Chapter 30
Potentials and Employment Impacts of Advanced Energy Production from Forest Residues in Sparsely Populated Areas

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30.1 Why Devote a Megaproject to Biomass Utilization?

30.1.1 Background and Aims

Interest in converting biomass to energy efficiently and on a large scale has been evolving for decades. Initially this interest was driven by concerns over potential shortages of crude oil, but in recent years the ecological advantages of biomass as energy have become an even more important factor. Energy policy supports the use of bioenergy to the extent that the European Union, for example, has set a target that in every member country should be obtaining 10% of its energy supply from biomass by 2010 (Faaij, 2006). To fulfil this aim the governments of the member countries can subsidize bioenergy production by means of tax concessions and other measures (Ericsson, Huttunen, Nilsson, & Svenningsson, 2004; Hakkila, 2006). Due to its extensive geographical coverage, this target will gradually lead to the implementation of megaprojects concerned with biomass use. A large amount of biomass will be needed, as the annual energy consumption per capita for the 453 million citizens of the European Union is 3.7 tonnes of oil equivalent and the current proportion of bioenergy is 3.9% (Wright, 2006: 708).

Technology, taxes, subsidies and R&D funding, as well as the development of emissions trading and the relatively high and fluctuating prices of fossil fuels, are the major factors that will affect how the use of bioenergy and the related industries will develop during the next 10 years. Bioenergy is already able to compete well with fossil fuels in some instances, particularly where industrial or other residues can be utilized, hence avoiding certain waste disposal problems, and it is clear that increasing the use of bioenergy will have favourable effects not only on the economy and the environment, but also on development in biomass-producing regions.

The increasing interest in bioenergy produced from forests has arisen from the facts that specially-grown energy crops such as tree plantations and oil plants

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can have a negative carbon balance (Pimentel, 2003; Tilman, Hill, & Lehman, 2006) and they take up land that could otherwise be used for food production. The open questions regarding the sustainability of specialized energy systems have increased interest in forest residues as a source of biomass, as also have expectations that the latter could improve rural employment (Hyttinen, Niskanen, Ottitsch, Tykkyläinen, & Väyrynen, 2002: 4–6).

The aim of this article is to investigate the impacts of the large-scale production of bioenergy from forest residues on regional incomes and employment and seek answers to the question of its potential for compensating for the power and heat generated by fossil fuels. It will cover the production of energy by combustion, the production of pellets, the refining of pyrolysis oil and the production of diesel fuel by Fischer-Tropsch synthesis. We will concentrate our analysis on the income and employment effects of these alternative technologies because job creation is generally an important argument for promoting bioenergy in a rural environment (Domac, Richards, & Risovic, 2005).

The employment effects will be calculated by means of an input-output model into which the production functions of new, hypothetical bioenergy industries are inserted, with the provision that bioenergy production should be limited by the constraints of the regionally available sources of forest residues. Thus, the analytical method used here is similar to that of Gan and Smith (2007) but differs from the business-based assessment of Thornley, Rogers, and Huang (2008). The empirical data were collected from North Karelia, a sparsely populated border region of Finland, representing a relatively remote area in the coniferous zone where the forest sector has been a significant employer for more than a century (on the definition of the forest sector, see Hyttinen et al. (2002: 4, 13–14). Although the calculations used here are case and region-specific, the results give a general picture of the potential for exploiting bioenergy in similar regions.

30.1.2 Benefits of Bioenergy Utilization

The advanced production of energy from forest biomass creates several benefits that have been objects of interest among researchers in recent years. These can be classified into two categories: environmental and socio-economic benefits, both of which may be either direct or indirect. The environmental benefits include the fact that careful collection of forest residues could reduce the diffusion of plant diseases and insect damage. Bioenergy production could also benefit forest management by offering opportunities for thinning, intermediate cuttings and stand rehabilitation (Manley & Richardson, 1995).

The local and regional socio-economic benefits of bioenergy depend very much on the social and institutional conditions in the area. In developed but restructuring rural economies, new jobs and economic returns are important benefits of the use of biomass for energy production, while the effects on the distribution of welfare, gender issues and self-reliance are seen as important in developing countries due to the different technological and institutional context (Borsboom, Hektor, McCallum,

& Remedio, 2002; Domac et al., 2005). In the current phase of regional development in many sparsely populated European areas, economic stimuli are welcomed in rural settings (Okkonen, 2008; Tykkyläinen & Lehtonen, 2008; Whitley, Zervos, Timmer, & Butera, 2004). Investments in bioenergy can improve the efficiency of use of rural resources such as infrastructure, land, labor and machines, and can offer increased flexibility in fuel supplies and improved energy security. From the viewpoint of regional development, the production of bioenergy is important as it can set up energy and production systems across rural regions with dispersed populations (Johansson, Kisch, & Mirata, 2005; Mirata, Nilsson, & Kuisma, 2005).

30.1.3 Bioenergy Production Requirements

Units generating bioenergy from forest residues require a suitable business environment for this purpose. This is an emerging aspect of the production chain in the forest sector, where the main value is added in forestry and in the production of sawn timber, boards, pulp and paper (Hyttinen et al., 2002: 4, 13–14). While the focus in new forms of energy production is usually on the establishment of new production systems, the provision of efficient and advanced technology and the granting of tax relief and subsidies while production is in its infancy, the large-scale utilization of forest residues are bound up not only with current local production chains and their multiplicative effects, but also with forest management practices and infrastructure.

The utilization of forest residues requires skilled harvesting practices and efficient technology. Firstly, their procurement requires an efficient forest management system that includes a final felling at the end of the lifespan of the forest that allows collection of the stumps and root wood, as these constitute about 30–40% of the total forest residue potential. Large scale bioenergy production associated with large scale wood-processing industries means the use of resources on a mega scale, especially if the system is implemented to produce substantial amounts of electricity, heat and fuels. Secondly, infrastructural improvements, such as a dense forest road network, enable the forest residues to be transported from the stand to the roadside at low cost and enlarge the area over which the procurement of residues can be cost-efficient. Transportation costs are central to this activity, as about 30–40% of the procurement costs come from transportation within the stand and from the stand to the power plant or refinery (Asikainen, Sikanen, & Laitila, 2004).

The satisfaction of these two requirements is greatly dependent on earlier forest resource utilization practices. In countries like Finland and Sweden, the procurement of forest residues is integrated with harvesting cycles, the stages of harvesting and regeneration and the synergetic use of machinery and logistics. Without the historically efficient use of forest resources the large-scale utilization of forest residues would not be possible, or at least it would require a new widespread infrastructure, including roads, skills, machinery and supporting business activities. It is this fact, for example, that makes it unlikely that countries with poor infrastructure such as Russia will be able to make efficient use of its forest resources for advanced bioenergy production in the short term.

Forestry is an areal mode of production that requires the deployment of labor and machinery wherever wood is to be procured. In the Finnish case the ownership of forest land is divided between private owners (60%), companies (9%), local authorities, parishes and communities (6%) and the state (26%) (*Finnish Statistical Yearbook of Forestry*, 2007), and procurement takes place on an open market. Thus energy production has to compete for the purchase of biomass with other uses of forests and their timber, including conservation and recreation. Consequently, our scenarios are contingent on the functioning of the markets as well as on technology and infrastructure.

30.2 Resources, Regional Modeling and Spatial Economics

30.2.1 The Potential for Forest Residues in North Karelia

The potential availability of forest residues for combustion and fuel production is highly dependent on the behavior forest owners, cutting practices and the production structure of the forest industries. Logging in North Karelia remains below the regionally determined objectives, and forest residues are a form of biomass which is of little value to the traditional forest industries but constitutes a suitable raw material for the production of renewable energy. For a forest owner, the sale of residues for energy production does not bring much benefit, as the price is a fraction of that obtainable for roundwood. If forest residues cannot be utilized for bioenergy, they are usually left on the forest floor to decompose.

The most common forest management practice is the periodic cover silviculture, where an even-aged forest is harvested by means of two thinnings and the growth of the trees at the end of rotation period ends in a single final felling. This practice allows the collecting of forest residues in connection with cutting. The residues from the thinning operations consist of undersized, low-quality wood and those from the final felling mainly of tops, branches, stumps, root wood and undersized pulp wood. Hence, the sale of residues is linked to cuttings and forest management.

The volume of forest residues available in North Karelia was estimated for the present purposes from the 2006 inventory data produced by the Finnish Forest Research Institute (Table 30.1). The maximum sustainable cut defines the highest constant availability of roundwood, but still lies below the annual growth, which is over 6 million m^3in North Karelia (*Finnish Statistical Yearbook of Forestry*, 2006). In the average plan the cut is set at 4.4 million m^3 and is calculated as the mean of the annual cuts in North Karelia over the period 2000–2005.

The utilization of forest residues has to take into account nutrient losses and changes in biodiversity (Richardson, Björheden, Hakkila, Lowe, & Smith, 2002). It is generally recommended that no more than 2/3 of the residues should be removed, and that, if possible, stands of specific ecological value should be excluded. In our calculations the utilization of forest residues would be limited to 70% of the total accumulation of residues in the region, even though nutrient losses can be

Table 30.1 Forest residues by cutting alternatives in North Karelia

Cutting scenario	Biomass	Gg/a	1,000 m^3/a	GWh/a
Maximum sustainable cutting	Tops, branches and undersized	344	795	1,863
	Roots and stumps	261	603	1,414
Average cutting (2000–2005)	Tops, branches and undersized	246	568	1,332
	Roots and stumps	201	464	1,089
Use in 2006	Forest residues	80	191	460

Source: Finnish Forest Research Institute (2008)

compensated for by returning the ashes after combustion. Intake can be tailored locally according to the soil requirements. In addition the current use of residues is lower the potential total. After these reductions the power generation industries will have about 787,600 m^3 (with the maximum sustainable cut) or 531,400 m^3 (with the average cut) of forest residues left to be used annually.

30.2.2 Regional Impacts of Forest Residue Utilization

The regional input-output model for North Karelia is constructed from the relevant input-output statistics (Statistics Finland, 2006). An input-output model is an application of the neo-classical theory of general equilibrium to the empirical analysis of the interdependence between economic sectors, such as industries, consumption and exports, and compensations for households and imports. It was originally developed to analyze the connections between different industries within a national economy (Leontief, 1966: 134), and is a useful tool for showing the structure of the economy in terms of the flows of goods and services and for analyzing the impacts of changes in final demand. The input–output model applied here takes as an initial assumption that industrial outputs are determined by the final demand as linear functions of inputs from other industries, labor, capital and imports. The model is written as

$$x = (I - A)^{-1} y \tag{30.1}$$

where the term A is an $n \times n$ matrix of input coefficients for n industries, $(I - A)^{-1}$ is known as the Leontief inverse and $B = (I - A)^{-1}$ whereupon the coefficients b_{ij} represent the direct and indirect requirements of industry i per unit of final demand for the output of industry j. The vector y is the final demand for the output of each industry and x is the column vector of gross outputs for each industry.

This basic model was augmented in order to be more comprehensive than the traditional basic model by closing it with respect to households. This extension assumes that changes in exports from North Karelia would alter salaries, wages and capital incomes in the region and adjust regional consumption as a fixed ratio of the gross output of each industry. Hence both the inputs and household consumption were added to the model. In matrix terms, matrix A is amended by a new row and a new column for the household sector – the former showing how its output (labor and capital) serves as inputs to industries and the latter showing the distribution of its purchases (consumption) from the region's industries.

Household consumption was already included in the regional input-output table produced by Statistics Finland, and the household income row was calculated by taking the sum of wages, salaries and entrepreneur and capital incomes in each sector. Entrepreneur and capital incomes were estimated from the databases of Statistics Finland (2007c) and the Finnish Forest Research Institute (*Finnish Statistical Yearbook of Forestry*, 2006). Income transfers between households were estimated from the national accounts (Statistics Finland, 2007a). Data on income transfers from outside the households were obtained from the Social Insurance Institution of Finland (Laine, 2007). The process of constructing the household row followed earlier studies (c.f. Rimler, Kurttila, Pesonen, & Koljonen, 2000; Vatanen, 2001).

A row containing household incomes by industry of origin was added to the table, and the column showing private consumption was removed from the final demand and attached to the transaction table, thus setting up a new coefficient matrix. A new input coefficient matrix including the household consumption (h_c) and income coefficients (h_i) vectors and a scalar cross-term for transfers between households ($h_.$) was constituted as

$$\overline{A} = \begin{bmatrix} A & h_c \\ h_i & h_. \end{bmatrix} \tag{30.2}$$

and the augmented input–output model was thus

$$x = \left(I - \overline{A}\right)^{-1} y \tag{30.3}$$

The revised input coefficients for 2002 consist of 34 industries, including the households. The vectors for gross outputs and final demand in the region in 2006 were updated from the Regional Accounting (Statistics Finland, 2007b), while the input coefficients describe the economic structure as it was in 2002 (Statistics Finland, 2006). The employment data are from 2006 (Statistics Finland, 2007b).

Since no utilization of forest residues has emerged on a large scale in the region, it was difficult to acquire any exact data regarding modified or new energy production processes. For simplicity, we assume as far as the production of heat, electricity and wood pellets is concerned that apart from fuel, other inputs to this energy production would be similar to those required by the already existing electricity, steam and hot water supply industry. This may be a rough assumption, but the coefficients are the best-available estimates, because the current equipment is compatible with the burning of forest residues and the operation and maintenance costs would not be much different from those of existing plants (Gan & Smith, 2007). In the case of the refining of fast pyrolysis liquids and the Fischer-Tropsch diesel refining process, new coefficients were constructed on the basis of a survey of companies, technical information and coefficients describing the manufacture of refined petroleum products. As these industries do not yet exist commercially, the input coefficients and the coefficients for supplies to other industries may not be as reliable as those for industries already operating in the economy.

Employment impacts were analyzed with input–output multipliers. The Type II multipliers used measure direct, indirect and induced effects on the direct employment change (Miller & Blair, 1985: 116–136; The Scottish Government, 2008). The induced effects take into account the effects of household incomes and expenditure, and therefore yield higher employment effects than the Type I multiplier, which only accounts for direct and indirect changes. When interpreting the results of the multiplier analysis, it had to be considered that the multiplier effects associated with forestry are region-specific and can vary significantly according to the structure of the regional economy in question.

30.2.3 Spatial Properties of the Forest Sector in North Karelia

North Karelia represents a suitable testing ground as it is a forested border region where much emphasis has been placed on the development of wood energy and where a severe restructuring of the forest industries is anticipated on account of the global economic crisis and the introduction of Russian export tariffs on roundwood (Tykkyläinen & Lehtonen, 2008). The forest industries of North Karelia are dominated by large-scale mills which, with the exception of the Joensuu plywood mill, are located in sparsely populated areas outside the growing Joensuu travel-to-work area (Fig. 30.1). Although increases in productivity since the 1990 s have reduced employment in the forest sector, the existing production still serves as the backbone for many industrial communities and forest work provides employment for small companies in a more dispersed spatial setting (see Fig. 30.1). The incomes generated via the forest sector keep services and many other businesses alive in these areas, which would otherwise probably be no more than uninhabited wilderness.

The dispersed spatial structure of forestry and the forest industries is mainly a legacy from the earlier locational choices affected by logistics and the post-war goal of exploiting the under-utilized resources of the rural areas. The importance and value of the present spatial structure of forestry and the forest industries for the country's regional structure are based on the fact that these distant areas cannot attract new businesses as easily as the Joensuu travel-to-work area does. The continuing selective out-migration has deprived the rural areas of its younger generations and thereby distorted their population structure (Lehtonen & Tykkyläinen, 2009). The rural areas of North Karelia are peripheries not only geographically, but also in terms of socio-economic development and demography (Table 30.2).

In sparsely populated countries such as Finland and Sweden the forest sector has served as a backbone for the regional structure. According to previous studies the Russian export tariffs planned to be imposed in 2009 were estimated to create a pressure to cut down and restructure production in the forest industries to hundreds of jobs in North Karelia (see Tykkyläinen & Lehtonen, 2008). The employment

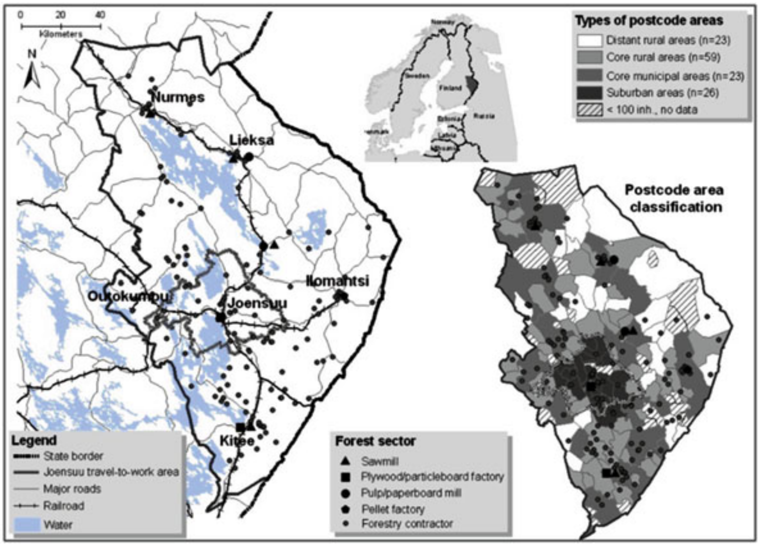

Fig. 30.1 North Karelia and its forest sector. The postcode areas are classified according to their socio-economic properties

Table 30.2 Forestry, the forest industries and socio-economic variables, by types of postcode area (see Fig. 30.1). Most of the information applies to 2005

Socio-economic characteristic	Core rural areas	Distant rural areas	Core municipal areas	Suburban areas
Forestry contractors	37	15	75	19
Large wood-processing companies	2	0	7	0
Median income (€)	11,821	10,245	12,588	16,268
Unemployment (%)	22	26	19	16
Proportion of persons over 65 years of age (%)	18	27	24	10
Persons working in primary production (%)	54.5	47.4	10.4	11.1
Persons working in secondary production (%)	17.1	9.9	22.5	26.7
Persons working in public services (%)	25.3	40.6	66.1	60.5
Distance from Joensuu (km)	66.2	82.8	65.6	16.1

Source: SuomiCD 2006 and State Provincial Office of Eastern Finland

opportunities in forestry would have increased by depending on the cutting scenario, but the reductions in employment in the forest industries otherwise would have diffused strongly through the whole regional economy, so that hundred or even thousands of jobs would have been in jeopardy depending on the levels of timber cuttings in the region and the market forecasts (ibid.). The post–September 15 global economic crisis is bringing about similar job losses, when mills are temporarily closed for many months. These results point to the need for new jobs and their potential importance. The production of bioenergy from residues would be one part of this development process and would ensure that more efficient use was made of the region's resources.

30.3 Potential Applications for Producing Energy

Various energy commodities can be produced from forest residues for use in power plants, buildings and vehicles. Residues can be burnt directly for heat and for the production of electricity, or they can be refined to compact solid fuels (e.g. pellets) or converted into gaseous or liquid fuels by technologies such as fast pyrolysis or Fischer-Tropsch synthesis. The following paragraphs present the technologies available for using and refining forest residues with a view to energy production, describing the principles which have been applied to determine the input levels and input coefficients of the power production and refining plants.

30.3.1 Forest Residues in Power Plants

Combustion is widely used on various scales to convert biomass to heat and/or electricity. Combustion plants are normally used to generate heat for district heating systems or in the case of larger units for generating electricity. The capacity of the latter plants usually varies from 1 MW to 200 MW, the largest bioenergy plant built in Finland, with a capacity of 500 MW, being designed to accept a variety of biomass fuels. Forest residues can also be used directly to replace fossil fuels in heat and electricity production.

The amount of electricity obtained from forest residues may be calculated as

$$E = \frac{1}{3,6}\,\eta\theta DV \tag{30.4}$$

where E is the amount of electricity generated (MWh), D is the density of the forest residues (t/m^{-1}) (from Hakkila, 1978), V is the volume of the forest residues (m^3), η is the efficiency of power conversion and θ is the energy content of the forest residues (GJ/t^{-1}) (from Impola, 2002). The empirical data on the coefficients of power plants were obtained from technical reports, applications for environmental permits and vectors applying to the energy sector in the input-output table for North Karelia.

30.3.2 Pellets from Forest Residues

Pellets are a wood-based fuel which has been obtained so far by drying and compressing residues from the mechanical wood-processing industries. They are often marketed as an environmentally friendly form of fuel and an alternative to fossil fuels, which are their main competitors. The greatest market potential for pellets has emerged predominantly from the replacement of oil-fired systems and electric heating in houses (Ericsson et al., 2004).

Since pellets are currently by-products of sawmills, their production in Finland is dependent on the production volumes of sawmills. Hence, to increase the production of pellets and to reduce the dependence of this on sawmilling, the producers will have to start using forest residues as raw materials. The main problems in processing forest residues to pellets are the high moisture level in the residues and the high transportation costs. A cost-efficient drying technology is necessary, but a significant amount of energy will still be needed in the drying process (Wolf, Vidlund, & Andersson, 2006). Some risks may arise from the fact that pellet producers are marginal players in the wood market.

The amount of pellets produced from forest residues may be calculated as

$$P = \frac{DV}{\omega} \tag{30.5}$$

where P is the amount of pellets produced (t) and ω is the compression ratio of pellets from residues (from Kallio & Kallio, 2004). D and V denote the same variables as in Equation (30.4). The data for constructing the input coefficients and supplies to other industries are based on technical reports regarding pellet production, annual reports and applications for environmental permits for pellet factories, together with regional input and output vectors depicting the manufacture of veneers, plywood and particle boards, panels and other wood products in North Karelia.

30.3.3 Pyrolysis Oil from Forest Residues

Fast pyrolysis is a high-temperature process in which the feedstock is rapidly heated to above 500°C in the absence of air, whereupon it vaporizes and condenses to a dark brown liquid which has a heating value of about half that of conventional fuel oil (Bridgwater & Peacocke, 2000). This technology, which maximizes the yield of liquid fuel from wood biomass, is often viewed as a very promising candidate for decentralized or small-scale power production, because the overall liquid yield may be about 75% by weight and it is just as easy to transport as heating oil (Chiaramonti, Oasmaa, & Solantausta, 2007).

The technology required for producing and using pyrolysis liquids is still under development. The main production problems originate from the fact that pyrolysis liquids are acidic, unstable, viscous liquids of heterogeneous quality that contain suspended solids and a large amount of chemically dissolved water (Chiaramonti et al., 2007). These properties have so far limited the range of biofuel applications because the high acidity causes erosion and corrosion in engines and turbines. The substitution of pyrolysis liquids for fuel oils in heat and power generation requires minor modifications to the installations (Czernik & Bridgwater, 2004), whereas the refining of pyrolysis liquids to a motor fuel, known as pyrolysis oil, is currently not profitable (Demirbas & Balat, 2006). At the moment no fast pyrolysis plants are in operation in Finland.

The amount of pyrolysis oil that can be extracted from forest residues may be determined by

$$Py = \frac{\mu DV}{\sigma} \tag{30.6}$$

where Py is the amount of pyrolysis oil produced (l), μ is the overall liquid yield from forest residues (t) (from Chiaramonti et al., 2007) and σ is the density of the pyrolysis oil (t/m^{-3}) (from Oasmaa, Peacocke, Gust, Meier, & Mc Lellan, 2005). Again D and V are as in Equation (30.4). The empirical data used here were based on an expert survey, from which the input coefficients were derived, and an earlier study (Laihanen et al., 2006).

30.3.4 Traffic Fuels Obtained from Forest Residues by the Fischer–Tropsch Pocess

Among the few options that exist for producing motor biofuels with commercial potential, the gasification of biomass to obtain Fischer–Tropsch (FT) diesel has received growing attention in recent years, as it offers a way of refining a clean and potentially carbon-neutral motor fuel that is directly usable in vehicles (Hamelinck, Faaij, den Uil, & Boerrigter, 2004).

The integration of wood biomass gasification with Fischer-Tropsch synthesis has not yet been demonstrated on a commercial scale, although commercial FT diesel production is at the pilot plant phase in Finland. The aim is to develop a commercially profitable refining process and hence to lower the risks for commercial investors. FT plants in Finland are planned to be joint ventures between the oil refining industry and the forest industries and the intention is to build them next to pulp and paper plants, to give greater efficiency in raw materials management and a measure of industrial synergy. The future of FT plants is highly dependent on the price of crude oil, because production costs for FT fuels are at the moment about 2–4 times higher than those for diesel refined from crude oil (Hamelinck et al., 2004).

The amount of FT diesel that can be produced from forest residues was determined by

$$FT = \lambda DV \tag{30.7}$$

where FT is the amount of FT diesel produced (l) and λ is the yield of FT diesel from forest residues (l/t) (from Huber, Iborra, & Corma, 2006). D and V are as in Equation (30.4). The empirical data are based on technical reports, earlier studies (Hamelinck & Faaij, 2002; Hamelinck et al., 2004), an expert survey and input-output flows in the oil refining industry in the Eastern Uusimaa region.

30.4 Impacts of Bioenergy Alternatives on Energy Production and Employment in North Karelia

30.4.1 Energy Generating Potential

Total energy consumption in North Karelia in 2004 was 10,390 GWh, of which 6,423 GWh (74.0%) was used in heating and power plants, 1,400 GWh (13.5%) in motor vehicles, 1,305 GWh (12.5%) for the direct heating of houses and 1,262 as electricity (*Pohjois-Karjalan bioenergiaohjelma 2015*, 2007). The proportion of regional energy commodities was already 69.8%, but North Karelia has the potential to become even more self-sufficient in energy if the remaining potential of the forest residues can be used for energy production.

Ignoring limiting factors such as energy prices, technological bottlenecks, labour constraints etc., forest residues and products refined from them have a considerable energy potential. The proportion of the total energy production obtained from forest residues is currently small, only 3.5%, but the energy content of the total volume of forest residues would be 3,277 GWh if the forests were harvested according to the maximum sustainable cutting plan, or 2,421 GWh with the average cutting plan, so that they could meet 31.5% or 23.3% of the total energy consumption, or 42.6% and 31.5% of the energy consumption of power plants, respectively (Table 30.3). Thus the energy content of forest residues alone would easily exceed the target of 10% set by the European Union for biomass energy supplies.

Although only 0.5% of detached houses in North Karelia were heated by pellets in 2004 (*Pohjois-Karjalan bioenergiaohjelma 2015*, 2007), they and firewood are expected to replace oil-fired systems and the electric heating of houses in the future, especially in sparsely populated areas, due to the increasing price of oil

Table 30.3 Annual energy potential of forest residues and their refined products under two harvesting plans

Type of consumption	Estimate for energy consumption 2004 (GWh)	Energy content potential (GWh)			Proportion of respective energy consumption (%)	
		Replacement biofuel	Maximum sustainable	Average	Maximum sustainable	Average
Total	10,390	Residues	3,277	2,421	31.5	23.3
Power plants*	7,685	Residues	3,277	2,421	42.6	31.5
Heavy and light fuel oils	1,367	Pellets	1,305	964	95.5	70.5
Heavy and light fuel oils	1,367	Pyrolysis oil	1,720	1,271	125.8	93.0
Traffic	1,400	FT diesel	405	283	28.9	20.2

Source: *Pohjois-Karjalan bioenergiaohjelma 2015* (2007)
*including imported electricity

and electricity. In spite of the small current use and demand, pellets produced from forest residues, could replace 96% of the energy content of the fuel oils currently consumed given the maximum cutting plan, or 71% with the average cutting plan (see Table 30.3). The energy content of the pellets would be equivalent to 12.5% or 9.3% of the region's total energy consumption, depending on the cutting plan adopted.

It is anticipated that fast pyrolysis oil will replace heavy and light fuel oils in the future. The consumption of fuel oil for heating and electricity production in 2004 was approximately 137 million l, corresponding to an energy content of 1,367 GWh. As the energy content of pyrolysis oil is about 46% of that of light fuel oil, about 210 million l of pyrolysis oil would have to be produced to obtain the corresponding amount of energy. Depending on the timber cutting plan, forest residues in North Karelia could yield approximately 265 million l of pyrolysis oil, equivalent to 126% of the energy content of the fuel oil consumed in 2004, or 195 million l, equivalent to 92% of the fuel oil consumed. It is assumed in these calculations that the overall liquid yield from dry biomass is 75% by weight (Chiaramonti et al. 2007), the rest consisting of natural moisture. Replacing fuel oils with fast pyrolysis oil would increase energy security in the region and its energy self-sufficiency by only 12 or 13 percentage points, measured as a proportion of total energy consumption in the region, depending on the cutting plan.

Vehicles consumed about 69.7 million l of petrol, 65.7 million l of diesel and 13.5 million l of light fuel oil in North Karelia in 2004 (*Pohjois*-Karjalan *bioenergiaohjelma 2015*, 2007). Our rough estimates of the potential for producing FT diesel from forest residues are based on the calculation made by the Energy Research Centre of the Netherlands that 1 metric tonne of biomass yields 120 l of FT diesel with the current technology (Huber et al. 2006). In the future, with improved technology, it is possible that about 210 l of FT diesel could be obtained per metric tonne of biomass (ibid.). Moreover, the FT process generates synthetic natural gas and electricity as by-products, but neither of these will be addressed here.

According to our calculation, it should be possible with the present technology to produce about 44 or 31 million l of FT diesel from forest residues, depending on the level of timber cutting, which would mean that North Karelia could meet over 29% or 21% of its requirement for motor fuels from forest residues alone. Due to the relatively inefficient nature of the FT conversion process, the majority of the energy content of residues would be consumed in the refining process or go into by-products, which could in part be used for other purposes. Future technological improvements could increase the yield of FT diesel to 51% or 35% of the region's motor fuel requirement. As a whole, pure FT diesel produced by a future technology, exclusive of by-products, could cover 6.8 and 4.7% of the total energy consumption in North Karelia. Thus implies, of course, that the significance of FT diesel alone would be small by comparison with the biomass energy target set by the European Union.

30.4.2 Employment Effects of Bioenergy Alternatives

30.4.2.1 Employment Effects of Forest Residue Potentials in Forestry

The profitable harvesting of forest residues and their treatment in order to be suitable for energy production are complex tasks. The process includes felling or extraction of the timber and its transportation and gathering into a heap in the forest, chipping or baling, transportation to a plant, handling, storing and drying and conveying on-site. The supply chains for chipped forest residues are usually divided into three categories according to the location of chipping, which can be done in the forest stand, beside the forest road or at a chipping terminal close to the place of use. The last option is based on a recent technique in which the material is compressed into cylindrical bales known as composite residue logs (Andersson et al., 2002), which can be transported with same equipment and trucks as roundwood. For the purposes of our model the labour input required for producing forest residues is derived from the study of Ahonen (2004), where chipping close to the place of use is identified as leading to the most cost-efficient supply chain (Table 30.4).

The procurement of forest residues generates both direct and indirect employment effects (Miller & Blair, 1985). If the maximum sustainable cutting plan is adopted the procurement of forest residues could employ from 243 to 814 persons in total, depending on the productivity of residue supply chain, while the average annual rate of cuttings would have a total employment effect of 164 to 552 persons (see Table 30.4). The results provide support for the notion that bioenergy provides ample employment opportunities and is therefore an effective tool for stimulating rural development.

Since the highly mechanized and developed systems used in forestry require fewer employees than the conventional method of cutting by a forest worker, the

Table 30.4 Potential effects on employment in forestry and transportation of exploiting forest residues in North Karelia, in person-years

			Direct employment effects		Induced employment effects		Total employment effects	
Supply chain	Raw material	MWh/ employee	Max	Avg	Max	Avg	Max	Avg
Composite residue logs	Forest residues	12,000	164	111	79	53	243	164
Chipping beside the forest road	Forest residues	6,153	320	217	154	104	474	321
Integrated harvesting	Small trees	5,714	344	234	166	112	510	346
Cutting by a forest worker	Small trees	3,582	550	373	264	179	814	552

Sources: Ahonen (2004; communications with experts)
Max – Maximum sustainable cuttings, *Avg* – Average cuttings

efficiency of the production chain which uses residue logs is more than 3 times higher than in the latter case (see Table 30.4). Technological development and rationalization have reduced the need for labor in forestry during the past decades, but now the utilization of forest residues could restore the number of employees to varying extents.

30.4.2.2 Employment Effects of Bioenergy Plants

Refining processes and power production are normally highly automated, and therefore the direct employment effects of conversion plants are relatively low. Interviews and earlier studies led to the outlining of five hypothetical conversion processes, the employment effects of which at the plant level were assessed by input-output analysis. The example plants were chosen with a view to the results being feasible for use in other regions, although the market values of the energy, infrastructure, actors and residue potentials involved would differ and could lead to different lines of development (Hillring, 2002). The calculated employment impacts quoted in Table 30.5 give at least rough estimates of the employment effects of the utilization of forest residues for energy directly and in refining plants of certain sizes. The results in terms of heat and power production are slightly lower than those reported in earlier studies (Borsboom et al., 2002) and show that the indirect impact in terms of job creation are much greater than the direct impact manifested the long regional bioenergy utilization chains (Thornley et al., 2008).

The employment opportunities generated by bioenergy vary with the energy product concerned and with the production volume. A small heat and power plant consuming 80,000 m^3 of forest residues per year would employ about 50 persons directly, via backward linkages to industries and via increased consumption by households in the region, whereas a large FT diesel plant accepting 850,000 m^3 of forest residues per year would employ about 400 persons altogether.

The induced and indirect employment effects are lowest in pellet factories, as the compressing of pellets is a short and simple production process linked directly to forestry (see Table 30.5), while the employment multipliers are highest in an FT diesel plant, due to the complex manufacturing process and linkages to supporting industries. Most of the induced and indirect employment opportunities, 40–60%, would be created in forestry and transportation, the exact amount being dependent on the type of bioenergy production. This is due to intensive links for all bioenergy projects with regional raw material inputs and logistic services. The impacts of bioenergy on other parts of the economy excluding forestry and transportation thus remain relatively small.

The design of the system in terms of the numbers and types of plants would indirectly affect the spatial distribution of employment opportunities and the possibilities for organizing units that could be synergistically connected with each other. The direct effects of large plants are concentrated in only a few localities, whereas small plants and their related forestry work would disseminate the effects much more widely geographically. The results indicate that the burning of forest residues

Table 30.5 Estimated potential employment effects of sample plants in North Karelia with a composite residue log supply chain

					Employment effects, person-years					
		Possible number of plants				Indirect and induced		Total		
Plant	Size	Max sust. Cut	Avg cut	Use of forest residues (m^3)	Direct	For. & trans.	Other	Sum	Per mill. (m^3)	Employment multiplier
Heat and power	35 MW	9	5	80,020	12	16	22	50	625	4.14
Heat and power	200 MW	2	1	404,800	60	76	113	249	615	4.14
Pellets	70,000 t/a	4	3	168,000	16	29	19	64	381	3.99
Pyrolysis oil	31,000 t/a	7	5	100,000	14	21	27	62	620	4.46
FT diesel	68,000 t/a	1	0	850,000	70	175	156	401	472	5.73

in power plants alone would generate relatively large regional employment impacts, whereas the other bioenergy industries would bring a smallish additional increase in employment, being labour-efficient production facilities situated at the end of the production chain, reflecting the results of Borsboom et al. (2002), for example. The employment multipliers for power plants are in the same range as in earlier studies (Gan & Smith, 2007).

30.4.2.3 Bioenergy Compensating for Jobs Lost in the Forest Industries

Given that considerable restructuring is expected to take place in the forest sector in North Karelia as the global economic recession downsizes production and if the Russian export tariffs on roundwood come into full effect (Tykkyläinen & Lehtonen, 2008), increased use of bioenergy could offset any resulting decline in employment in a longer run. The number of jobs for which the production of bioenergy could compensate would be dependent on the strategic choices made in national energy policy and in the extent of cutting in the region. It can also be assumed that various stakeholders might go further in the degree to which forest residues could be used to replace fossil fuels in heat and power generation in the existing power plants and in determining whether forest residues should be refined to pellets, pyrolysis oil or FT diesel in the new plants. It is expected that energy policy will be regulated in order to create an institutional environment that is suitable for increasing the use of regional resources.

If forest residues replace fossil fuels in heat and power generation, new jobs will be created in the forest residue supply chain but the possibilities for compensating for the jobs lost in mechanical and chemical wood-processing will be rather small. More beneficial to the restructuring industries from the viewpoint of job compensation would be to refine forest residues in integrated plants, such as refineries for fast pyrolysis liquids and Fischer-Tropsch diesel refineries, thereby creating new jobs at the high end of the production chains, in synergy with conventional wood-processing. The refining of forest residues to fuels would have additional impacts on the regional economy and could strengthen the overall competitiveness of the regional forest cluster. In addition to backward linkages to forestry and transportation and synergy with conventional forest industries, high-end plants would have effects via household consumption. The utilization of forest residues could yield about 490 jobs (in 9.8 plants of capacity 35 MW each) or 202 jobs (in 3.2 pellet plants of 70,000 t/a each) in North Karelia, covering between 9.7 and 65.3% of the total impact of the cessation of wood imports, depending on the timber-cutting scenario, given the most probable trend in market development.

30.5 Conclusions

The European Union target of increasing bioenergy will result in megaprojects with wide geographical impacts as technology is commercialized. Considerable amounts of the biomass contained in forest residues from the wooded areas of Europe could be exploited. According to our results for North Karelia, such means of energy production could prove to be worth developing, being linked to forest management and the synergetic advantages to be gained from connections with the forest industries.

The results show that forest residues could efficiently replace fossil fuels in power and district heating plants. The existing technology is suitable for plants of various sizes, and harvesting to produce composite residue logs, although leading to smaller employment effects, would be the most cost-effective way of producing the necessary raw materials. Either pellets or pyrolysis oil could replace the light and heavy fuel oils used in the heating of houses in the region and could be used in power plants to a substantial degree, pyrolysis oil being more similar in use to light oil than pellets, as it can be used as conventional heating oil, although with reservations as to its quality. The lowest energy content is obtained at present by Fischer-Tropsch synthesis, which is still under commercial development. The more complex the energy production process is, the more it can benefit from synergy with the conventional wood-processing industries. Moreover, as the procurement of raw materials is linked to the conventions of harvesting logs and pulp wood and to forest improvements, the spatial structure of this wood-based energy must co-exist with that of the conventional forest industries.

The use of forest residues does not need any specific harvesting rounds, as procurement can take place in connection with commercial cuttings for the conventional forest industries and with forest management. The employment impacts of the utilization of forest residues would be geographically widespread, as forest residues are available everywhere in the region, and therefore the utilization of forest residues could slow down the decline taking place in extensive rural areas by providing jobs and thereby helping to achieve a more vital demographic structure and better provision of services. In the transformation process affecting rural areas this pressure to develop bioenergy from forest resources should be seen as a normal pattern of evolution of the rural economy towards the more advanced utilization of local resources in a spatially omnipresent context.

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