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Pulling effects of district heating plants on the adoption and spread of willow plantations for biomass: The power plant in Enköping (Sweden)

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ABSTRACT

The development of the willow cultivation for bioenergy in the municipality of Enköping was analysed, with special attention to the changes in the capacity and use of wood fuels of the municipality's combined power and heat plant, during the period 1986–2005. The evolution is compared with the municipality of Örebro, in Central Sweden, a pioneer in the use of willow plantations. The study was performed including the geographical location of all the plantations and owners using a GIS platform, and a methodology based on *n*-sigmoidal curves was proposed to study the adoption curves of willow before and after the changes in the district heating plant. The results show significant enlargements of the area planted with willow observed after the enlargement of the plant in 1994; most of these new plantations being located within 30 km from the plant. The method applied seems to be suited to explain the effects in adoption of the power plant. Around 28% of the growers seem to be attributed to the effects of the plant. The results of this study provide empirical evidence of the effect of the district heating systems on the development and promotion of willow plantations. The methodology provided can be valuable in understanding the success or failure of the energy programmes, from the farmer's perspective, and can aid policy makers in achieving their goals.

1. Introduction

Research on the expansion and adoption of new energy crops by farmers plays a key role in the successful development and implementation of the energy plans. The achievement of the energetic goals set during the end of the 90s by the European Union [1] and in more recent years (i.e. the Biomass Action Plan [2], the Energy Policy for Europe [3] and the objectives of the directive on the promotion of the use of energy from renewable sources [4]) will require a remarkable enlargement of the area cultivated by ligno-cellulosic energy crops in Europe. Currently, however, Sweden is the only country that has promoted short rotation forestry to a commercial level, and can offer empirical experience and data regarding willows as energy crops.

During the 1990s, the area of willow plantations for bioenergy was expanded in Sweden, reaching a total of 16,000 ha planted [5], and additionally a market for willow chips was successfully established [6]. This rapid progression was due to a combination of policy incentives, creative research and innovation in the field, and the demand for wood fuels by the district heating systems. On one hand, the Swedish agricultural reform led to low grain prices and offered compensation for set-aside land as well as specific subsidies for willow plantations. In addition to these incentives, the taxation on fossil fuels during the 1990s made biomass more competitive,

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which resulted in higher demand: the wood-fuel consumption by the district heating systems in Sweden increased from 3700 GWh in 1990–14,200 GWh in 2004 [7]. Altogether, the market for wood fuel is considerable, and during the last years, biomass from various origins constituted around a third of the total fuel consumption of the district heating systems in Sweden [6].

Although the main wood fuel of the district heating systems in Sweden was forest biomass, the district heating played a significant role in the expansion of the willow based energy systems. The positive green publicity of wood energy and the development of the infrastructure for the logistics and distribution of wood fuel from forest to the district heating plants benefits willow production, since it can use the already existing distribution chain. In addition, the existence of a district heating plant, with an increasing demand of biofuels, raises the confidence of the growers in the development of a market for willow chips [8]. Efficient district heating also reduces the risks taken by the farmer, which is fundamental in order to encourage farmers to increase their investments in willow plantations [9]. Finally, the enlargement of the wood fuel capacity of the district heating plants leads to an increment in the demand for wood fuel, and in some cases to the need to cultivate short rotation plantations in the nearby areas. Therefore the study of the interactions of the district heating plants and the willow plantations plays a central role in the promotion of willow cultivation as they act as a pulling factor in the development of the willow cultivation.

2. The Enköping heating system

To study these interactions, we have focused on the municipality of Enköping, in central-eastern Sweden, with around 20 000 inhabitants. Since the 1980s, the municipality of Enköping has been using biofuels for heat generation [9], and the use grew significantly when the main central energy plant was completed in 1994. In 1997, the last one of the oil-fired boilers at the main central boiler station was configured to burn wood pellets, and since then Enköping's district heating generation relies completely on biofuels, running at about 90% of efficiency [10].

Nowadays, there are three energy plants in the municipality [11]. The combined heat and power (CHP) plant belongs to ENA Kraft AB, supplying district heating to the central areas of the town, and electrical power to the trunk line network. The plant contains a forest fuel-fired steam boiler with capacity for 55 MW of heat and 24 MW of electricity production, in addition to a wood powder-fired boiler (22 MW) and two oil-fired boilers (combined power of 75 MW). There are two additional smaller plants in the municipality, the Stenvreten and the Tjädern plants, which were used before the main energy plant was completed. Nowadays both are used as back-up units in the event of breakdowns or maintenance of the main one [11].

Between 10% and 20% of the biofuels consumed by the power plant come from willow plantations [12]. In addition to willow chips, the plant uses bark, sawdust from the sawmill industry and forest residues. The average transport distance is estimated to be around 70 km. The energy plant also provides service to the willow growers of the area, and the ashes resulting from the combustion are mixed with equal amounts of dewatered digested sludge from the purification plant and are used as fertiliser on the willow plantations of the area [13]. Also, the municipality of Enköping has been a pioneer in the use of willow plantations as vegetation filters, planting 80 ha of willow for cleaning polluted water in 2000 [13].

The example of the Enköping CHP plant has received worldwide attention as a successful case of the use of short rotation crops to produce energy [14] and has been regarded as a study case of the efficient use of bioenergy [9,10,12]. We aim to study the effects of this new district heating plant on the local adoption of willow plantations. The study of the development of energy crops based on empirical data provides tools to develop strategies for the cultivation and promotion of short rotation crops.

3. Material, methods and hypotheses addressed

The methodology used for describing the adoption of willow plantations by local farmers in the area of Enköping is based on sigmoidal shapes. This approach was first proposed by theoretical studies on the adoption of new agriculture varieties, having its origins in the work of [15], and has been confirmed by later empirical evidence (a review of works using this approach can be found in Rubas [16]). In willow cultivation, as in any other new crop, only a few farmers are willing to invest in what is perceived as a high risk enterprise. However, as time passes, more farmers are convinced of the possible benefits of the innovation and decide to adopt it. Finally, the least risk-takers join and the maximum number of possible adopters in an area is reached.

For each spatial unit of aggregation can be defined an adoption ceiling. However, this adoption ceiling is not necessarily fixed, since as circumstances change, the number of adopters can keep increasing, raising the adoption ceiling. If the adoption ceiling of a system changes significantly during a period of logistic growth, a second period of logistic growth with a different carrying capacity can superimpose on the first growth pulse [17].

The assumption taken is that the number of willow farmers, and the area planted with willow in a specific area, can be defined by two types of factors. On one hand, factors linked to the local characteristics, which are more or less fixed, such as the farmers' attitude, the main land uses, the average productivity of the alternative cultivations and so forth. On the other hand, there are factors defined by a variable economic context, and are subject to the policy framework (i.e. subsidies for establishing willow cultivation) and changes in the market conditions (i.e. prices of willow chips, increments of the local demand). The policy framework is also acting upon the energy plants and the economic profitability of the willow plantations in general. Additional influences can come from local attitudes and development of business models adopted by both the energy plants and the local farmers.

The application of this approach for willow plantations in Sweden revealed, among others, the effects of the county demand of wood fuel on the willow adoption along time [18]. In this study we assume that there is a first population of willow adopters in the municipality of Enköping, starting during the early 1990s and mostly driven by the subsidies implemented in order to develop willow plantations. However, a second and more local population of willow adopters would start in parallel with the construction of the new power plant in Enköping, driven by the increasing demand for wood fuels, and the expectations of a secure market. This new population would overlap with the main one, and both would contribute to the expansion of the willow cultivation in the area. By this means, we present methodological tools to analyse and quantify the effects of the local demand for biomass. The applied method will offer interesting conclusions for policy makers, in order to promote these cultivations in different areas of the EU.

3.1. Data from willow farmers in Sweden

The data from the growers and their plantations were provided by Lantmännen Agroenergi AB (formerly known as Agrobränsle AB), which manages planting and are the administrators of the harvesting of willow plantations. The records included information regarding to the ownership as well as the year of establishment of the plantations. Data with inconsistent records or lacking information regarding the ownership of the plantations, the area planted or the location were excluded from the calculations. All plots were georeferenced to a 1 km precision. A new grower (adopter) was defined as a farmer planting willow for bioenergy for first time, and an experienced grower was defined as a farmer that has planted willow at least once in the previous years. Their number was calculated from the dataset by comparing the dates of the plantations grouped by ownership.

The data regarding the wood fuel consumption by the district heating systems was provided by Svensk Fjärrvärme AB. The data was expressed in GWh, aggregated by municipalities. This dataset did not cover the whole period studied: the years 1986–1991, 2002 and 2005 were missing, and their figures were interpolated. The estimations of agricultural land and land uses were based on the Image & Corine Land Cover 2000 (I&CLC2000) vector map for Sweden [19], using 250 m resolution.

3.2. Modelling the pulling effects

For the descriptive analyses, the data were grouped according to municipalities and years. The analysis compared the municipalities of Enköping with the municipality of Örebro, one of the pioneer municipalities in the development of willow plantations, used as a reference. In every municipality was calculated the evolution of the number of new growers per year, the total area planted by the new and experienced growers, as well as their aggregates.

In order to examine the effects of the district heating plant in the nearby areas, all plantations in a radius of 100 km around Enköping were also examined. The linear distances to the nearest wood-fuelled heating plants in the area were calculated for each plantation, in order to discriminate the effect of the demand of the Enköping power plant from other power plants in the area. The heating plants of Eskilstuna, Hallstammar, Sala, Stockholm, Uppsala, and Surahammar were considered. The plantations whose closest distance was Enköping's plant were then aggregated in rings every 5 km starting at the power plant (Fig. 1). The area planted with willow within every ring was weighted according to the total agricultural land inside the ring, and calculated for each year for the period 1986–2005.

To analyse the evolution in the adoption of willow, an n-sigmoidal model was applied for the municipalities of Enköping, Uppsala and Örebro. The models were restricted to the period 1986 (start of the plantations) to 1996 (reduction of the subsidies).

The general model can be defined as:

$$N_t = \sum_{i=1}^{n} \frac{K_i}{1 + e^{-\frac{\ln(81)}{a_i}(t-b_i)}} + \varepsilon_t \quad (1)$$

where N_t is the aggregated number of adopters in year t, K_i is the adoption ceiling of the i sigmoidal, a_i is the growth interval (the interval of time in which the logistic varies from 10% to 90% of K) of the i sigmoidal and b_i is the midpoint of the i sigmoidal, in both cases expressed in years. Two options were

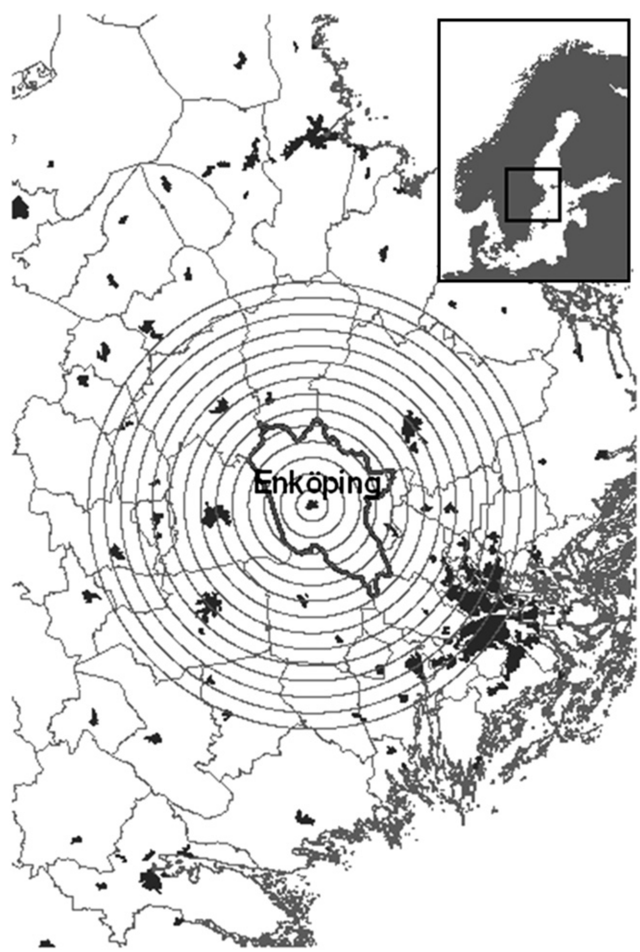

Fig. 1 – Location of the municipality of Enköping, in Central-Eastern Sweden. Buffer areas around the city centre were calculated every 5 km in straight line from the municipality's main power plant.

considered, with $n = 1$ (single sigmoidal) and $n = 2$ (bi-sigmoidal model).

The curve fitting was carried out using loglet lab software v1.1.4 [20]. The confidence intervals for the parameters are estimated using a bootstrap approach based on Monte Carlo methods [21]. In order to estimate the performance of the models and the accuracy of the estimations, the absolute and relative bias and RMSEs were calculated for all the models proposed.

4. Results

The evolution of both the area planted with willow and the number of willow growers is presented in Fig. 2. In general, an increment is noticeable in the municipality of Enköping after 1994, in both area and number of growers. This increment is also noticed in the neighbouring municipalities of Uppsala and Eskilstuna. On the other hand, Örebro (the municipality used as reference) does not show the same increment after 1994, and the evolution seems to be of a single sigmoidal type. Around 63% of the willow area in the municipality of Enköping was planted after 1994, compared to 24% Örebro. These increments are parallel to the changes in the wood fuel demand of the district heating plant of the municipalities studied (Fig. 3). The enlargement of the Enköping power plant is translated into an important increment in the wood-fuel consumption after 1994. On the other hand, Örebro does not reveal any increments after 1994, and the wood-fuel consumption slightly declines after that year.

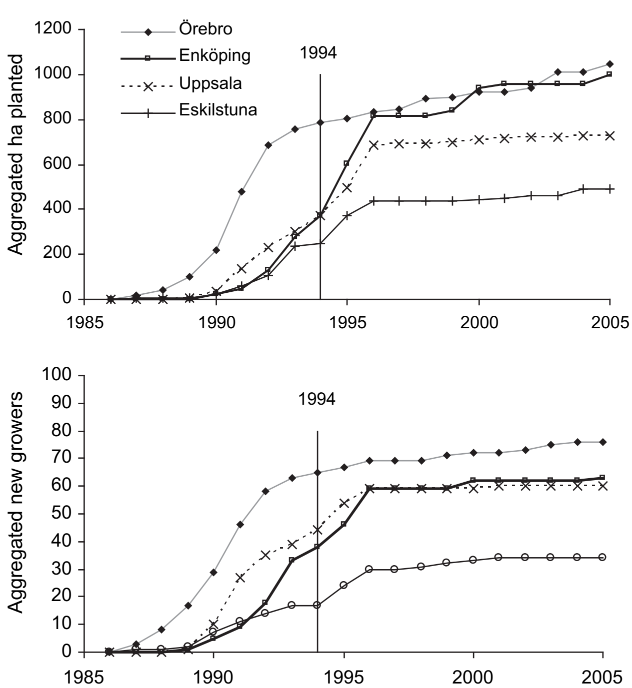

Fig. 2 – Aggregated area planted with willow (above) and absolute number of new growers (below) in the municipalities of Örebro, Enköping, and neighbouring municipalities Eskilstuna and Uppsala, during the period 1986–2005.

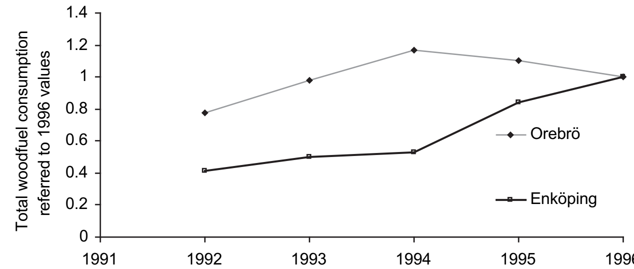

Fig. 3 – Wood fuel consumption referred to 1996 values, for the district heating systems of the municipalities of Enköping and Örebro, for the period 1992–1996.

The years 1995 and 1996 show a significant increment in the ratio (willow vs. total agric. land) of area planted around Enköping (Fig. 4). In 1995 the maximum ratio is of 0.31 ha planted of willow per 100 ha of agriculture land, slightly less to the peak of 1996, 0.33 ha planted per 100 ha of agriculture. In both cases, this maximum is registered in the first 20 km from the town centre.

Regarding the farmers, in the municipality of Enköping the area planted after 1994 is due mostly to new growers, especially in 1996. In clear opposition, in the case of Örebro, the enlargement of the area planted with willow is due mostly to experienced growers after 1991 (Fig. 5).

The n-sigmoidal models showed good fits for the evolution of the adoption in the municipalities studied. The bi-sigmoidal curves adapted well to the municipalities of Enköping and Uppsala. The ANOVA test proved significant differences when compared to the single sigmoidal alternative ($p < 0.000$). Also, the RMSE and bias indicators were significantly lower (Table 1). For the municipality of Örebro there were no significant differences between both alternatives, although smaller bias (both absolute and relative) were obtained using a single sigmoidal curve.

The ranges of the adoption ceiling (K) were broader in the case of Enköping. The midpoint of the first sigmoidal was in 1992 in Enköping, and in 1990 in Örebro. For the second sigmoidal, the midpoint was in 1996 for Enköping. The graphical performance of the best fitted curves is shown in Fig. 6. The original data is also presented linearized using the Fisher-Pry transform [22] based on the adoption ceiling calculated for every sigmoidal. According to these results, the population of growers attributed

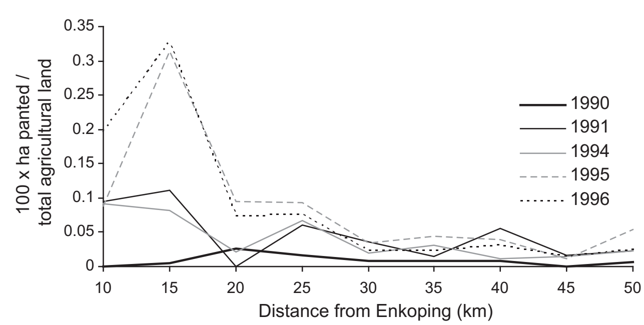

Fig. 4 – Ratio of annual area planted with willow for energy purposes per total available agricultural land in the areas surrounding Enköping's heating plant. The figures are aggregated every 5 km from the plant.

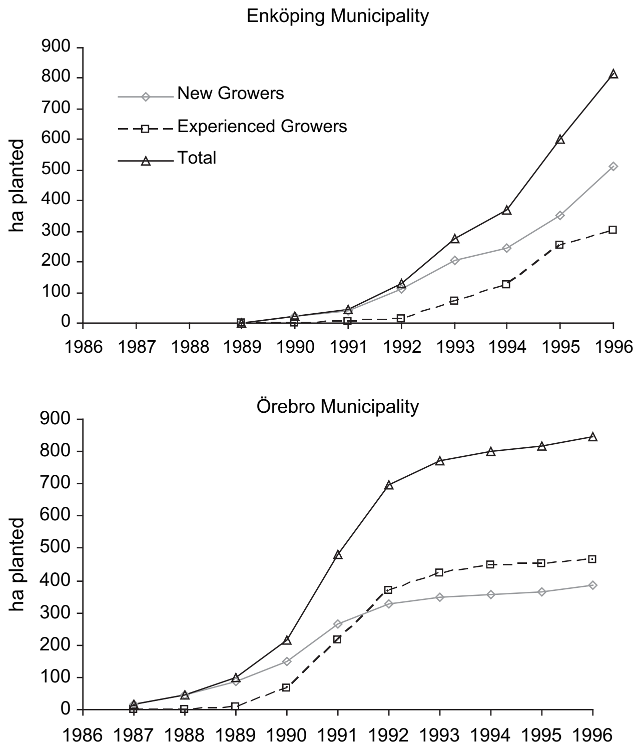

Fig. 5 – Aggregated area planted with willow in the municipalities of Enköping, and Örebro, for new growers and experienced growers, during the period 1986–1996.

to the effect of the power plant would be around 28% of the total number of growers for the period 1986–1996.

5. Discussion

This study focussed on the evolution of short rotation willow plantations in the municipality of Enköping and the nearby regions, and the effects of the municipality's wood-fuelled plant with the adoption and spread of willow cultivation in the area during the period 1986–2005. The data available for this study included almost extensive information about the areas planted, their location and the number of owners, although it must be taken into account that it did not include the absolute total number of willow plantations during the studied period, since some records lacked the geographical location of the farms or the specific year of the first plantation.

The municipality of Enköping was among the municipalities that enlarged or developed their wood fuel capacity for district heating during the 1990s, as a consequence of the increasing taxation on fossil fuels as a result of the Swedish energy policy. One of the main advantages that offers for this study is that the enlargement of the power plant was due some years before the reduction of the establishing subsidies for willow in Sweden in 1996 [6]. This allows the study of the possible effects on the willow cultivation, by observing changes in the evolution of the adoption of willow and area planted.

The case of the municipality of Örebro, on the other hand, can be used as a reference for a stable evolution of the number of willow planters and area cultivated with willow. In fact, Örebro was one of the first municipalities in Sweden where willow was planted to a significant extent [18,23], additionally it offers series of data of enough years to define a clear curve of adoption. In this municipality, the CHP was already converted to burn wood fuels in 1990 [24], before the introduction of establishment subsidies in 1991, and during the 1990s the wood fuel consumption for district heating was stable in general terms.

In both cases, the demand of wood fuels seems to be a driving factor behind the spread of the willow plantations, as it is in the developing of the bioenergy sector [25,26].

The combined heat and power plants have played a central role in the rapid expansion of bioenergy in Sweden [6]. During the 1990s, new wood-fuelled CHP systems were established in Sweden or were converted to use wood fuels [27], due principally to the taxation system. Since the existence of wood-fuelled plants in an area means an increasing demand of biofuels, this significantly affects the confidence of the farmers in the development of a market for their willow chips [8] and encourages farmers to invest in energy crops [9]. The

Table 1 – Estimates and intervals of confidence of the parameters of the models for Enköping, Uppsala and Örebro, and absolute and relative bias and RMSEs, for single sigmoidal and bi-sigmoidal models.

Parameter	Enköping 1st Sigmoidal	2nd Sigmoidal	Örebro Main Sigmoidal	
K	43.5	30	68.1	
	(37.4–49.6)	(10.2–58.8)	(67.1–69)	
a	1992.2	1996	1990.25	
	(1991.9–1992.5)	(1995.3–1996.6)	(1990.2–1990.3)	
b	3.9	4.6	4.65	
	(3.2–4.6)	(0.5–3.5)	(4.4–4.9)	
	Assuming single sigmoidal	Assuming bi-sigmoidal	Assuming single sigmoidal	Assuming bi-sigmoidal
bias	−0.620	0.023	−0.073	−0.111
bias %	−3.26%	0.12%	−0.19%	−0.29%
RMSE	3.695	0.981	0.888	0.874
RMSE %	19.4%	5.2%	2.3%	2.3%

The intervals of confidence of the estimations using the bootstrap method are given in parenthesis From Eq (1): K=Saturation point, a = midpoint, b = growth interval. Parameter K is expressed in aggregated number of willow growers and parameters a and b are expressed in years.

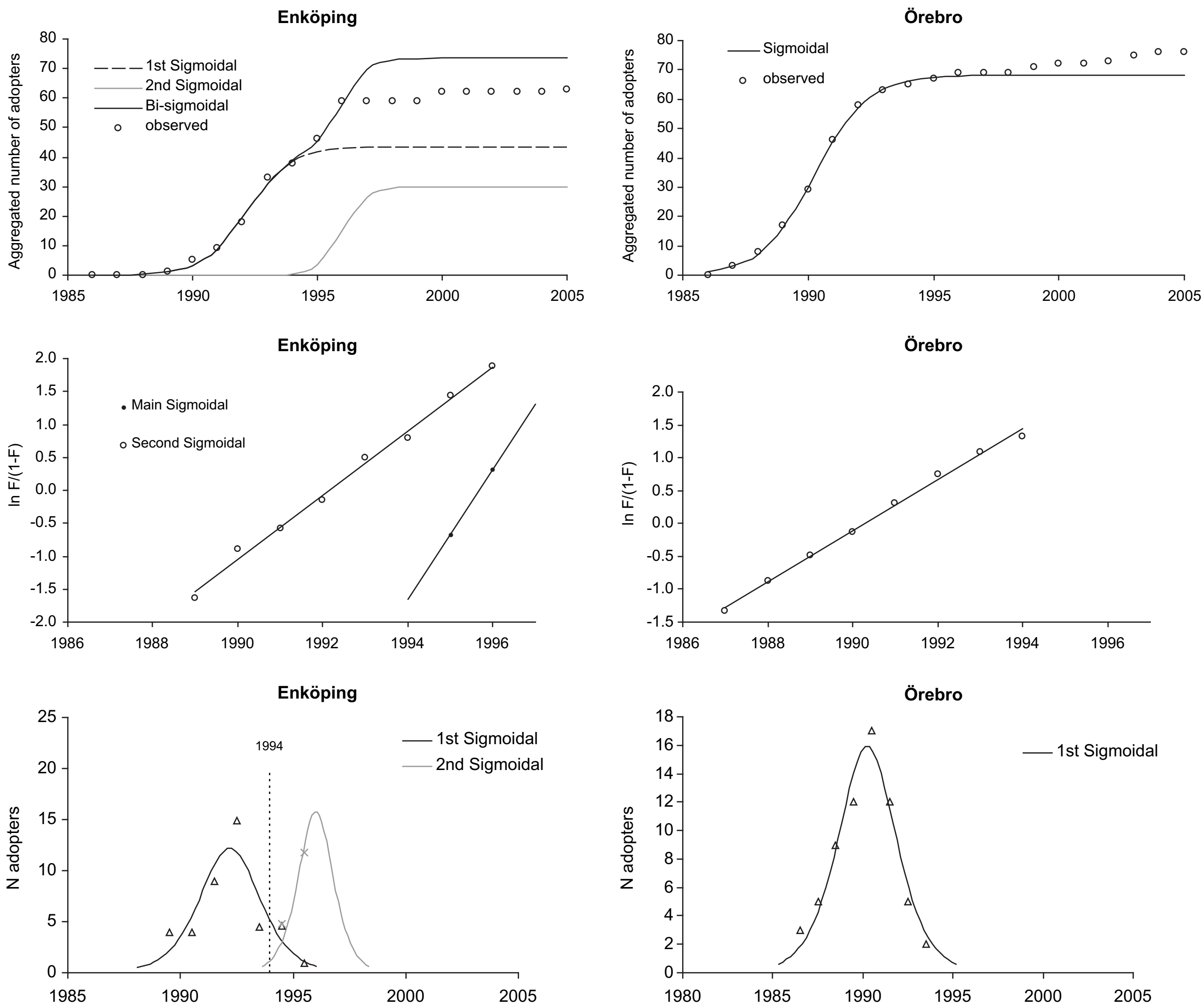

Fig. 6 – Observed aggregated number of new growers in the municipality of Enköping as compared to Örebro, and curves resulting of the model fitting. The curves are based on bi-sigmoidal models (Enköping) and single sigmoidal (Örebro). The models were adjusted only for the period 1986–1996. In the case of the bi-sigmoidal, the curves are presented aggregated and separated (up), with their respective Fisher-Pry transform version (middle), and the resulting distributions according to the curves modelled (bottom).

assurance of a market for willow chips is then acting as a pulling factor in the development of the willow cultivation in the area. In addition, the developing of a chain to supply forest biomass to the CHP also contributes to the development of the logistics associated to the economy of the willow chips.

Although the role of the demand of wood fuels is clear as a driving force to spread willow cultivation, most of the Swedish measures to promote willow cultivation were oriented towards the production of biomass, based mostly on establishing subsidies. No policies other than taxation on fossil fuels were specifically implemented in order to ensure a demand for energy crops [25]. In general, the demand for willow chips was left to market forces. However, during the 1990s oil and electricity prices were quite low to boost the demand for willow chips [6,25].

Among the proposed measures influencing demand, there is the establishment of long-term contracts between district heating companies and farmers, with the state as facilitator and sponsor [25]. This has been one of the characteristics of the model followed in Enköping, based on agreements between the main actors involved in the biomass supply and demand [13]. The mutual agreements include the obligation of the CHP plant to buy the harvested willow at the current market price, and the farmer is expected to sell their willow chips to the plant. In addition, the CHP was allowed to recycle the wood ash back to the plantation, and there are some other rather informal agreements working between the CHP and the sewage plant operators.

The effects of the increment in demand, and the securing of a market results in an increase in the area planted, as a result of actions by both the initial growers but also by new growers. In fact, the effects of the increase of biofuel capacity by the power plant seem to have attracted many new farmers, which were responsible for most of the new hectares planted after 1994. According to the results of this study, this new population of farmers accounts for about 35% of the total amount of farmers growing willow in 1996. These estimations, however, must be taken with precautions since there was only available a limited number of years to define a clear trend, and slight changes in the initial data can lead to large differences in the predicted saturation points. Further studies on more CHP plants in Sweden or other countries can confirm the applicability of this methodology, and the possible generalization of the conclusions of this study. In addition, questionnaires addressed to the farmers involved could be of great help in adding information to the motivations behind the farmer's decisions, and to establish a direct causality relations between the facts analysed. However, the method proposed can be applied as a confirmatory analysis, and invariably suggests an important effect in the number of willow farmers after 1994, which is reinforced by the fact that most of the new willow plantations were established close to the plant. The results also seem to confirm previous research on adoption [9,16,18,25].

To conclude, this study gives evidences of the effects of the district heating systems and the development and promotion of willow plantations, and it helps to analyse the effects of the market and the legislation on the development of the plantations. The evolution of the willow plantations in the area of Enköping provides interesting clues about the factors that affect the development and spread of energy cultivations. The general effects of taxation, encouraging the use of biofuels by the district energy systems, seem to have an important effect on the willow cultivation when working together with innovative business models of collaboration between energy actors and farmers. The analysis of the adoption of willow by the local farmers provides a valuable understanding of the success or failure of the energy programmes and aids policy makers in achieving their goals. This research can contribute to countries initiating energy programmes oriented to the development of energy plantations.

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