Are tradable green certificates a cost-efficient policy driving technical change or a rent-generating machine? Lessons from Sweden 2003-2008

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Are Tradable Green Certificates a cost-efficient policy driving technical change or a rent-generating machine? Lessons from Sweden 2003-2008

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Abstract

In the European policy debate, tradable green certificates (TGC) have been suggested to be a superior regulatory framework for promoting the diffusion of renewable electricity technologies. The purpose of this paper is to assess the performance of the Swedish TGC system, contributing to the European debate on the suitability of different types of frameworks. The expectations of the TGC system were that it would: a) be effective in terms of increasing the supply of "green" electricity; b) do this in a cost effective manner (from both a social and a consumer perspective); c) generate an equitable distribution of costs and benefits and d) drive technical change. So far, it has performed adequately in terms of effectiveness and social cost effectiveness. However, consumer costs have been substantially higher than expected, very large rents are generated and, at best, it contributes marginally to technical change. Thus, a TGC framework should be selected if the overriding concern is to minimize short term social costs of reaching a certain goal with a high degree of predictability. However, it cannot be expected to also drive technical change, keep consumer costs down and be equitable. Such trade-offs need to be revealed and not obscured by analysts.

Key words: Tradable green certificates; rents; technical change

1. Introduction

For more than a decade, the European Union has recognised the need to tackle the challenges of climate change. Initially, EU outlined a 15 percent reduction target for greenhouse gas emissions by the year 2010, as from the 1990 level (European Commission, 1997). Since energy generation is a prominent source of CO_2 emissions, an increased use of renewable energy, in particular electricity produced from renewable energy sources, was considered an important condition for reaching this target (European Commission, 1997; European Parliament and Council, 2001).

For this reason, but also to ensure security of supply as well as social and economic cohesion, a 21 percent target for renewable electricity penetration by 2010 was adopted by the European Parliament and Council (2001). Whereas EU member states seem to be making good progress in meeting this target, much stronger efforts will be needed to reach the reduction targets for greenhouse gas emission set in 2007, which calls for a 30 percent reduction by 2020 and a 60-80 percent reduction by 2050 compared to 1990 (European Parliament, 2007, 2008). This accentuates the question of which government policy instruments are likely to be effective in stimulating the required investments in renewable electricity generation equipment, such as wind turbines, photovoltaic cells and biomass combined heat and power plants.

For a couple of decades, various regulatory frameworks have been experimented with to stimulate investments in such renewable energy technologies. Two main types of policy instruments have been deployed: feed-in tariffs and tradable green certificates-based quotas (TGCs). In countries with feed-in tariffs, owners of distribution networks are required to accept renewable electricity fed into the network and pay a fixed, regulated price (or price premium) for that electricity. This type of system was adopted by Denmark in the 1980s and by Germany and Spain in the 1990s, and is now the dominant system in the EU15 (cf. e.g. Rowlands, 2005; Rickerson et al., 2007; Fouquet and Johansson, 2008). The price premium is covered through cross-subsidies among electricity consumers, by the taxpayers via the government budget or through a combination of these systems (Menanteau et al., 2003).

Based on the experiences of these and other countries, several assessments of the efficiency and effectiveness of feed-in tariffs have been published (e.g. Morthorst, 2000; Menanteau et al., 2003; Meyer, 2003; Ürge-Vorsatz et al., 2004; Madlener and Stagl, 2005; Ragwitz and Huber, 2005; Rowlands, 2005; Contaldi et al., 2006; Ringel, 2006; Finon and Perez, 2007; del

Río and Gual, 2007; Diekman, 2008; Verhaegen et al., 2009). The main advantage of this system, as described in these assessments, is its effectiveness in promoting technology development and diffusion (especially with regards to wind power in e.g. Germany and Spain).[1]

In tradable green certificate-based quota systems (TGCs), renewable electricity is sold in the usual electricity market at market prices, but these sales are complemented by certificate trading in a separate market for green certificates. The certificates are demanded by obligated buyers (e.g. electricity suppliers or consumers) who must buy certificates corresponding to a certain quota of their total electricity sales or consumption. Here, countries such as Belgium (Flanders), Sweden and the UK have been early adopters. According to the existing academic literature (most of which are based on either theoretical analyses or simulation approaches), the expected main advantages of TGCs are that they (1) are cost-efficient, (2) ensure a stable development towards set deployment goals and (3) drive innovation and cost-reduction through "double" competition in both electricity and certificate markets (cf. Morthorst, 2000; Menanteau et al., 2003; Ürge-Vorsatz et al., 2004; Madlener and Stagl, 2005; Contaldi et al., 2006; Ringel, 2006; del Río and Gual, 2007; Verhaegen et al., 2009).

However, it is still very much unclear whether certificate systems can meet these expectations; in previous assessments it has been concluded that the experiences of these systems are too limited to allow for a thorough analysis of their performance (cf. Menanteau et al., 2003).[2] However, after six years of operation, there is now enough data to make an assessment of the performance of the Swedish "electricity certificate system" so far. *The purpose of this paper is, therefore, to assess the performance of the Swedish TGC system and, thereby, contribute to the European-level debate on the suitability of different types of systems for the support of renewable electricity.*[3]

The paper is structured as follows. In section 2, we summarise the expectations on TGC systems. We begin with outlining the expectations formed by the European Commission and the European Parliament in the second half of the 1990s, simply since these were very

[1] The main disadvantages that are mentioned are that (1) the fixed tariff system can become very expensive for the electricity consumers/tax payers, (2) the windfall profits can be high, (3) the system cannot guarantee that a certain amount of renewable electricity will be provided at a certain time and (4) the incentives for cost reductions are sometimes insufficient.

[2] For an exception, see Verbruggen (2004, 2009).

[3] It would certainly be of interest to compare TGC systems with feed-in tariffs with regards to performance. However, this is outside the scope of this paper. Our results, can however be used for that purpose if combined with data from other studies.

influential for the later Swedish choice of regulatory framework (Åstrand, 2005). We proceed with specifying the expectations of the Swedish government, as expressed in a number of government bills and in a central government committee of inquiry. On the basis of these expectations, we identify four criteria for assessing the performance of the Swedish TGC system. In section 3, the design of the Swedish TGC system is described and the performance of the system is analysed in relation to the identified criteria. In section 4, we end the paper with a concluding discussion of the lessons learned.

2. TGCs in the European and Swedish policy debate: Expectations and assessment criteria

2.1 Policy expectations on TGCs at the EU level

Against the background of a belief in a growing importance of renewable electricity in the European power balance, a report from the European Commission (1998) pointed to advantages of a harmonisation in terms of support schemes for renewables in Europe. As a consequence, it identified a need to determine the relative merits and disadvantages of the different approaches in the Member States. The results of a largely theoretical assessment of various support schemes were reported in 1999 in a Commission working paper (cf. European Commission, 1999), which made it very clear the Commission advocated a quota, or "competitive-based", system.

A number of expected advantages of such systems were identified. They would (i) be compatible with the EU treaty rules, (ii) provide a "considerable" level of security (depending on design) and (iii) ensure static efficiency, i.e. "… that electricity is generated *and sold* at minimum cost" (European Commission, 1999, p. 15, our italics). The expectations referred, thus, to cost efficiency in terms of not only social costs[4] but also in terms of consumer costs, which is not surprising considering that low electricity prices for consumers is one of the main goals of EU environmental-energy policy (Sáenz de Miera et al., 2008). This goal is also reflected in the Renewables Directive, where one of the main arguments in favour of a future pan-European support scheme is to keep consumer costs down:

> Such a framework would "enable electricity from renewable energy sources to compete with electricity produced from non-renewable energy sources *and limit the cost to the consumer*,

[4] The social cost is the total cost to society of an economic activity. It is the sum of the opportunity cost of the resources used to carry out that activity and any additional costs imposed on society from the activity in the form of externalities (The Penguin Dictionary of Economics, Fourth Edition, 1988). In the analysis below, we disregard potential external economies.

> while, in the medium-term, reduce the need for public support" (European Parliament and Council, 2001, p. 34, our emphasis).

In part, the focus on consumer costs stem from a worry that too high prices for consumers would erode public support for increasing generation of renewable electricity:

> "Once a significant level of renewables generated electricity develops, and the consequent price uplift to overall electricity tariffs becomes appreciable, the need to demonstrate 'value for money' /…/ becomes increasingly vital if continued public support for large levels of Res-electricity is to be maintained". (European Commission, 1999, p. 16)

Finally, in contrast to a feed-in solution, a quota based scheme was expected to (iv) stimulate innovation:

> "As the system [feed-in tariff schemes] is not one based on direct competition ... the incentive for innovation must, by definition, be less pronounced than under a scheme that is based on competition." (European Commission, 1999, p. 16)
>
> "[Q]uota/competition-based schemes have been the most effective in the EU in driving down prices for renewable generated electricity and, according to economic theory, as a result of the competition, stimulating innovation." (European Commission, 1999, p. 18).

In spite of these powerful expectations, the Commission was not ready to suggest a harmonised quota-based system, probably due at least in part to the opposition from member states having adopted feed-in tariffs (Lauber, 2007). In the proposal for a directive on the promotion of electricity from renewable energy sources, it was argued that although a harmonised European-level support scheme would be beneficial, the experiences of different support schemes were too limited to conclude which model should form the basis of an internal market for renewable electricity, "in particular with regard to the innovative 'green certificate' system …" (European Commission, 2000, p. 6).

2.2 Policy expectations of TGC in Sweden[5]

The policy expectations in Sweden overlap to a very large degree with those of the EU. In particular, European Commission (1999) appears to have had a major influence on Swedish policy documents. The core arguments in favour of TGC were drawn from that paper and reproduced in both SOU 2001:77 (a key Government committee of inquiry) and in a prior Government bill introducing the certificate system (Swedish Government, 2000).

A first expectation of the Swedish TGC system was to substantially increase the share of electricity generated from renewable energy sources:

> "The certificates are, thus, a means which primarily relate to the goal of increasing the share of electricity from renewable energy sources. The objective of this goal is, in the long run, to obtain

[5] All quotes in this section are our translations.

> a sustainable energy system built on renewable energy sources. In Sweden, such a development is necessary in order to manage the transition of the energy system in connection with the phasing out of nuclear power" (SOU 2001:77, p. 108-109).

An initial goal of adding 10 TWh 'green' power to the power balance by 2010 was a response to the European Parliament and Council (2001) directive on the promotion of electricity produced from renewable energy sources. This goal was subsequently raised to 17 TWh by 2016 and a new target of 25 TWh by 2020 was recently suggested by the Swedish Government (2009).

A second expectation was that the expansion in the supply of 'green' power was to be done in a cost efficient manner. As in the Commission working paper referred to above, the concept of 'cost' included both the social cost and consumer cost. With respect to social cost, we can refer to an influential government committee of inquiry and a later Government bill:

> "An efficient promotion of electricity from renewable energy sources implies ... that the total cost ... shall be as low as possible. An efficient solution that is adjusted to the conditions of the market is to let the quota rise gradually. Investments with low marginal cost will be included first and only thereafter will investments with a higher marginal cost be included." (SOU 2001:77, p. 125)

> "A basic idea in the system is that the price of the certificates shall mirror marginal costs for a new investment ... for the production of renewable power. This means that investments which are most cost efficient and most simple shall be implemented first" (Swedish Government, 2006a, p. 29)

The emphasis on cost efficiency reflected, however, also a strong perceived need of keeping the costs for the electricity consumers down (Thornström, 2005). Thus, as a Government bill put it:

> "The costs of the support system must be kept down in order for it to achieve acceptance among the public, to maintain the competitive strength of industry and an improved competitiveness of the renewable energy sources." (Swedish Government, 2002a, p. 88)

The concern for electricity consumers is also demonstrated by the implementation of a limited quota obligation fee (a penalty fee for obligated buyers who fail to meet their obligation) that prevented the certificate price from shooting up (cf. SOU 2001:77, p. 173; Swedish Government, 2002b, p. 117). This focus on consumer costs, in addition to social cost, mirrors that in the European Commission (1999) and European Parliament and Council (2001) and is related to the issue of equity, i.e. the fairness in the distribution of costs and benefits between different actor groups. A main concern was, therefore, to avoid overcompensation of the power industry (Swedish Government, 2000, p. 14). It was, hence, clearly specified that the TGC scheme should only support renewable power production that was not commercially competitive (Swedish Government, 2000, p. 20-21; 2002b, p. 40).

A third expectation of the Swedish TGC scheme was that it would increase the competitiveness of electricity from renewable energy sources through technical change (Swedish Government, 2002a). The expectations were that a TGC scheme would be an elegant solution to obtaining the twin benefits of cost efficiency and technological development:

> ”The transition to market based solutions to promote power from renewable energy sources means that conditions are created for an effective competition between different forms of power from renewable energy sources. *An effective competition leads to cost efficiency and to the development of new technical solutions*” (SOU 2001:77, p. 104, our italics).

2.3 Criteria for assessing the performance of the Swedish TGC system

Comparing the expectations of a TGC system, in Sweden and on the EU-level,[6] there is a substantial agreement in terms of what the most important criteria to consider are: (1) effectiveness (ability to increase renewable electricity generation/meet targets), (2) costs efficiency, in terms of both social cost and consumer cost, (3) equity (avoiding overcompensation)[7] and (4) the ability to stimulate technical change and drive costs down in the longer term. We will now define these criteria more precisely.

Effectiveness is measured as the amount of new renewable electricity production generated in the TGC system relative to the expectations, using official data from the Swedish Energy Agency and Svenska Kraftnät.[8] We also use qualitative sources to discuss the extent to which this new production can be seen as an outcome of the TGC system rather than of other incentives. The results of this analysis are given in Section 3.2.

Cost-efficiency is assessed by the achievement of a prior determined target at a minimum cost and we label this the cost-effectiveness of the system (cf. del Río and Gual, 2007).[9] The cost-effectiveness in terms of the *social cost* of the system is discussed in Section 3.2 (although this is played down in relation to the following criteria). In line with the concern for *consumer costs* revealed in Swedish and EU policy documents, we also include measurements related to the total cost for the consumers, including transaction costs (cf. del Río and Gual, 2007). In

[6] These expectations overlap partly with those in the academic literature (see Section 1). The exception lies in policy makers’ expectations that both social costs and consumer costs may be minimised with a TGC system.
[7] The issue of equity is not explicitly dealt with in the EU document referred to above but follows from the focus on keeping consumer costs down.
[8] Svenska Kraftnät is a state utility, which administers and runs the national electrical grid. It is also in charge of the electricity certificate register.
[9] An alternative approach is to compare the environmental benefits and other socioeconomic benefits with the (societal) costs of the scheme (static efficiency) (del Río and Gual, 2007). This is, however, outside the scope of this paper.

Section 3.2, we use official data supplied by the Swedish Energy Agency as the basis of an analysis of the *total gross cost for the consumers* in relation to the expectations, including the *transaction costs* paid by electricity suppliers.

Equity, i.e. how the costs and benefits of promotion are shared between actors, is assessed in terms of who receives support and for what type of investments. In Section 3.3, we analyse the *rents/producer surplus* generated in the system, i.e. various types of "abnormal" profits that benefit electricity producers at the expense of electricity consumers (cf. Verbruggen, 2004, 2008; Finon and Perez, 2007). We define and discuss the concept of 'rents' and our estimation method in further detail in Section 3.3.

The system's ability to foster technological development is assessed in Section 3.4 on the basis of an analysis where insights from modern innovation research are applied to the field of renewable electricity.

3. The Swedish TGC system: characteristics and outcomes

3.1 Essentials of the Swedish TGC system

The Swedish TGC system came into force on 1 May 2003. After a first assessment by the Swedish Energy Agency in November 2004 (Swedish Energy Agency, 2005a, b), the scheme was revised in 2006 with regards to both goals and design. In the following, we will describe the system (originally and after the 2006 revision) to provide a background for the subsequent performance assessment.

The system has two main components: (1) a right for producers of renewable electricity to receive certificates and (2) a quota obligation for electricity consumers/suppliers (excluding the energy-intensive industry), creating a demand for the certificates.

3.1.1 Certificates for producers of renewable electricity

Producers of electricity from selected renewable sources receive one "electricity certificate" for each MWh of renewable electricity they produce. The system includes existing and new wind power plants, biomass-based power/combined-heat and power plants, geothermal power plants, solar power plants, hydropower plants (<1.5 MW) and wave power plants.[10] A

[10] From 1 April 2004, electricity produced from peat is also included in the system. All new hydro power plants are, in principle, eligible for support, but legislation protecting unexploited rivers prevents the building of additional large-scale hydropower plants.

particularity of the Swedish system is that existing power plants were included in the system from the start. Since the 2006 revision, however, the support period for these plants is limited to 2012 or 2014 (depending on whether the plant in question has received any previous government support or not). New power plants (built 2003-2016) are guaranteed certificates for 15 consecutive years.

The certificates can be traded in a special "certificate market". This generates an income stream in addition to that stemming from sales of the electricity (on the conventional electricity market). Holders of certificates can also choose to "bank" the certificates and sell them later on. Since all eligible electricity production receive the same amount of certificates per MWh, all types of electricity sources receive the same amount of support. This implies that a common, "technology-neutral" market is created, in which the eligible renewable electricity sources compete with each other directly and investments occur in stages depending on the cost level of different sources. The basic idea is that the certificate price at a certain point in time will correspond to the additional cost (in comparison to conventional power production) of the marginal renewable power plant in the system.

3.1.2 Quota obligation and quota levels

Each year by April 1st, all obligated buyers have to hold, and hand over to the state, certificates corresponding to a certain share (quota) of their total electricity consumption/sales the previous year. Originally, this obligation referred to the electricity consumers, but in the 2006 revision it was moved to the electricity suppliers (with some exceptions). Electricity consumed in the manufacturing process in electricity-intensive industries or produced in small (<50 kW) plants is wholly or partly exempted.[11] In total, approximately two thirds (100 TWh) of the total electricity use in Sweden is included in the certificate system.

The quota is decided by the Swedish Parliament. Originally, it was set to increase from 7.4 percent of consumed/invoiced electricity in 2003 to 16.9 percent in 2010 (see Table 1). This was estimated to correspond to 10 TWh increase in renewable electricity production in comparison to the 2002 level. In 2006, the quota was adjusted to correspond to the new target

[11] Originally, companies were defined as electricity-intensive based on which sector they belonged to. Since the beginning of 2007, a company is defined as electricity-intensive if its use of electricity in the manufacturing process amounts to 40 MWh per million SEK of total sales value (Swedish Energy Agency, 2008).

of 17 TWh by 2016.[12] The development of the quota takes into consideration the phase-out of plants that are no longer eligible for support (as described above).

Obligated buyers that do not meet their obligation are required to pay a penalty to the state. This "quota obligation fee" currently amounts to 150 percent of the average certificate price in the previous accounting period. In 2004 and 2005, the fee was limited upwards to 175 SEK and 240 SEK respectively. This price cap was removed in the 2006 revision.

TABLE 1: *Quota obligation 2003-2030 in the Swedish TGC system (number of certificates per consumed/sold MWh of electricity).*

YEAR	QUOTA ACCORDING TO ORIGINAL DESIGN	QUOTA ACCORDING TO REVISED DESIGN	FORECAST OF NEW RENEWABLE ELECTRICITY (TWH)
2003	0.074		0.64
2004	0.081		1.35
2005	0.104		3.65
2006	0.126		5.89
2007	0.141	0.151	8.96
2008	0.153	0.163	10.30
2009	0.160	0.170	11.15
2010	0.169	0.179	12.22
2011		0.156	11.76
2012		0.161	12.36
2013		0.089	12.96
2014		0.094	13.56
2015		0.097	15.55
2016		0.111	17.02
2017		0.111	17.11
2018		0.111	17.20
2019		0.112	17.29
2020		0.112	17.38
2021		0.113	17.47
2022		0.106	17.56
2023		0.094	17.65
2024		0.090	17.74
2025		0.083	17.83
2026		0.075	17.92
2027		0.067	18.01
2028		0.059	18.10
2029		0.050	18.20
2030		0.042	18.29

Sources: Swedish Government (2002b, 2006a).

[12] In October 2006, the Swedish Government (2006b, p. 15) suggested yet another revision of the quota obligation, but since it was not accompanied with a new forecast of renewable electricity production, we will use the first revision. This will not have much influence on our results, since the last revision implied very minor changes to the quota obligation and only concerned a couple of years (2011 and 2012).

3.2 System outcomes I: Effectiveness and costs

In this section, we begin our assessment of the Swedish TGC system. Section 3.2.1 contains a description of the effectiveness of the system in terms of added supply of renewable electricity in comparison to the expectations and discusses to what extent the social cost of achieving the set target has been reasonable. Section 3.2.2 briefly describes the system's performance in terms of consumer costs, including transaction costs.

3.2.1 New renewable electricity production 2003-2008 and social costs of the system

Table 2 shows the production of renewable electricity in the Swedish TGC system in the period 2003-2008, with the existing production in year 2002 included as a reference. In 2008, the total production was 15 TWh. As the TGC system provides a uniform premium, this secures that the currently most cost-efficient technologies are invested in. Thus, the vast majority of the production (10.4 TWh) consisted of biomass-based (incl. peat) electricity production in industrial back-pressure plants and combined heat and power (CHP) plants. Small-scale hydro power and wind power contributed 2.6 TWh and 2.0 TWh respectively. In comparison with the 2002 level (6.5 TWh), this implies an increase in renewable electricity production of roughly 8.5 TWh, i.e. 82 percent of the forecast of 10.3 TWh (see Table 1). Thus, the Swedish TGC system has not quite met the expectations, but seems to have been reasonably effective.

TABLE 2: *Electricity production in the Swedish TGC system by type of production, 2003-2008 (GWh).*

YEAR	HYDRO	WIND	BIOMASS & PEAT	TOTAL	*INCREASE*
2002	n.a.	n.a.	n.a.	6,500	–
2003 (May-Dec)	964	456	4,218	5,638	–
2004	1,968	865	8,216	11,048	*4,548*
2005	1,799	939	8,560	11,298	*4,798*
2006	2,019	988	9,150	12,157	*5,657*
2007	2,195	1,431	9,629	13,256	*6,756*
2008	2,607	1,996	10,436	15,037	*8,517*

N.B. The total Swedish renewable electricity production in 2002 is included as a reference.

Source: Swedish Energy Agency (2009, Table 4).

Of the renewable electricity produced in 2007, only 2.5 TWh were produced in plants taken in operation after 1 May 2003 (Swedish Energy Agency, 2009). This implies that most of the production increase has, so far, been achieved in plants that were *already in operation* in May 2003, in main part through low-cost measures such as increases in power outputs in biomass-based CHP plants or conversion from fossil fuels to biomass in existing CHP plants.[13] As mentioned previously, these plants may receive certificates until year 2012 or 2014 depending on whether they have received government investment subsidies or not. The system, thus, seems to have performed well so far in terms of social cost-effectiveness, in particular as most increase in output has been achieved at a very low social cost in already existing plants.

The low share of output from new plants is, of course, not surprising since it takes a number of years for the power industry to react to new incentives, to get permits for new power plants and for the capital goods industry to deliver these. Thus, to get a more complete picture of the outcomes of the TGC system, we also need to look at planned investments. Here, it is clear that the TGC system has stimulated a great interest in the paper and pulp industry and among utilities to make further investments in biomass CHP plants. This has been particularly evident after the extension of the system to 2030 (Hirsmark and Larsson, 2005; Jacobsson, 2008). The interest in investments in wind power has also increased, although there are still substantial obstacles for wind power deployment in terms of e.g. a slow permit process (Michanek and Söderholm, 2006) and the limited capacity of the global wind turbine industry to supply wind turbines (Swedish Energy Agency, 2007a).

This increased interest to invest in renewable electricity production is, however, also due to other factors. Investment decisions are made in a very complex reality, and may be influenced by a large number of different factors. These include increases in electricity prices in recent years (partly driven by the Emission Trading System in the EU), various investment support measures, demand for ‘green’ electricity and industry’s willingness to invest in power production in order to secure access to electricity at reasonably stable prices. This implies that some investments would surely have been made even if the TGC system had not been introduced. However, Hirsmark and Larsson (2007) report that 63 percent of the CHP producers claim that the TGC system has had a decisive influence on their investment

[13] Sweden has a large capacity for biomass CHP at quite low cost due to (1) large district heating networks, covering most city centres that either are already fuelled with biomass or can be quite cheaply converted to biomass from oil, and (2) large-scale back-pressure production of (mostly biomass) electricity in the pulp and paper industry. Both these types of plants benefit from having a market for by-products such as heat or steam. The pulp and paper industry has for a long time used biomass for the production of process steam and electricity and the step to biomass CHP and larger-scale electricity production is quite small.

decisions and that 23 percent agree that the system has had some influence. Similarly, Michanek and Söderholm (2007) show that the TGC system has been of crucial importance to investments in new wind power plants.

To conclude, there has been a quite rapid increase in renewable electricity production in Sweden since the introduction of the TGC system, from 6.5 TWh in 2002 to 15 TWh in 2008. Whilst only about 2.5 TWh of the increase was produced in new power plants, the TGC system has spurred the interest of potential investors in renewable electricity production and we may, thus, come to experience a continued increase in the future.[14] *Taken jointly, it would be reasonable to say that the Swedish TGC has, so far, been effective in that it has almost met expectations as regards increase in renewable electricity production. It has also, so far, met the expectations of cost-effectiveness in social terms, in particular as most of the increase in output has been achieved at low cost in already existing plants*.

3.2.2 Consumer costs, including transaction costs 2003-2008

In the first six (almost) years, the Swedish TGC system has resulted in (gross) consumer costs[15] of 19.5 billion SEK (approx. 2.1 billion €).[16] In relation to the total amount of quota-obligated electricity consumption (approx. 95 TWh in 2008), the additional consumer cost per kWh of electricity used (the amount shown on the electricity bill) increased from 0.02 SEK/kWh in 2003 to 0.05 SEK/kWh in 2008. These figures should be compared to the expected level of 0.006-0.015 SEK/kWh (SOU 2001:77), since this reflects the cost level policy makers apparently considered reasonable beforehand. *The cost for the consumers has, thus, been substantially higher than expected.*[17]

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[14] According to Swedish Energy Agency (2008), there are many planned projects that are likely to be implemented in the next few years, especially since the current price of certificates makes investment in further renewable production more favourable. However, the TGC system also faces a number of challenges in the future, most notably the issue of whether the expected extensive overhaul and updating for existing plants will be entitled to a further allocation period of certificates. The Swedish Energy Agency (2009) suggests that the increase in production is likely to be 13.8 TWh by 2012, which is above expectations.

[15] It should be noted that all calculations of consumer costs concern gross costs. The net consumer costs may very well be lower than the gross cost, due to the interaction between the TGC system and the conventional electricity market: When a separate market for renewable electricity is created (as in the Swedish TGC) and electricity demand is stable, the most expensive conventional electricity production may be out-competed and the producer surplus decrease. According to a recently published study, this effect has been clearly evident in Germany (BMU, 2007). Similarly, Sáenz de Miera et al. (2008) have recently shown that the increase in the costs of renewable electricity support may be offset by the short/medium-term reduction in the wholesale electricity price, leading to a reduction of retail electricity prices. However, it has not been possible for us in this paper to take this type of interaction effects into consideration.

[16] All conversions between Swedish Krona (SEK) and Euro are based on official exchange rate statistics from the European Central Bank (www.ecb.int).

[17] According to Swedish official statistics, the higher than expected certificate price has not been compensated for by lower electricity prices.

The consumer cost can be divided into the following main components:

- value-added tax (VAT) paid to the state
- quota obligation fees (penalty fee for obligated buyers who fail to meet their obligation) paid to the state
- administrative and transaction costs
- support to producers of renewable electricity (payment received for certificates)

The distribution between the different components is shown in Figure 1. A first item is VAT and quota obligation fees paid to the state, which amounted to 4.1 billion SEK (21 % of the total consumer costs 2003-2008). Approximately 1.9 billion SEK (10 %) are estimated to have been transferred to electricity suppliers in order to cover their transaction costs and administrative cost. Although these costs have decreased over time, they were still substantial in 2008: 185 million SEK. It should also be noted that the official data only include transaction costs of electricity suppliers. To these should be added the transaction costs of electricity producers and consumers, which are probably higher than those of the electricity suppliers (cf. Van der Linden et al., 2005; Kåberger et al., 2004). Hence, *a worry of the EU Commission (1999) of possible high transaction costs of quota based systems has proved to be of substance*.

Yet, the largest cost item is, of course, payments to the producers for traded certificates that have been cancelled, which amounted to 13.5 billion SEK (69 %). We will now turn to analyse the extent to which these are constituted by various types of rents rather than "well-earned" compensation for higher production costs of renewable electricity in comparison to conventional electricity.

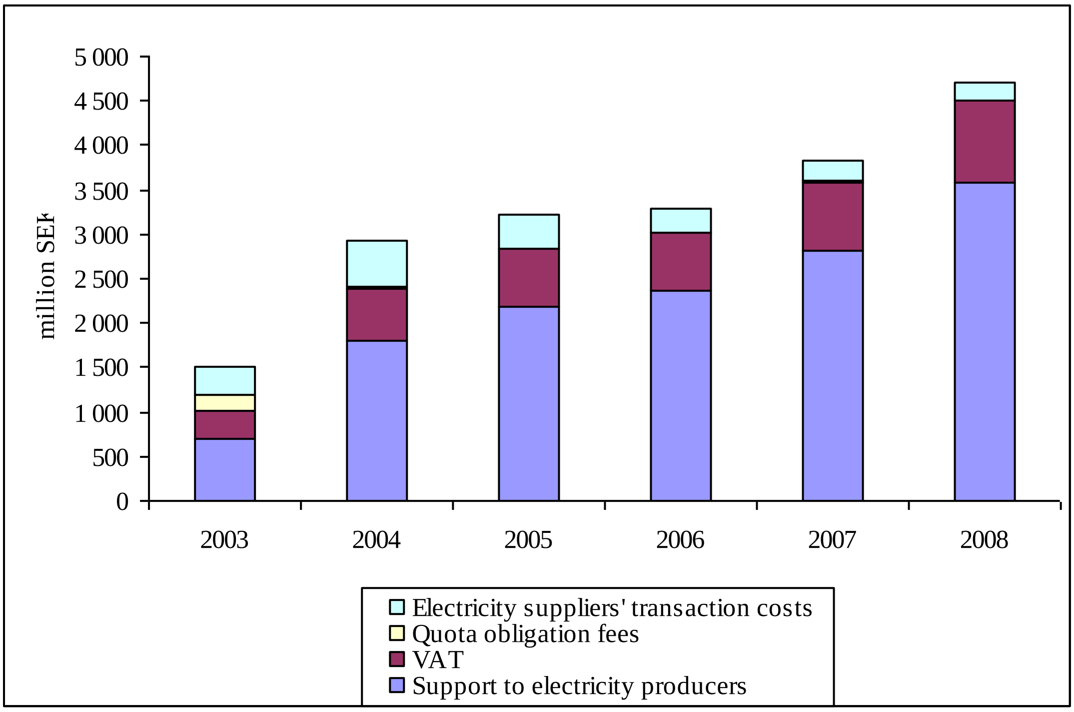

Figure 1: Consumers' costs for electricity certificates in the Swedish TGC system (Source: Swedish Energy Agency, 2009)

3.3 System outcomes II: Equity and rent generation

The principal idea of a TGC system is that the payment producers of renewable electricity receive from selling the certificates they are awarded should cover the extra costs involved in producing renewable electricity in comparison with conventional electricity. The certificate price should, thus, correspond to the difference between the marginal cost of renewables – i.e. the cost of the marginal renewable power plant in the system – at the determined quantity Q (mc*) and the market price for electricity (PE) (see Figure 2).

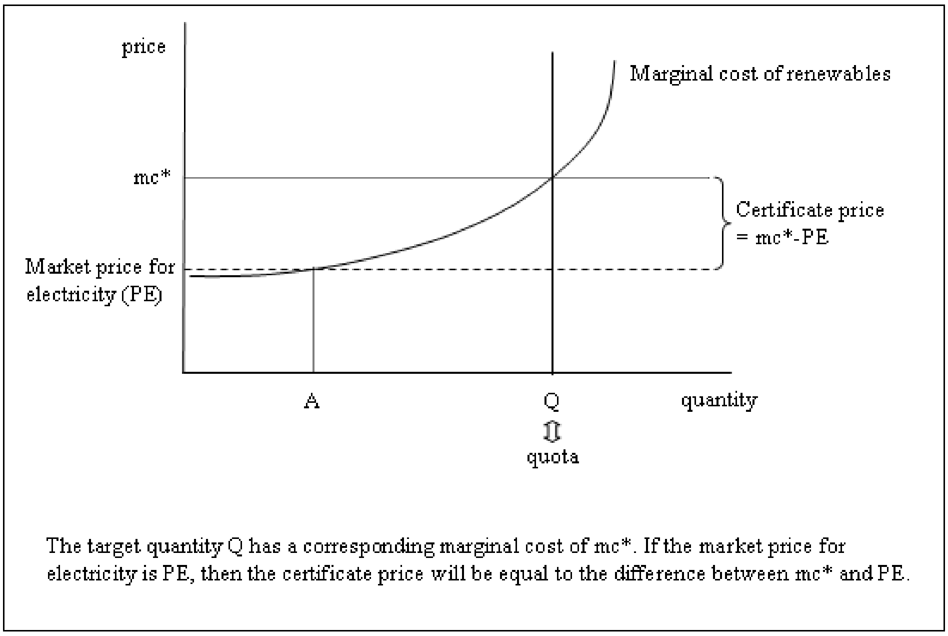

Figure 2: A schematic illustration of a TGC system (Adapted from Schaeffer et al. (1999))

However, for some plants payments are expected to exceed the extra cost. The producer surplus generated by such plants constitutes a "rent".[18] In previous literature, these rents are often referred to as "windfall profits" (e.g. Verbruggen, 2004; Finon and Perez, 2007), since they do not correspond to any extra achievement by the profiting parties and are largely uncontrolled by them.

We may distinguish between two types of rents. The first type is generated in plants which were already profitable without the extra payments provided via the certificate market (i.e. the renewable electricity up to quantity A in Figure 2). For these producers, the system creates an extra profit which does not correspond to any extra achievement on their part (the difference between mc* and PE in Figure 2).

The second type occurs due to the fact that the overall marginal cost curve for renewables consists of several different curves, one for each technology (see Figure 3). At each point in time, the certificate price will correspond to the most expensive technology included in the system (the "marginal" technology), and all technologies with lower costs will, thus, receive an extra profit. As more and more expensive technologies are required to fill the quota

[18] Verbruggen (2009) makes a distinction between "real rents" and "excess (swindle) profits". The former are differential (Ricardian) rents produced within a technology group that are the result of natural endowments and/or higher proficiency of some producers leading to cost differences between plants of the same type. The latter are created by differences in costs between technologies included in the same support scheme. Verbruggen (2008) argues that the rents created in TGC systems are better described as "swindle profits".

obligation, an increasing share of the funds transferred from consumers to producers will be rents to sub-marginal producers (cf. Verbruggen, 2004). Figure 3 illustrates how the marginal cost mc*, corresponding to the cost of technology C at target quantity Q, produces rents for technology A (light grey area), technology B (medium grey area) and some plants within technology C (dark grey area).

In the following, we will estimate the size of these two types of rents in the Swedish TGC system.

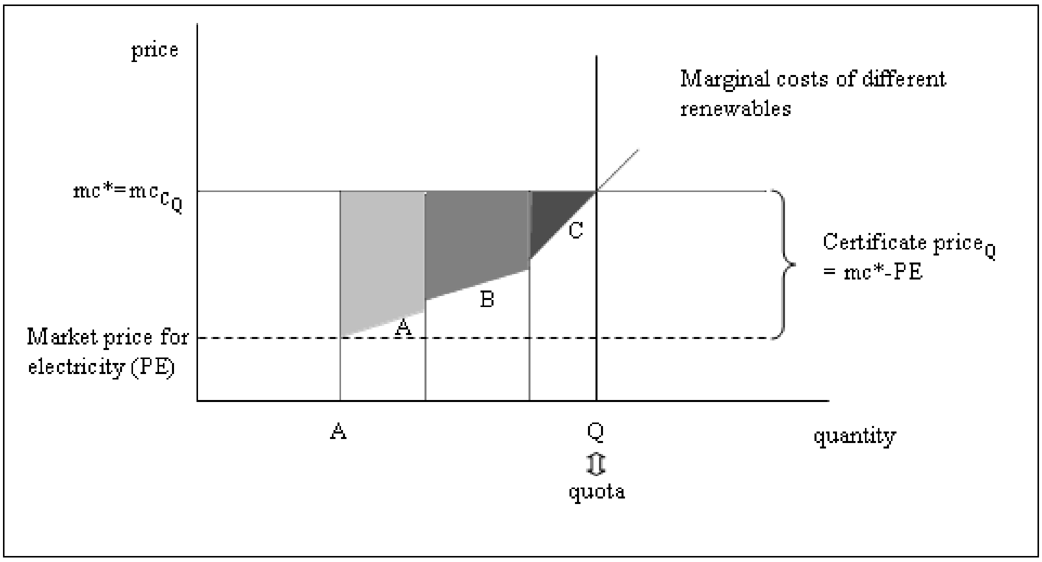

Figure 3: Type II rents in a TGC system.

3.3.1 Type I rents: Payments to already profitable electricity production plants

Due to some particularities of the Swedish TGC system, Type I rents currently constitute a major part of the total rents generated. First, as mentioned previously a number of already existing production plants were included in the system from the start, with the right to receive certificates for 10-12 years (to 2012 or 2014). One reason for their inclusion was to ensure enough liquidity in the certificate market (cf. SOU 2001:77). Another reason was to prevent existing biomass plants to switch back to fossil fuels (SOU 2001:77).[19] Some of the existing plants that were included in the system had previously received investment subsidies and/or production support, whereas others (especially some industrial plants) had been built without

[19] This argument may, however, be questioned since fossil fuel prices have increased substantially in the 2000s at the same time as the EU emissions trading system has been established, which promotes biomass before e.g. oil.

any government support. Most of this production was already competitive or at least needed far less support than entirely new production plants.

Second, there was a relatively large potential for "easily accessible" production increases in existing CHP plants, for example through fuel conversion and increase in the number of full-load hours. Although some of these increases required investments, these were much lower than the investments in new wind turbines or CHP plants that would come to determine the certificate price level.

In order to capture these two sources of Type I rents, we make two estimations. In the first, we only include the rents to existing renewable electricity production in 2002 (6.5 TWh according to the Swedish Energy Agency (2007b)). For this production, we assume an extra cost of 0 SEK/kWh, since most of the plants were already profitable.

In our second estimation, we also include the "easily accessible" production increases in existing plants. Here, we use data on the actual electricity production in these plants in 2006 (10.8 TWh according to the Swedish Energy Agency (2007b)).[20] We use this number since it corresponds well to the sum of total production in 2002 and the short-term bio power potential identified by the Government committee of inquiry responsible for suggesting a design for a future certificate system (SOU 2001:77).[21] We assume that these plants will be phased out according to the prognosis presented Swedish Government (2006a). The extra cost (in relation to the electricity price) of increasing the production of renewable electricity in existing CHP plants ranged from 0 SEK/kWH (increases in the number of full-load hours) to 80 SEK/MWh (for conversion from fossil fuels to biomass) (SOU 2001:77). Since we lack data on the exact distribution between different types of investments, we use an average cost of 40 SEK/MWh.

We use actual yearly certificate prices for the period 2003-2008 (cf. Swedish Energy Agency, 2009). For the period 2009-2014, we use three different price levels: 200 SEK, 250 SEK and 300 SEK. For comparison, we may note that the average certificate prices was 218 SEK in the

[20]For the period 2003-2008, we use the actual number of annulled certificates corresponding to the two estimates. For reasons of simplicity, we assume that the number of annulled certificates each year includes all certificates for existing production, except when the number of annulled certificates corresponds to a lower production than the existing production. Saved certificates in this period are included in the period 2009-2014.

[21]This committee of inquiry estimated the short-term potential to 3.7-4.7 TWh in total, including a 2 TWh increase in biomass CHP in district heating plants and a 1.7-2.7 TWh increase in industrial back-pressure processes. This implies that the "easily accessible" production in 2002 was 10.2-11.2 TWh (including 6.5 TWh of existing production in 2002), i.e. a mean value of 10.7 TWh. An alternative way to calculate the "easily accessible" production would be to take the actual production in 2007 (13.2 TWh) and reduce that figure with production in that year in plants that have been built after 2002 (1.6 TWh). This would amount to 11.6 TWh. Yet, we choose to be cautious and use, therefore, the lower figure of 10.8 TWh.

period of 2003 (May)-2008 and 289 SEK in the last year (1 May 2008 – 30 April 2009) (Svenska Kraftnät, 2009). The first two estimates are, therefore, quite likely on the low side, whereas the third seems more realistic.

The results of the analysis are presented in Table 3. According to our calculations (see Appendix B), the Swedish TGC system has already (2003-2008) produced Type I rents in the order of 8-11 billion SEK (830-1,160 M€), where the higher figure is more reasonable considering the easily accessible production increases discussed previously. These rents constitute up to as much as 79 percent of the total payments to electricity producers (approx. 14 billion SEK).

For the period of 2009-2014, our calculations indicate that Type I rents may amount to 5-7 billion SEK (if we only include the existing production) or 8-13 billion SEK (if we also include the "easily accessible" production) (see Appendix B). In total, the Type I rents may amount to 12-23 billion SEK (1.3-2.4 billion €) in the period of 2003-2014. Again, considering that the average price was SEK 289 in the last year and the quite low estimate of the "easily accessible" production, the highest figure (assuming a certificate price of 300 SEK/certificate and 10.8 TWh of existing and "easily accessible" production) is not at all unrealistic. In such a case, Type I rents would amount to about 59 percent of the total payments to producers in the period of 2003-2014 (see Appendix C).

TABLE 3: *Estimated Type I rents in the period of 2003-2014 to plants in operation in 2002.*

	RENTS 2003-2008 (MSEK)	RENT 2009-2014 (DIFFERENT AVERAGE CERTIFICATE PRICES)			TOTAL RENT 2003-2014 (DIFFERENT AVERAGE CERTIFICATE PRICES)		
		SEK 200 (MSEK)	SEK 250 (MSEK)	SEK 300 (MSEK)	SEK 200 (MSEK)	SEK 250 (MSEK)	SEK 300 (MSEK)
6.5 TWh existing production in 2002	7,731	4,532	5,665	6,798	12,263	13,396	14,529
10.8 TWh existing or "easily accessible" production in 2002	10,834	8,095	10,341	12,588	18,929	21,175	23,422

3.3.2 Type II rents: Overcompensation to sub-marginal producers as more expensive renewable electricity technologies are introduced in the system

As technologies with higher costs have to be introduced to meet the quota obligation, the certificate price will increase above the cost of the previously marginal renewable power plant in the system. The size of the rents generated is obviously dependent on the size of the quota, the potential of the "cheaper" production technologies and the cost difference between different technologies in the specific country. In the Swedish case, the cheapest new renewable electricity production is bio power and land-based wind power. As the combined potential of these technologies in Sweden is estimated to be about 22 TWh in 2015 (Swedish Energy Agency, 2005b), the current quota obligation of an additional 17 TWh by 2016 of new renewable electricity to the 2002 level of 6.5 TWh, can most likely be met by these technologies alone (together with an already achieved growth in small scale hydro). Since these are quite close in terms of production costs, type II rents will probably not become a main issue within this time frame.

However, if there is a need to introduce off-shore wind power (or other more expensive production technologies) in the Swedish TGC system to meet the quota obligation, substantial Type II rents may be generated for producers of bio power and land-based wind power. This may be the case if the quota obligation is increased or if land-based wind power diffusion is blocked by remaining difficulties in obtaining building permits. Both these events are highly probable. Indeed, the Swedish government recently announced its intentions to raise the quota to 25 TWh by 2020 in order to increase the share of renewable power substantially:

> To reduce vulnerability and increase the security of supply, a third leg needs to be developed for electricity supply, thereby reducing the dependence on nuclear and hydro power. To achieve this, combined heat and power, wind power and other renewable power production must account for a substantial share of the power production. (Swedish Government, 2009, p. 3, our translation)

Although it is not clear what "substantial" is, it would not be unreasonable to interpret this as "one third" considering that renewable sources are described as "a third leg" of the future Swedish electricity supply. This would require a contribution of renewable electricity sources within the TGC system of about 50 TWh. Thus, although we cannot say with any certainty when Type II rents may appear in the Swedish TGC system, it is clear that they will appear sooner or later.

To give an indication of the size of the potential Type II rents, we assume that off-shore wind power (or another technology with a corresponding cost level) will be introduced in the system starting in 2015. According to an early estimate by the Swedish Energy Agency (2005b), the introduction of off-shore wind power could result in certificate prices of up to 370 SEK/certificate. In a more recent report by the same Agency, it is suggested that the certificate price would have to be doubled (from approx. 250 SEK/MWh) in order for off-shore wind power to be profitable (Swedish Energy Agency, 2007c). In our estimate, we assume, therefore, a certificate price of 500 SEK/MWh.

This price results in an over-compensation to plants built between 2003 and 2014. We assume that these will be profitable at certificate price levels of 206 SEK/certificate for plants built in 2003-2007 (the average certificate price in this period) and 300 SEK/certificate for plants built in 2008-2014. The latter figure corresponds to the highest certificate price level used in the calculation of the Type I rents and is, as previously mentioned, only slightly higher than last year's average price. For reasons of simplicity we, thus, assume that all plants in each group will receive the same over-compensation per certificate from 2015 to the year they are phased out after 15 years of operation, in accordance with current legislation (see Appendix B).

The estimated amount of renewable electricity produced in plants taken into operation in 2003-2007 is based on data on the production in these plants in 2007. For 2008-2014, the estimated amounts are derived from a prognosis of new production based on an exponential increase in investments (see Appendix B).

Under these assumptions, Type II rents generated in 2015-2030 for new plants taken into operation in 2003-2014 would total in the order of 19 billion SEK (i.e. about 2 billion Euro) at a certificate price of 500 SEK (see Appendix B).

3.3.3 Conclusions: Total rents and their share of payments to producers

To sum up, the Swedish TGC system has already produced Type I rents (i.e. overcompensation to already existing production) in the order of 8-11 billion SEK, equalling 57-79 percent of the payments to producers depending on whether we include only the 6.5 TWh of existing production in 2002 or all the 10.8 TWh of "easily accessible" production in existing plants. In the most realistic of our estimates for the entire period 2003-2014 (based on a certificate price of 300 SEK in 2009-2014), Type I rents will amount to up to 23 billion SEK, which would constitute as much as 58 percent of producer payments. The estimation of Type II rents (i.e. overcompensation to cheaper technologies as more expensive technologies are introduced in the system) generated in the period 2015-2030 are, of course, much more uncertain but an indication could be about 19 billion SEK.[22]

Taken jointly, Type I and Type II rents for the existing plants at the start of the scheme and for those constructed up to 2014, are estimated to amount to about 33-42 billion SEK in the period 2003-2030 (see Table 4). With an average certificate price of SEK 300 in 2009-2014 and SEK 500 in 2015-2030, this corresponds to 22-28 percent of the total payments to producers 2003-2030 (see Appendix C).

These figures are, arguably, not in line with the expectations from the EU Commission and the Swedish government that the TGC system would be cost-efficient in terms of low consumer costs, nor that it should avoid overcompensation to power producers, as emphasized by the Swedish Government. On the contrary, the TGC system has turned into a "rent-generating machine". *The Swedish TGC scheme performs, therefore, badly not only in terms of consumer costs but also with respect to equity*.[23]

TABLE 4: *Total estimated rents and their share of payments to producers 2003-2030 (see Appendices B and C).*

		RENTS (MSEK)		PAYMENTS TO PRODUCERS (MSEK)	RENTS' SHARE OF PAYMENTS
	Type I	Type II	Sum		
6.5 TWH EXISTING PRODUCTION	14,529	18,952	33,481	151,134	22%
10.8 TWH "EASILY ACCESSIBLE "PRODUCTION	23,422	18,952	42,374		28%

3.4 System outcomes III: TGC as a driver for technology development

As shown in Section 2, a TGC scheme was expected to stimulate technical change and drive down costs. This theme is a recurring one in the Swedish policy literature (e.g. in various Government bills). For instance, a TGC will "… give rise to a market dynamic that create the conditions for cost efficiency and technical change" (Swedish Government, 2000, p. 1). In what follows, we will argue that this expectation is unreasonable. We will do so by relating the TGC scheme to the literature in innovation studies.

[22] As from 2009, the German feed-in-law prescribes a payment to producers of off-shore wind power of 15 euro cents/KWh (about SEK 1.5) (Markard and Petersen, 2009). If this is cost-covering, our assumption of a certificate price of SEK 0.5/kWh would be too restrictive and we would, thus, underestimate the Type II rents.
[23] These rents could, of course, be taxed and used for other purposes. This is, however, not done in Sweden.

That market dynamic influence technical change is well-known in the field of innovation studies, where the close relationship between technical change (and cost reduction) and diffusion has been emphasised for a very long time, indeed already by Adam Smith in 1776 (Smith, 1776/2003).This is, for example, reflected in the literature on so-called "learning curves" (e.g. Neij et al., 2003) that describe how an increase in performance, or reduction in costs, stimulates diffusion which, in turn, generates opportunities for more learning. In part, these opportunities stem from the larger funds available for R&D among capital goods suppliers as their sales increase (Klepper, 1997), but they are more general than so (Kemp et al., 1998; Jacobsson and Bergek, 2004).

This means that it is not enough for a government to fund R&D, pilot plants and the occasional demonstration plant for a learning process to unfold. Learning and technical change is dependent on market formation. This market formation needs to be started very early on and *in parallel* to R&D support – the process is not linear (Kline and Rosenberg, 1986).

In an early phase, diffusion rests on the formation of *nursing markets*, where the new technology is protected from competition for quite a long time, often decades. These nursing markets may be conventional niche markets, where the new technology is superior in some dimension, but in the energy field they are often created through some kind of state support, e.g. in the form of demonstration programmes.[24] Although very small, these markets are strategic in terms of technical change since they create a base for learning and self-reinforcing processes which enable the new technology to begin to improve its price/performance ratio and to adjust to the demand from specific segments (Kemp et al., 1998; Jacobsson and Bergek, 2004; Suurs, 2009), There is, though, a large discrepancy between the demand from these early niche markets and the fully commercial mass market. *Bridging markets* may, therefore, need to form to allow for different types of self-reinforcing process to gain strength (Andersson and Jacobsson, 2000).

Without nursing and bridging markets, there is little incentive for capital goods suppliers to enter into the new industry and provide resources for product, process and market development. Without a capital goods industry being formed, learning is limited to that taking place in academic R&D organisations. *The link between policy, market formation and*

[24] See Jacobsson and Bergek (2004) and Stern (2006) with respect to some of the reasons for the need for intervention to form initial markets.

technical change goes, therefore, via the capital goods industry. This link is particularly strong in early phases where an initially immature, expensive and poorly performing technology is embarking on a long learning process. By forming initial markets, policy may induce firms to enter into the capital goods industry and take the new technology through this process. Initial markets are, therefore, necessary for the new technology to be put "on the shelf" (Sandén and Azar, 2005).

As an example of successful market formation and capital goods industry development, we may take the German wind turbine case. German support to wind turbines from the mid-1970s and forward induced the entry of about 14 firms in the period 1977-91 (Jacobsson and Bergek, 2004). The initial nursing market was very small: in 1989, about 15 years after the start of the wind turbine programme, the total installed effect of wind turbines was only 20 MW (221 turbines) (Bergek and Jacobsson, 2003). This was followed by the formation of a bridging market in the form of a 250 MW demonstration programme with investment subsidies. This market was 12 times larger than the initial nursing market and strongly supported the development of the domestic wind turbine industry.[25] Yet, it was still a very small market compared to what was to come. In the first half of the 1990s, the first version of the feed-in law, with fixed tariffs for e.g. wind power, was implemented. Together with the 250 MW programme, this induced a growth of annual installations from 10 MW in 1989, via 500 MW in 1995 to a peak of over 3,200 MW in 2002 (see Figure 4).

[25] The capital goods suppliers benefitted from this generous support both by the creation of a domestic market and by the transfer of some of the support to the capital goods suppliers through high equipment prices, which to a large part were used for technology development (Bergek and Jacobsson, 2003). In addition, German turbine manufacturers were partly protected from competition from the Danish firms through the design of federal and local support systems, which ensured them a 50 % share of the German market.

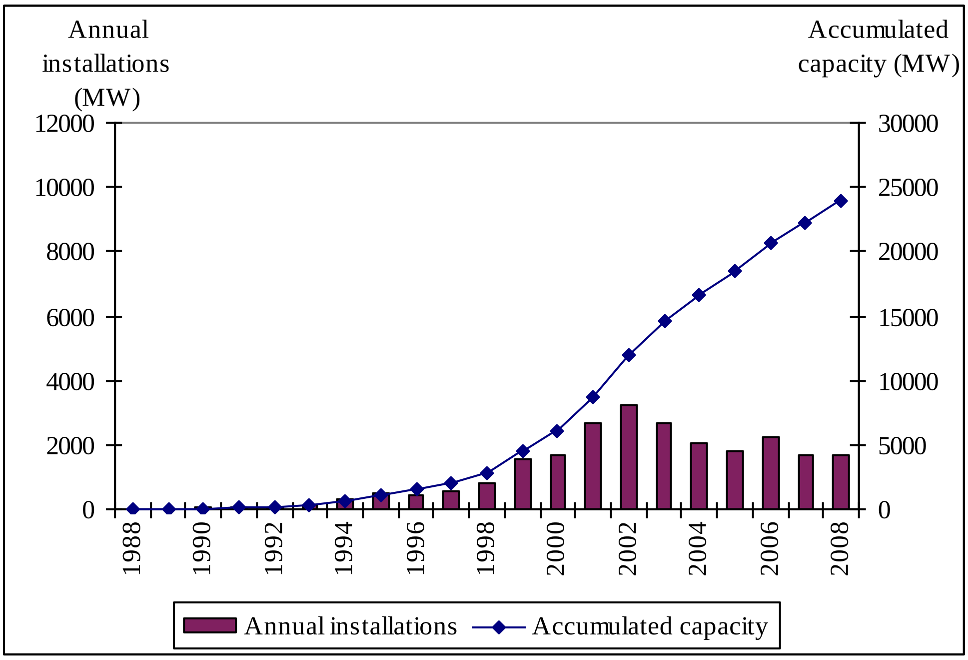

Figure 4:The German wind turbine market 1983-2008 (Sources: Elaboration on Bergek and Jacobsson (2003) and BWE (2009))

This growth created a large space for the German wind turbine industry. More firms entered and a division of labour emerged in a growing industrial system (Bergek and Jacobsson, 2003). A substantial learning process followed, which most notably involved a rapid up-scaling of the turbines. The capital goods suppliers' contribution to technical change was reflected in a learning effect which was in parity with the Danish (Neij et al., 2003). Today Germany accounts for about 30 percent of EU's supply of wind turbines (compared to Denmark's 40 percent) (EWEA, 2009a) and 35 percent of the direct employment in the European wind industry (EWEA, 2009b).

Both nursing and bridging markets can, thus, be rather small; contrast the figures above for wind power (20 and 250 MW respectively) with the situation in 2008, when the German installed effect of wind turbines was almost 24,000 MW (see Figure 4)! However, these markets were still instrumental in setting in motion learning processes that eventually led to the development of a range of domestic turbine alternatives to the more established Danish wind turbine industry.

How, then, does the TGC scheme compare with this? As noted above, uniform TGC systems, such as the Swedish TGC system, create a "technology-neutral" market where all eligible technologies compete. This leads, of course, to a step-wise investment pattern where the lowest cost technologies are included first:

> ”A basic principle of the system was that the different renewable energy sources should compete with each others so that the most cost efficient electricity production is built first. Only thereafter may the more expensive production be gradually built as the level of ambition (the quota) is raised” (Swedish Government, 2006b, p. 106).

A uniform TGC scheme, thus, creates a market for relatively mature technologies (Midtun and Gautesen, 2007), whereas immature technologies are locked out, perhaps for an extended period of time (unless the quota is raised to a very high level).[26] This means that it applies to early mass markets, for which more mature technologies are available (see Figure 5). It needs to be emphasized that this is not an unintended consequence of this regulatory framework. It is rather a basic principle that investment should be made”… at a rate that is economically justified and not prematurely” (Swedish Ministry of Industry, 2002, s. 38). *It is, thus, deliberately designed to avoid forming nursing and bridging markets*.

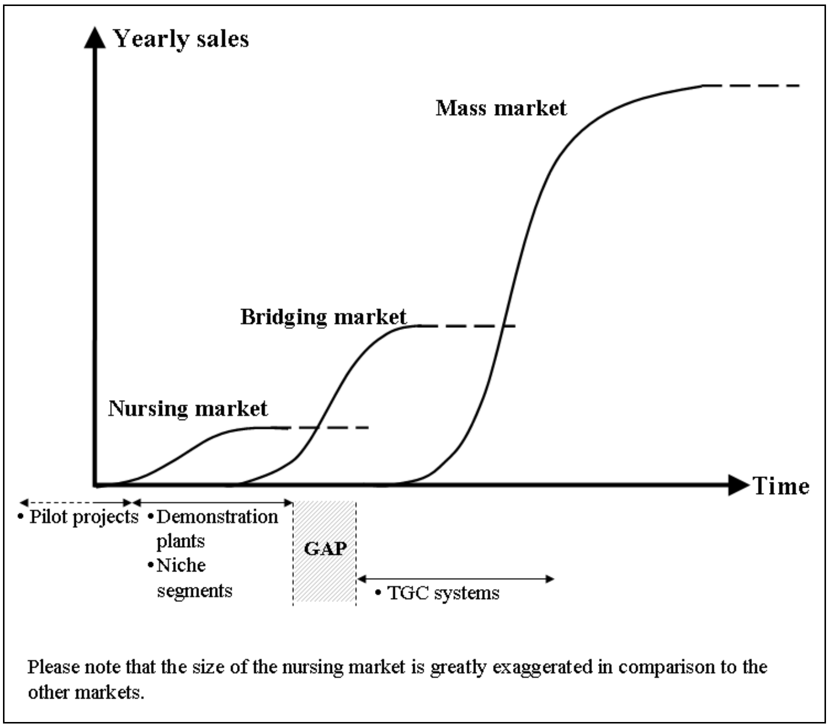

Figure 5: Three types of markets and the relevance of TGC for their evolution.

This implies, on the one hand, that TGC schemes like the Swedish one may improve the conditions for a further development of relatively mature technologies as these begin to exploit mass markets. One example could be conventional technology for biomass based combined heat and power plants. This is a mature technology dominated by a handful of suppliers of boilers (e.g. AEE, Metso Power and Foster Wheeler). In such a field, a market

[26] An alternative to having a uniform TGC system would be to introduce different technology “bands” . Technologies with different cost levels could then be supported, just as in the case of feed-in tariffs.

expansion driven by the Swedish TGC scheme may induce further technical change. Thus, some learning of this kind may have been generated by the Swedish TGC scheme.[27] Given that the Swedish market is only a fraction of the global, the impact can not, however, be expected to be more than marginal. Moreover, this learning is largely external to Sweden as we do not have any larger wind turbine manufacturers and only one strong supplier of CHP equipment (Metso Power, which originates from two Swedish firms: Götaverken and Generator).

On the other hand, the focus on relatively mature technologies implies that uniform TGC systems cannot be expected to drive technical change in the first vital few decades in a new technology's life. Nor can it be expected to contribute to generating an early and supportive home base for Swedish capital goods firms in new technology fields. A "gap" has, therefore, been created in the Swedish policy package between R&D, pilot projects/occasional demonstration plant and the more mass market flavoured TGC scheme (see Figure 5). This gap means that Swedish policy does not provide a space for learning, where firms establish themselves early in the capital goods industry and invest resources into technology and market development. A case at hand is the Swedish development of thin-film solar cells, in which the academic spin-off Solibro AB was forced to leave Sweden for Germany in order to get the investments needed to build up a production plant (see Box 1).

BOX 1: *The case of Solibro AB*

Research on thin film solar cells started at The Royal Institute of Technology (KTH) in Stockholm in the 1980s. Key researchers moved to Uppsala University in the 1990s and participated in forming Ångström Solar Centre in 1996. A Plan for commercialisation of the world class R&D results involved spinning off a firm and seeking a Swedish industrial consortium that could add competence and capital to it. Yet, interest among Swedish actors was very low. After an intervention from the highest political level, a new discussion took place with leading Swedish industrialists (Malmqvist, 2000). A spin-off company, Solibro AB, was founded in 2000 by four researchers and a small amount of capital was supplied by a group of firms and a pension fund. Although development money was supplied by the Swedish Energy Agency, there was little interest by these firms to become suppliers of solar cells (Bengtsson, 2007). When funding was subsequently sought for up-scaling of the production technology and to build a manufacturing plant, Solibro AB eventually had to enter into a joint venture with the German firm Q-cells, forming Solibro GmbH. Solibro GmbH invested SEK 500 million in a plant and started production of cells in May 2008 (Alpman, 2008). As expected, the TGC system did not provide this firm with a home market, nor was there a home market that could induce the small group of firms that had already put a little bit of money into Solibro to invest in up-scaling the technology.

Sources: Alpman (2008), Bengtsson (2007) and Malmqvist (2000).

[27] A possible example is the Finish firm Wärtsilä's development of module based smaller CHP plants that reduce the scale sensitivity of power production (Jacobsson, 2008). This development was initiated in Finland and did not come as a response to the Swedish TGC scheme. However, the currently growing Swedish market has enabled Wärtsilä to gain additional experiences.

To conclude, without an early home market, Swedish capital goods firms are placed in a disadvantageous position vis-à-vis firms operating in countries with an early home market. This hampers the ability of Swedish firms to exploit the fruits of academic research, lead the process of technical change and take part in the rapidly expanding global market for renewable energy technologies. The Government has, therefore, perhaps unconsciously, played down the importance of fostering a Swedish capital goods industry and, consequently, made sure that the Swedish contribution to technical change and cost reduction will be small. *The Swedish TGC scheme cannot, therefore, be expected to fulfill the goal of contributing to technical change and cost reduction more than in a marginal way*.

4. Concluding discussion and some lessons learned

The purpose of this paper was to assess the performance of the Swedish TGC system in relation to expectations at the EU and Swedish policy levels, contributing to the European-level debate on the suitability of different types of schemes for the support of renewable electricity production. On the positive side, we concluded that the Swedish TGC system passed on the criteria of effectiveness and short term social cost efficiency. The TGC scheme has strongly contributed to a considerable change in the interest among firms to invest in biomass CHP and wind turbines as compared with the 1990s and the expansion of 'green' power to reach the first set target has been achieved at a low social cost.

On the negative side, we first noted that the cost for the consumers have so far greatly exceeded expectations; certificate prices and payments by electricity consumers have been far higher than expected, including substantial transactions costs. The main problems of the Swedish TGC system, in relation to expectations, are, however, related to the equity and technology development assessment criteria. We will elaborate on these and conclude with some lessons for policy.

4.1 Equity: the Swedish TGC system as a rent-generating 'machine'

Our estimates show that the Swedish TGC system has so far (2003-2008) generated rents to already profitable production units that amount to up to 11 billion SEK (79 % of the payments to the producers). These rents may increase to in the order of 23 billion SEK (59 % of the payments to producers) in the period 2003-2014, if the certificate price reaches 300 SEK. These very substantial rents, thus, follow from the decision to include already existing plants in the scheme. However, Verbruggen (2009) similarly suggests that 64 percent of the turnover of the equivalent Flanders system was constituted by excess profits, which indicates that rent-generation is not only a peculiarity of the Swedish TGC system.

As and when more expensive technologies have to be introduced in the system to meet the quota, further rents will be generated. Whilst the size of these are very uncertain, a calculation assuming a certificate price of SEK 500 by 2015 (reflecting the higher cost of e.g. off-shore wind power) could generate rents to previous investments in lower-cost production (on-shore wind and biomass CHP) in the period 2003-2014 of in the order of 19 billion SEK. Hence, for the existing plants at the start of the scheme and for those constructed up to 2014, the combined rents may amount to up to 42 billion SEK in the period 2003-2030. Assuming that no further sources of rents emerge, this would constitute a share of rents of up to 28 percent of the payments to producers. The TGC scheme is, indeed, a rent-generating machine!

These rents mean that the TGC scheme does not pass on the Swedish Government criteria of equity, avoiding overcompensation (to the power industry) and securing the legitimacy of the system, a point also emphasised by the European Commission (1999).[28] The big risk of these rents is, however, not that it threatens the legitimacy of the TGC scheme but that of renewable energy technology (obstructing the Government's ambition of securing a "third leg" in the Swedish power balance (in addition to nuclear and hydro power).

This feature ought not to come as a surprise. Type II rents are inherent in economic activities with marginal cost pricing and an upward sloping cost curve.[29] In addition, the ease of expanding output in already existing plants and the difficulties involved in designing the system to avoid overcompensation to power producers (Type I rents) was well described by the government committee of inquiry investigating the future TGC system in Sweden:

> "According to our opinion, the expansion in existing plants can occur soon after the introduction of the certificate system. It can come about with moderate or zero investments and small changeover efforts, e.g. through fuel conversion and increased amount of full-load hours." (SOU 2001:77, p. 74)
>
> "One of the difficulties is to construct the model so that existing plants will not be strongly overcompensated, with consequent excess costs for the consumers, as new investments will be given adequate cost coverage." (SOU 2001:77, p. 158).

[28] See also Söderholm (2008) for a discussion about the legitimacy challenges involved designing international tradable certificate markets.

[29] Theoretically, it is straightforward to show that social cost-effectiveness will not imply minimum impacts on the electricity consumer collective. The empirical analysis in section in section 3 demonstrated the orders of magnitude involved. It is, therefore, surprising that policy makers expected to minimise both social costs and consumer costs.

Interestingly, however, *we have in no official Swedish documents before or after the system was launched come across any calculations of neither potential nor actual rents*. This is, indeed, remarkable as it is obviously so that a very large share of the turnover of the scheme is wasted in the sense that it could have been used to fund a much higher level of investments in renewable energy technology.

4.2 Technology development: the gap in Swedish energy policy

The expectations on the TGC system to drive technical change neglects two fundamental features of the development of new technologies: a) longer term learning processes as a source of innovations and cost reductions and b) the role of the capital goods industry in these learning processes. The Swedish TGC system was, thus, deliberately designed so as *not* to stimulate early nursing and bridging markets, where those that invest in new energy technologies, as well as those capital goods firms who develop such technologies, are rewarded. On the contrary, our analysis shows that the substantial rents in the TGC system are reaped by investors in relatively mature technologies. These rents are, therefore, not – as appropriate in a market economy – the reward to successful entrepreneurs developing and applying relatively immature technologies.

A "gap" has, therefore, been created in the Swedish policy package between R&D, pilot projects/occasional demonstration plant and the TGC scheme. This gap points to a very large opportunity cost of the massive rents generated within the Swedish TGC scheme. These rents are the result of legislation and can, therefore, be regarded as a tax that is collected by industry – i.e. a hidden industrial subsidy. Of course, these rents may be used in a socially desirable way, but this is beyond the control of the Parliament that voted for the TGC scheme.

If we compare the rents with the size of measures put into more direct use for the purpose of furthering technology development in the energy field, a simple example is the annual Swedish public expenditure on energy R&D, which was SEK 875 million in 2008. Of greater importance is the lack of funds for larger demonstration programmes to fill the gap referred to above, for instance for off shore wind, wave, tidal and solar power as well as alternative fuels, such as gasified biomass. Recently, the government decided to scale up the funding to such plants and allocated SEK 875 million to a demonstration programme for renewable fuel and power. This is, so far at least, seen as a one-off program where the funding will be dispersed over 3-4 years. With access to the rents generated within the TGC system (perhaps SEK 23 billion in the period 2003-2014 only, see Table 3), RD&D funding could thus have been greatly increased, improving the opportunities for Swedish capital goods firms to contribute to the process of technical change.

4.3 Lessons learned for policy

Given this outcome of the Swedish TGC system, it is fair to say that such a scheme should be selected if the overriding concern is to minimize short term social costs of reaching a certain goal (e.g. fulfil an EU Directive) with a high degree of predictability. However, it is clearly uninformed to have an ambition that a TGC system of this kind should also drive technical change, keep consumer costs down and be equitable.

There are, thus, trade-offs involved in selecting a support system. Choosing a TGC scheme implies that the significance of rents and the importance of driving technical change/creating opportunities for industrial development would need to be played down dramatically. Of course, as the TGC scheme fares poorly with respect to driving technical change, this option is only available if the capital goods can be imported from countries with regulatory frameworks that drive technical change and the formation of capital goods industries.[30] Other alternatives should be sought if a) society recognises the value, and even the necessity, of industrial development and technical change and b) it is deemed important to keep rents down and by implication, maximise the production of renewable power in relation to the support given to industry.

These trade-offs were, however, not identified neither by the European Commission (1999) nor in various policy documents in Sweden prior to the selection of a TGC scheme. Indeed, they were obscured by arguments claiming that TGC would lead to both static efficiency (in terms of both social and consumer cost) and technical change. In this expectation, there is a striking similarity between the European Commission (1999) and various Swedish government propositions and reports. This suggests that there were shared beliefs between EU and Swedish policy makers, as argued by Åstrand (2005).

Indeed, Sweden had in the 1990s, encouraged by the European Commission, gone through a massive deregulation of e.g. the power and telecommunication sectors and it is not far-fetched to believe that the same thinking was now applied to renewable power (cf. European

[30] For an analysis of the implications of having a pan-EU TGC system and the necessity to foster a European capital goods sector in this field, please see Jacobsson et al. (2009).

Commission, 1999). However, it is a vast difference between deregulating mature industries (where it is likely that the twin benefits of cost reduction and innovation will be achieved) and building up new industries. It is also a huge difference between the initial ambition of the Swedish TGC scheme to add only 10 TWh by 2010 and the long-term goal to build a 'third leg' in the Swedish power balance, which would imply a capacity to supply about 50 TWh. Assessing the Swedish TGC scheme in that light would unavoidably have led to an identification of the issue of rents early on. Policy makers must thus appreciate these kinds of differences and design policies accordingly. 'One size fits all' policies must be avoided!

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Appendices

Appendix A: Estimation of number of certificates in the system 2003-2030

TABLE A1: *Quota, prognosis of renewable electricity production and estimation of number of electricity certificates in Sweden 2003-2030*

	(A) QUOTA	(B) TOTAL RENEWABLE ELECTRICITY	(C) NEW PRODUCTION	(D) ACCUMULATED NEW RENEWABLE ELECTRICITY	(E) PHASE-OUT	(F) MILLION CERTIFICATES IN SYSTEM[a]		
		(TWh)	(TWh)	(TWh)	(TWh)	Total	Existing production (6.5 TWh)	"Easily accessible" production (10.8 TWh)
2003	0.07	7.16	0.64	0.64		7.16	6,50	7,16
2004	0.08	7.85	0.71	1.35		7.87	6,50	7,85
2005	0.10	10.15	2.30	3.65		10.17	6,50	10,15
2006	0.13	12.39	2.24	5.89		12.41	6,50	10,80
2007	0.15	15.46	3.07	8.96		15.48	6,50	10,80
2008	0.16	16.80	1.34	10.30		16.82	6,50	10,80
2009	0.17	17.65	0.85	11.15		17.67	6,50	10,80
2010	0.18	18.72	1.07	12.22		18.74	6,50	10,80
2011	0.16	18.28	-0.46	11.76	1.88	16.40	4,62	8,92
2012	0.16	18.86	0.60	12.36		17.00	4,62	8,92
2013	0.09	19.46	0.60	12.96	8.21	9.39	0	0,71
2014	0.09	20.06	0.60	13.56		9.99	0	0,71
2015	0.10	22.05	1.99	15.55	1.61	10.37	0	0
2016	0.11	23.52	1.47	17.02		11.84	0	0
2017	0.11	23.61	0.09	17.11		11.93	0	0
2018	0.11	23.70	0.09	17.20		12.02	0	0
2019	0.11	23.79	0.09	17.29		12.11	0	0
2020	0.11	23.88	0.09	17.38		12.20	0	0
2021	0.11	23.97	0.09	17.47		12.29	0	0
2022	0.11	24.06	0.09	17.56		12.38	0	0
2023	0.09	24.15	0.09	17.65	1.35	11.12	0	0
2024	0.09	24.24	0.09	17.74	0.45	10.76	0	0
2025	0.08	24.33	0.09	17.83	0.85	10.00	0	0
2026	0.08	24.42	0.09	17.92	0.90	9.19	0	0
2027	0.07	24.51	0.09	18.01	1.00	8.28	0	0
2028	0.06	24.60	0.09	18.10	1.00	7.37	0	0
2029	0.05	24.70	0.10	18.20	1.00	6.47	0	0
2030	0.04	24.79	0.09	18.29	1.00	5.56	0	0
Total						322.99	22.24	40.86

[a] We assume that existing/"easily accessible" production will be phased out according to Column E.

Source: Elaboration on Swedish Government (2006a)

Appendix B: Estimation of rents 2003-2030

TABLE B1: *Estimation of Type I rents 2003-2008*

	(A) ANNULLED CERTIFICATES[b] (1,000 CERTIFICATES)			(B) OVERCOMPENSATION PER CERTIFICATE[c] (SEK)		(C) TYPE I RENTS (MSEK)	
	(A1) Total	(A2) 6.5 TWh	(A3) 6.5-10.8 TWh	(B1) ≤ 6.5 TWh	(B2) >6.5 TW	(C1) 6.5 TWh[d]	(C2) 10.8 TWh[e]
2003[a]	3,490	3,490	0	201	161	701	701
2004	7,832	6,500	1,332	231	191	1,504	1,759
2005	10,120	6,500	3,620	216	176	1,407	2,046
2006	12,391	6,500	4,300	191	151	1,242	1,892
2007	14,464	6,500	4,300	195	155	1,270	1,938
2008	15,322	6,500	4,300	247	207	1,607	2,498
Total	63,619	35,990	17,852			7,731	10,834

[a] May-December

[b] We assume that certificates corresponding to existing/"easily accessible" production have been the first to be annulled. A2 and A3, thus, equal 6.5 TWh and (10.8-6.5 TWh) of production except when the total number of annulled certificates (A1) is lower than 6.5 TWh/10.8 TWh.

[c] Average certificate price minus extra cost of 1 MWh of renewable electricity production in each case. The extra cost is assumed to be 0 SEK/MWh for existing production (0-6.5 TWh) and 40 SEK/certificate for the remaining "easily accessible" production (up to 10.8 TWh).

[d] (Column A2 x Column B1) / 1,000

[e] ((Column A2 x Column B1) + (Column A3 x Column B2)) / 1,000

Source: Elaboration on Svenska Kraftnät (2008, 2009) (annulled certificates and average certificate prices)

TABLE B2: *Estimation of Type I rents 2009-2030*

		(A) NUMBER OF CERTIFICATES ANNULLED 2009-2014 (1,000 CERTIFICATES)			(B) EXTRA COST PER CERTIFICATE (SEK)	(C) TYPE I RENTS 2009-2030 (MSEK) AT DIFFERENT AVERAGE CERTIFICATE PRICES (IN SEK)[c]		
		New[a]	Saved[b]	Total		200	250	300
Existing production	0-6.5 TWh	22,240	420	22,660	0	4,532	5,665	6,798
"Easily accessible" production	0-6.5 TWh	22,240	420	22,660	0	4,532	5,665	6,798
	6.5-10.8 TWh	18,620	3,648	22,268	40	3,563	4,676	5,790
	Total	*40,860*	*4,068*	*44,928*		*8,095*	*10,341*	*12,588*

[a] See Appendix Table A1, Columns F2 and F3.

[b] We assume that certificates issued in 2003-2008 to existing/"easily accessible" production, but were not annulled in this period will be annulled in the period of 2009-2014. In calculating the number of saved certificates related to existing/"easily accessible" production, we have assumed that certificates corresponding to this production have been the first to be annulled.

[c] Column Ci = Column A3 x (certificate price Ci - Column B) / 1,000 (i = 1-3) (except for row "Total", which is the sum of the previous two rows)

TABLE B3: *Estimated Type II rents 2015-2030 for investments made in 2003-2014*

(A) FIRST OPERATION YEAR	(B) END YEAR	(C) NUMBER OF YEAR WITH HIGHER PRICE[a]	(D) ELECTRICITY SUPPLY[b] (GWH)	(E) COST-COVERING CERTIFICATE PRICE (SEK)	(F) PRODUCER SURPLUS AT CERTIFICATE PRICE 500 SEK (SEK)	(G) RENTS 2015-2030 (MSEK)[c]
2003	2017	3	127	206	294	112
2004	2018	4	210	206	294	247
2005	2019	5	328	206	294	482
2006	2020	6	243	206	294	429
2007	2021	7	733	206	294	1,509
2008	2022	8	729	300	200	1,167
2009	2023	9	808	300	200	1,455
2010	2024	10	895	300	200	1,791
2011	2025	11	992	300	200	2,182
2012	2026	12	1,099	300	200	2,637
2013	2027	13	1,217	300	200	3,165
2014	2028	14	1,349	300	200	3,777
TOTAL						18,952

[a] Plants are allowed to receive certificates for 15 years. This number is the number of years that plants built in a certain year will receive certificates in the period of 2015-2030 (with higher prices in this estimate). For example, plants built in 2003 will be included in the system 2003-2017 and will, thus, only receive certificates with higher prices for three years.

[b] 2003-2007: Elaboration on Swedish Energy Agency (2008) (Table 5.1 and Table 6) and Swedish Energy Agency (2007b) (Table 5); 2008-2014: Instead of using the official prognosis (see Appendix Table A.1, Column C), we have here assumed an exponential increase from the amount of new renewable electricity production in 2007 (6.76 TWh) to the target quantity of 17 TWh new production by 2016. The reason for this is that the real new production in 2007 was 2.2 TWh lower than the official prognosis and this need to be compensated for within the period of 2008-2016 in order to fulfill the quota. We have chosen to use an exponential development since it seems more realistic to assume that yearly investments will increase over the years rather than be very high initially and decrease over time (as the official prognosis suggests).

[c] Column G = (Column C x Column D x Column F)/1,000

TABLE B4: *Estimated total rents (Type I + Type II) 2003-2030 for investments made in 2003-2014 (with certificate price 300 SEK 2009-2014 and 500 SEK 2015-2030)*

	TYPE I RENTS[a]			TYPE II RENTS[b]	TOTAL RENTS
	2003-2008	2009-2014	SUM	2015-2030	2003-2030
6.5 TWH EXISTING PRODUCTION	7,731	6,798	14,529	18,952	33,481
10.8 TWH "EASILY ACCESSIBLE "PRODUCTION	10,834	12,588	23,422	18,952	42,374

[a] See Appendix Tables B1 and B2.

[b] See Appendix Table B3.

Appendix C: Estimate of payments to producers 2003-2030 and the share of these that are rents

TABLE C1: *Payments to producers 2003-2008 (real) and 2009-2014/2030 (estimate based on three different certificate prices for the period of 2009-2014 and one certificate price 2015-2030)*

	(A) ANNULLED CERTIFICATES (1,000 CERTIFICATES)		(B) CERTIFICATE PRICE (SEK)			(C) PAYMENTS TO PRODUCERS[C] (MSEK)			(D) ACCUMULATED PAYMENTS (MSEK)		
	(A1) Real[a]	(A2) Prognosis[b]	B1	B2	B3	C1	C2	C3	C1	C2	C3
2003	3,490			201			701			701	
2004	7,832			231			1,812			2,513	
2005	10,120			216			2,191			4,704	
2006	12,391			191			2,368			7,072	
2007	14,464			195			2,826			9,898	
2008	15,322	*15,193* [d]		247			3,788			13,686	
2009		16,001	200	250	300	3,200	4,000	4,800	16,886	17,686	18,486
2010		16,897	200	250	300	3,379	4,224	5,069	20,266	21,910	23,555
2011		16,009	200	250	300	3,202	4,002	4,803	23,467	25,913	28,358
2012		17,107	200	250	300	3,421	4,277	5,132	26,889	30,189	33,490
2013		10,115	200	250	300	2,023	2,529	3,034	28,912	32,718	36,525
2014		11,464	200	250	300	2,293	2,866	3,439	*31,205*	*35,584*	*39,964*
2015		11,348			500			5,674			45,638
2016		13,004			500			6,502			52,140
2017		14,498			500			7,249			59,389
2018		16,154			500			8,077			67,466
2019		16,244			500			8,122			75,588
2020		16,334			500			8,167			83,755
2021		16,424			500			8,212			91,967
2022		16,514			500			8,257			100,224
2023		15,254			500			7,627			107,851
2024		14,894			500			7,447			115,298
2025		14,134			500			7,067			122,364
2026		13,324			500			6,662			129,026
2027		12,414			500			6,207			135,233
2028		11,504			500			5,752			140,985
2029		10,604			500			5,302			146,287
2030		9,694			500			4,847			151,134

[a] Source: Svenska Kraftnät (2008, 2009)

[b] See Appendix Table B3, note [b].

[c] Column C = Column A1 x Column B (2003-2008); Column A2 x Column B1-B3 (2009-2014/2030)

[d] The difference between this estimate and the actual value for 2008 is considered to be small enough to disregard. We thus use the actual number of annulled certificates in 2008 in order to get comparable values with previous calculations.

TABLE C2: *Type I rents vs. total payments to producers 2003-2014*

		ASSUMED CERTIFICATE PRICE 2009-2014 (SEK)		
		200	250	300
ACCUMULATED PAYMENTS TO PRODUCERS 2003-2014 (MSEK)[a]		31,205	35,584	39,694
TYPE I RENT 2003-2014 (MSEK)[b] (Share of accumulated payments to producers)	6.5 TWh existing production	12,263 (39%)	13,396 (38%)	14,529 (36%)
	10.8 TWh existing or "easily accessible" production	18,929 (61%)	21,175 (60%)	23,422 (59%)

[a] See Appendix Table C1, Columns D1-D3, row 2014.

[b] See Appendix Tables B1 and B2.

TABLE C3: *Total rents (Type I + II) vs. total payments to producers 2003-2030, assuming a certificate price of 300 SEK 2009-2014 and 500 SEK 2015-2030.*

ACCUMULATED PAYMENTS TO PRODUCERS 2003-2030 (MSEK)[a]		151,134
RENTS 2003-2030 (MSEK)[b] (Share of accumulated payments to producers)	6.5 TWh existing production	33,481 (22%)
	10.8 TWh existing or "easily accessible" production	42,374 (28%)

[a] See Appendix Table C1, Column D3, row 2030.

[b] See Appendix Table B4.