% of the investment cost (NUTEK 1992). In 1993 the level was increased to 35% (NUTEK 1995). In the first period 350 wind turbines (equivalent to 110 MW installed capacity) were supported by the subsidy (Lundström 2002). This first subsidy period was followed by a second period, between 1998 and 2002. The aim of the second investment subsidy was to increase the annual power generation from wind turbines by 0.5 TWh during the period. The subsidy covered 15% of the investment cost and was awarded for turbines with an effect over 200 kW. The compensation was reduced to 10% in 2002 (Ministry of Industry, Employment and Communications, 2000b). The subsidy was given to 374 turbines (290 MW installed capacity) (Lundström 2002).

[5] The bonus corresponded to the electricity tax for households, which was approximately EUR 0.010 per kWh in 1994 and EUR 0.019 per kWh in 2000. Technically, the bonus was administrated as a tax deduction for power distributors. Power distributors were given the right to deduct tax for each kWh delivered by a wind power plant. The amount deduced; i.e. the bonus, was returned to the wind electricity producers through a regulated contract between the wind energy producers and suppliers (Ministry of Industry, Employment and Communications 2000b).

[6] The production subsidy was EUR 0.011 per kWh.

In all, EUR 216 million was used in 1975-2000 for the development of wind power in Sweden.[7] Between 1975 and 2000 EUR 128 million has been spent on RD&D in Sweden. A major part of these funds, EUR 100 million, was allocated in the 1970s and 1980s for the development and demonstration of a few larger turbines. The funding of the first investment subsidy programme between 1991 and 1996 was EUR 41 million, of which EUR 3 million was allocated to the technology procurement programme of wind turbines in 1995-1996.[8] The funding for the second investment subsidy programme between 1998 and 2002 was EUR 42 million, of which EUR 20 million was spent in 1998-2000. The Environmental Bonus was funded with EUR 27 million until year 2000.

Despite three decades of policy intervention the installed capacity in Sweden was only 265 MW in 2000, compared with 6,107 MW in Germany, 2,836 MW in Spain and 2,341 MW in Denmark (BTM Consult, 2002). The installed capacity in Sweden has increased to 358 MW by April 2003. Wind power contributes with 0,3% of the total Swedish electricity supply.

Swedish Evaluations of Wind Power Programmes

Wind power programmes have been evaluated several times since the 1970s.[9] However, not all programmes have been evaluated, see Figure 2. (The evaluations will be referred to by the Roman numerals given in Figure 2). The programmes have been evaluated by external evaluators, commissioned by the energy authorities.[10] Several of the evaluations have concerned ongoing programmes and some of the evaluation reports have dealt with more than one energy technology, including wind power. The aim, scope and assessment criteria have varied between the different evaluations. Most of the evaluations have evaluated programme results and effects on technology and market development. Several evaluations have also included achievement of policy goals and/or programme goals. A few evaluations have evaluated the administration of the public programme. The purpose of the evaluations, as defined in some, but not all, of the evaluation reports, has in general been to investigate the potential of wind power as a significant energy supply technology in Sweden. Provision of information to policymakers has been another general objective of the evaluations.

[7] The calculations of governmental spending are based on data from the Swedish Energy Authority (Persson 2000; Lundström 2002). All cost data has been recalculated to prices of year 2000 using a national GDP deflator (IEA 2001). These data has then been recalculated to euros using an exchange rate of 1EUR=8.45SEK for the year of 2000 given by the Swedish National Bank. The temporary production support to small scale electricity of EUR 0.011 per kWh, added during year 2000, is not included.

[8] Five companies, both large utilities and wind power developers, combined their procurement activities in a consortium on the initiative of the energy authority at the time NUTEK. The request for wind turbine tenders was focused on cost effective electricity generation (per kWh) and low noise levels (IEA 1996).

[9] See Moberg (1979); Statens energiverk (1985); Lund (1993); CGM Rationel Planering (1993); Aeronautical Research Institute (1993); CGM Rationel Planering et al (1994); Aronsson (1996); Teknikupphandling (1998) and Pedersen et al (2001).

[10] The Energy Authorities has changed organisation over the years. The current organisation is The Swedish Energy Agency (STEM), established in 1998. The predecessor was NUTEK and earlier the organisation was called Statens energiverk.

Programme	Evaluation		Year	Evaluators
Wind energy research programmes **Introduced 1975**	**I**	*Värdering av insatserna inom vindenergiområdet. Rapport från ett av DFE utlagt värderingsuppdrag*	1979	Erik Moberg Konsultbyrå AB[1] for the "Delegation for energy research" (Delegationen för energiforskning)
	II	*Vindkraft – resultat och slutsatser från det svenska vindenergiprogrammet*	1985	Statens Energiverks elteknikbyrå, Studsvik Energiteknik AB, Teknikgruppen AB
	III	*Utvärdering av vindkraftsprogrammet – VKK*	2001	B. Maribo Pedersen Esa Peltola Lars Walfridsson
Energy Technology Fund **Introduced 1988**	**IV**	*Utvärdering av stödet till solvärme och vindkraft.*	1993	Peter Lund[1]
	V	*Energiteknikfonden. En analys av satsningar och bidrag till utveckling ur ett marknadsperspektiv.*	1994	CGM Rationell Planering AB, Andergia AB
Investment subsidy 1 **1991-1996**	**IV**	*Utvärdering av stödet till solvärme och vindkraft*	1993	Peter Lund[1]
	VI	*Utvärdering av insatser till omställning av energisystem, en konsultstudie*	1993	The Aeronautical Research Institute of Sweden (Försvarets forskningsanstalt)
	VII	*Utvärdering av stödet till biobränsleeldad kraftvärme samt vindkraft*	1993	CGM Rationell Planering AB, Andergia AB. Nordiska Ledningsgruppen AB
	VIII	*Utvärdering av investeringsstöd till vindkraft och solvärme 1991-1996*	1996	Price Waterhouse[1]
Investment subsidy 2 **1998-2002**		**Not evaluated**		
Technology procurement **1995-1996**	**IX**	*Teknikupphandling av vindkraftverk. En sammanställning av erfarenheter och slutsatser*	1998	Unknown
Environmental bonus **Introduced 1994**		**Not evaluated**		
Temporary support for small-scale electricity **Introduced 2000**		**Not evaluated**		

Comment: (1) One-man evaluations.

Figure 2. Evaluations of Swedish public wind power between 1975 and 2001

Aim and Scope of the Evaluations

Evaluations of public activities can have several objectives and motives. An important aspect is the usefulness of evaluations. Evaluations can be a learning process in which interested parties can interact with policymakers, and they can provide information for improving policy programmes and for determining public policy. The latter applies to Swedish evaluations of wind power programmes. Evaluations may also have a hidden agenda, for example to conceal what is

actually happening or a failure to act. Even though the wind power development has been limited in Sweden, there is no reason to believe that evaluations have had a hidden agenda, e.g. to cover for a vague and indecisive energy policy. On the contrary, most evaluations have examined the programme results and effects carefully and thoroughly, even though there has not been any standard method or strategy for the evaluations. The evaluators seem to have decided on a method based on an interpretation of the aims of the evaluation and/or programme.

The first evaluations were evaluations of the wind energy research programme (I and II). These two evaluations aimed at providing decision-makers with data for decisions regarding continued policy interventions for a possible large-scale introduction of wind power into the Swedish energy system. Both of these evaluations were focused on the future need for wind power development rather than the results of the programmes, which was natural since wind power technology and market development were still in their infancy (Gipe 1995). The second and more comprehensive evaluation (II) from 1985 did, however, assess the results of the development of the first two Swedish large-scale demonstration turbines, installed in 1982 (3 MW) and in 1983 (2 MW), from different perspectives including technology development and actors.

In 1993 and 1994, the Swedish energy authority NUTEK commissioned evaluations of the policy programmes introduced in 1991. Effects on technology and market development and changes on the energy market resulting from the ongoing programmes were evaluated for technologies for both energy efficiency and renewable energy production. In the case of wind power, it was primarily the results and effects of the investment subsidy that were evaluated (IV, VI and VII). The effects of the Energy Technology Fund (to support demonstration and applied R&D) were also evaluated (IV and V).

The different evaluations had different purposes. The aim of evaluation VI was to evaluate the dynamics of the development process and to assess whether the investment subsidy had contributed to the establishment of wind power. The objectives of evaluations VII and V were to assess the impacts of the investment subsidy and the Energy Technology Fund on market development. The evaluations should also determine the changes in the opinions and behaviour of the market actors, and finally assess if these changes had led to increased market introduction.[11] Moreover, the evaluations from 1993 (IV, VI and VII) were future-oriented. Like earlier evaluations of the R&D programmes, these evaluations analysed the possibilities of achieving the long-term policy goal of increasing installed capacity in Sweden. Even though these evaluations from 1993 and 1994 did not follow a clear strategy or method for evaluation, they did cover different aspects of the socio-technological wind power system. Furthermore, changes caused by policy programmes, or at least influenced by the policy interventions, were also assessed. These evaluations provided a broad understanding of the combined effects of policy on technology development and particularly on market development. This understanding did influence the design of the programmes. In 1994 the budget for the investment subsidy was reduced in favour of the activities of the Energy Technology Fund, technology procurement and technological assessment of the turbines that had been supported by the investment subsidy (NUTEK 1994; NUTEK 1995).

[11] These evaluations were to a large extent carried out by the same evaluators and the wind power sections were based on the same material (interviews, surveys etc).

There were few programme evaluations between 1994 and 2001. The first investment subsidy programme was evaluated ex-post in 1996 (VIII). The results of the programme and its impacts on market development were evaluated, as was the administration of the programme. The objective was to provide the energy authorities with data and experience from the programme to be used in reports to the Government and in designing a possible future investment subsidy programme. In 1998, the effects and administration of the technology procurement were assessed. The results of the procurement programme - which was the installation of 15 turbines at 600 kW each from the Danish manufacture Bonus Energy AS – were not analysed in particular. The aim of the programme was to stimulate wind power installation (Örtegren 1996). In 2001 a third evaluation of the R&D programme was carried out. This evaluation was focused on achievement of program goals and programme administration rather than on the effects on technology and market development. The aim was to evaluate the programme's relevance and quality.

The data used for the different evaluations have varied. The sources of the data range from interviews with actors participating in the programmes (including administrators) and actors affected by the programmes, market surveys and questionnaires to programme reports, wind power studies and theoretical literature.

Assessment Criteria for Evaluation of Technology and Market Development

The evaluations have analysed programme effects and impacts on technology and market development and monitored changes in the structure and function of the market. Taken together, the evaluations have assessed several aspects of technology development, costs and actors' behaviour and commitment to market development. This can be seen in Table 1, where we have made a distinction between assessment of technology development, costs and actors' behaviour and commitment to market development. Naturally, the evaluations have assessed other effects of the programmes as well, such as effects on the environment, public opinion and land use. A few of the evaluators have used the same titles of the assessment categories, as in Table 1. The evaluations of Swedish wind power development have not been carefully planned from the start of the programmes. Thus, technology and market development have been evaluated using different methods and with assessment criteria that are not easily comparable. For instance, the evaluation criteria were focused on *future* technology and market development in the first evaluations of the RD&D programmes (I, II), although the evaluation from 1985 (II) assessed the results of the programme in terms of technology development and actors' involvement in the R&D programme as well as costs for development of large scale turbines.

The number and kind of assessment criteria used for analysis of market development have varied considerably between the different evaluations and purposes. The evaluations which have included assessment of *technology development* have only to a limited extent evaluated development of turbine design, technological components and turbine sizes. The criteria used for assessment of technology development have for example been energy supply, availability, reliability, operation and maintenance, generated capacity, security, lifetime of different components, interruption of operation, integration with the power grid, etc. The choice to focus RD&D funds on large-scale two-bladed technology has not been assessed since 1985 (II). The assessment of technology development has rather been focused on the development of technological competence and knowledge among programme actors (III, V, VI, VII). This is

probably a result of the market transformation focus in the evaluations from 1993 and the limited development of Swedish turbines and the turbine industry in Sweden. In 1993 and 1994, criteria for assessment of *market actors* were applied to a greater extent. The assessment criteria described for example market shares, recipient of investment subsidy, effect on turbine manufacturers, knowledge, dissemination of knowledge and competence (IV, V, VI, VII). The use of criteria indicating changes in actors' behaviour and commitment have not been followed up in later evaluations. *Wind turbine costs* has been evaluated using criteria such as construction costs, project costs, capital costs, maintenance and operating costs, as well as additional costs for grid integration. In subsequent evaluations, costs and benefits have been assessed, along with the profitability of investments (IV, VIII).

Taken together, the evolution approaches from 1993 did provide a comprehensive understanding of the combined affects on both technology and market development. Unfortunately, the turbine development in Sweden was not evaluated at the same time. Evaluation approaches incorporating R&D measures and effects of those in evaluations of market development - in one or several, parallel reports – could probably have assisted in explanation of the slow market development of turbine technology developed in Sweden.

Table 1. Assessment criteria used for evaluation of technology development, costs and actor-related change

Evaluation / Type of assessment criteria	I	II	IV	V	VI	VII	VIII
Technology development		x			x		x
Costs	x	x	x		x		x
Actors' behaviour and commitment to market development	x	x	x	x	x	x	

Comments:

(I) Costs are assessed in terms of profitability. The starting point for the analysis is a comparison of the production costs for wind power with the alternative costs for non-introduction of wind power in Sweden. Different actors' contributions to the programme were also discussed.

(II) Apart from technological experience, costs and competence developed within the programme, the development of large wind turbines, public opinion, and additional costs for grid integration are assessed in relation to the programme activities. Environmental aspects, risks, land use, siting and even offshore siting are also discussed in more general terms.

(IV) The effects of the investment subsidy are assessed on the basis of investment costs, installed capacity, actors' behaviour and the time dynamic of market introduction. Market potential is assessed via electricity prices, potential energy production (TWh/year), costs and subsidies.

(V) Market development is assessed on the basis of dissemination of knowledge, market conditions, market actors and dissemination of results.

(VI) Profitability is analysed on the basis of business economics, but environmental impacts, security of supply, reliability and knowledge are also included. Development and dissemination of competence are analysed by product development, learning and demonstration of profitability.

(VII) The effects of the investment subsidy are assessed by analysis of the market actors' choice of technology and experience from the programme.

(VIII) The evaluation is primarily an economic analysis of the effect of the investment subsidy on costs and of profitability of investments in wind power. Technological aspects of the installed turbines are only discussed in general terms.

Concluding remarks

There has been no clear strategy for systemic and systematic evaluation of technology and market development of wind power in Sweden. Nor did a strategy developed over the years.[12] To begin with, not all wind power policy interventions have been followed up and evaluated, during or after programme implementation. The evaluations seem to have been commissioned ad hoc, except for in the early 1990s. Secondly, the aim, scope, method and assessment criteria have differed between the different evaluations over the years. The evaluators seem to have decided on a method based on an interpretation of the aims of the evaluation and/or programme. Thirdly, evaluation of technology and market development has not been the main goal for all evaluations. Seven out of nine evaluations of wind energy programmes have assessed several aspects of technology development, costs and actors' behaviour and commitment. However, the assessment criteria used for evaluation of wind power technology and market development have not exhaustively analysed the combined effects on technology, costs and actors. The assessment criteria used have only to a limited extent allowed systematic and systemic monitoring of changes over time. Finally, provision of information to policymakers and data for decision-making has been an important objective of several evaluations. Several assessments have projected future market transformation effects with a long-term perspective. This is an important aspect, since the time-lag of programme influence on technology and market development can be several years (Neij, 1999).

The lack of a systemic evaluation strategy seems to have complicated a comprehensive understanding of drivers and barriers to wind power development in Sweden and a comparison of programme effects over time. The exception are the evaluations from 1993, where the subsidy and support to demonstration and applied technology development were evaluated using a systemic approach; addressing technology development, costs and actor's commitment and behaviour. These evaluations were also used in reports to the Government and influenced the design of future programmes and policy decisions. Unfortunately this broad evaluation approach was not applied in subsequent evaluations.

Altogether, clearer, systemic evaluation strategies for assessment of the combined policy effects would probably have an impact on the efficiency of the wind power programmes, in terms of stimulation of installation of capacity, as indicated by the results, effects and use of the 1993 evaluations. A systemic approach does, however, seem to require thorough monitoring of the wind system development over time, in order to get a better understanding of the changing dynamics of the system, to, in turn, know where to concentrate Governmental interventions, and where not to intervene. This is especially crucial for the development of a new energy technology, for which technology development is hard to predict. The analysis of evaluation methods for assessment of Swedish wind energy programmes shows that there is a need for improved evaluation methods to achieve a better understanding of how policy programmes effect and interact with system dynamics, driving and hindering technology and market development of renewable energy technologies.

[12] First in 2000 a plan for evaluation of the 1997s energy programmes was presented (Ministry of Industry, Employment and Communications 2000a).

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