# Optimisation of renewable forest fuel supply for more sustainable energy production of CHP plant in Finland

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**Abstract:** In this study, a potential fuel procurement planning model to sustainable energy production problems is considered. In Finland peat is commonly used as a fuel of energy plants. However, it is recently considered as non-renewable fuel. Therefore, we tested the model using Finnish Government's peat fuel tax policy decisions for sustainable energy production. However, due to the complex nature of the renewable fuel-procurement problem, the optimisation model cannot be directly used to solve the problem in a manner that is relevant to the forest industry. Therefore, this model was combined with an energy-production model to better describe the combinatorial complexity of energy flows. The properties of the model are discussed and we present the examples of how the model works based on real-world data and optional fuel procurement constraints. The results show peat and forest fuel relationships which indicate that meeting peat tax targets may not be adequate for the future success of renewable energy production, because energy production costs are increasing and forest fuel procurement targets can not be achieved.

**Keywords:** forest technology; forest fuel; fossil fuel; information logistics; peat; procurement logistics; wood-waste fuel; sustainable energy production; sustainable development.

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## 1 Introduction

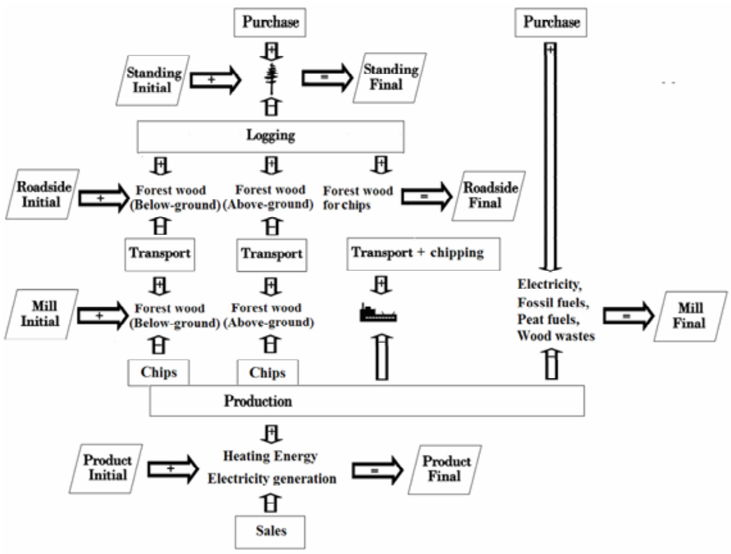
As part of the EUs response to climate change (Commission of European Communities, 2010), the Finnish Government has proposed that renewable energy production should account for 38% of the national total by 2020, and believes that the utilisation of forest fuels in energy production is a promising approach to accomplish this goal (Lund, 2007). In Finland, 13.5 million solid $m^3$ of wood biomass were used to generate 26 TWh of energy in 2009 (VTV, 2010). This was 35% from produced wood energy and 7% from produced total energy. In the year 2007 about 1.3% of the total energy consumption in Finland was covered by forest chips, of which 60% consisted of logging residues mostly collected from clear-cut areas (Peltola, 2008). There are currently targets to increase the annual use of forest chips to between 8 and 12 million solid $m^3$ per year (16 to 24 TWh) by 2015 (Finnish Ministry of Agriculture and Forestry, 2008). This target presupposes that the delivery of forest fuels to the energy-production industry can be doubled compared with the current delivery volume (6.2 million solid $m^3$). This will require significant changes in the logistics environment for fossil and peat fuels, but the changes are also complicated by the sequence-dependent procurement chains for forest fuels.

Finland expects to achieve its renewable energy target through the implementation of additional policy measures (Lund, 2007). The target will require incentive-based policies, including the use of carbon taxes that will increase the relative cost of non-renewable fuels, which will decrease consumption of fossil fuels by 2020 (Pöyry Management Consulting, 2010; VTV, 2010; Finnish Forest Research Institute, 2012). The policy measures also include taxes for heating fuels that will increase the costs of peat fuels. These taxes can increase consumption of forest wood biomass, because up to 20 million tones of it per year is left unused in Finland, mainly in the forests during forestry operations (Kuokkanen et al., 2009).

The forest fuel supply chain includes various forestry operations in Europe (Angus-Hankin et al., 1995; Cuchet et al., 2004; Cremer, 2009). The most common supply chain in Central Europe and Nordic countries is based on clear-cutting and comminuting the forest fuels at the roadside (Stampfer and Kanzian, 2006). In Scandinavia, the technical potential of residue procurement from clear-cuts is not fully exploited – for instance, logging residue is collected from ca. 25% of clear-cuts in privately owned forests in Finland (Peltola, 2008). There is also unused biomass potential in first and intermediate thinnings that offer quite a substantial reserve of harvestable biomass. This potential may not be fully exploitable without significant subsidies, since energy wood procurement is not necessarily profitable in thinnings at the current price levels (Ahtikoski et al., 2008; Petty and Kärhä, 2011). However, proper industrial energy wood and peat procurement could increase the profitability of energy wood procurement to satisfactory levels (Lund, 2007). In addition to forestry operations, logistics infrastructure and energy plants' operations are different in the EU region, and that therefore increase the alternatives of the operation methods used in the fuel procurement planning (Asikainen, 1995; Kanzian et al., 2009). Besides the manual short-term planning methods, computer supported optimisation methods offer fairly useful tools for long-term scheduling of the fuel procurement (Palander, 1998; Palander and Vesa, 2009).

The fuel procurement problem studied in the present paper is based on long-term production scheduling at a Finnish energy plant, where in addition to electricity, mixtures of forest, fossil, peat, and wood-waste fuels are used to produce energy (Figure 1). The general energy flow model shows that a wide mixture of fuel assortments can be maintained and production costs minimised, if orders from the energy plant (the customer) are directly transformed into procurement tasks, ideally without storing considerable volumes of fuels as a buffer at the plant or as roadside inventories. The challenge is to allocate the tasks in the procurement chains to supply sufficient fuels for energy production so that the release periods are obeyed, due periods met, and the total procurement and inventory cost is minimised. Because supply planning over a long period contains many different energy-fuel sources, global fossil fuel delivery chains, national peat fuel procurement chains, a company's flows of forest fuels, mill's wood-waste fuels and a district's electrical network, the scheduling is too difficult to handle manually.

**Figure 1** Dynamics of the energy-resource inventories for an energy plant: vertical arrows represent sequence-dependent effects for the system; horizontal arrows represent time-dependent effects for the system




Notes: Arrows labelled with + represent inputs to a component of the system; arrows labelled with – represent withdrawals from a component.

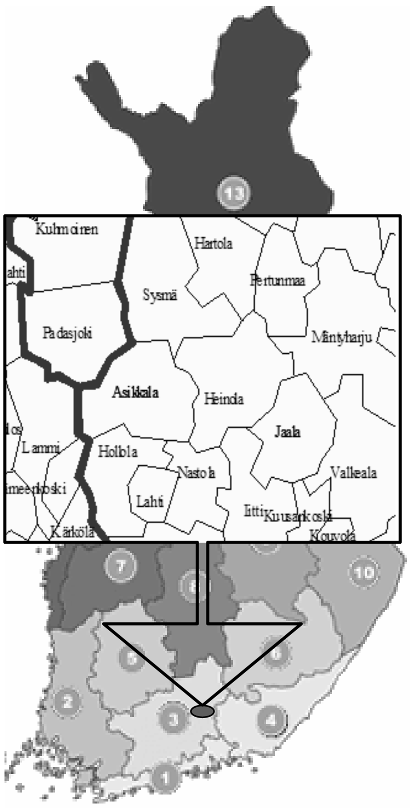
The overall objective of this paper was to discuss various aspects of the procurement problem of renewable and non-renewable fuels from both methodological and practical points of view. Instead of modelling only renewable energy-fuel flows, we address the combinatorial complexity of the problem by modelling the procurement relationships of peat and forest fuels, and solve the model using adaptive techniques to provide an updated and multi-objective procurement schedule. Our main focus is on the modelling, not on optimising the allocation of energy flows among multiple plants. Therefore, we only consider the case for a single energy plant.

## 2 Mathematical model and methods

### *2.1 Forest and peat fuel procurement problem*

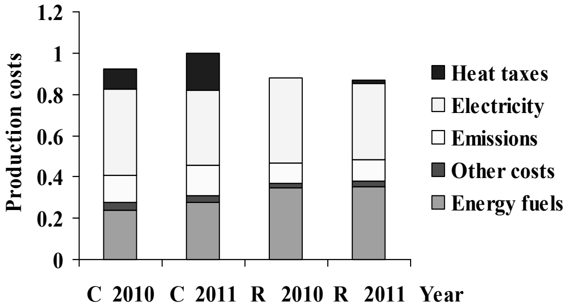
The research area comprised the operating areas of the Kymenlaakso and Etelä-Karjala provinces in southern Finland. The provinces were divided into nine procurement areas, which were used to represent the wood procurement teams around Stora Enso Fluting Mill in Heinola (Figure 2).

**Figure 2** Forest fuel procurement area locates in the southern Finland, which is described by the municipalities (teams) on the map




Finnish energy plants' general production costs are described in Figure 3 for a fossil production structure and a partial renewable production structure (Pöyry Management Consulting, 2010). In general fossil, peat, forest and wood-waste fuels are mixed together as energy fuels. In this example, price predictions are used in calculations for domestic fuels of plants. Further, price futures are used for year 2011 for costs of imported fuels. In addition to solid fuel costs, electricity costs are calculated for production by using market price of electricity.

**Figure 3** Energy plants' production costs for a fossil production and a partial renewable production: C = coal, 2011 = 1; R = peat + forest fuels (60% + 40%)




The energy production cost of peat was almost same or lower than costs of renewable fuels in 2010, if produced energy (MWh) is considered (Pöyry Management Consulting, 2010). During year 2011 the peat fuel tax decreased peat's competitive advantage because the energy production cost of peat was higher than the production cost of forest fuels. In 2013, the peat fuel tax is going to be increased from +1.9 € $MWh^{-1}$ to +3.9 € $MWh^{-1}$. Energy production costs of fuels determine the fuel mixture of energy plant. The most cost efficient fuel is used first and consumed more than other fuels. Fuel mixture may also change for technology rates or changes in emissions and electricity market prices. In this study we optimised energy production examples in which fuel mixtures included renewable fuels and were affected by the peat fuel taxes and the peat procurement rates. To illustrate the planning model, real-life examples of the model are presented here. The example described by A1 and B1 based on the data provided by the plant simulated by our model, and follows an old procurement structure that does not account for the peat fuel tax costs and the peat procurement rate constraints for increasing use of renewable forest fuels.

Other examples are similar, but include the peat tax cost that accounts for the greenhouse-effect gases released by the energy plant and that therefore increases the unit cost of the purchase function used in the model. In addition, examples include a peat procurement rate that accounts for the volumes of peat fuels procured and that therefore can also increase the cost of the fuel procurement functions used in the model. In our examples A2 and A3, the peat fuel tax costs were +1.9 € $MWh^{-1}$ and +3.9 € $MWh^{-1}$ and peat and forest fuel procurement volumes (MWh) were predicted in the supply chain that included a procurement rate change possibility from 0% to 100%.

## *2.2 Optimisation with multiple fuel procurement objectives*

There are three main objectives in constructing the optimal procurement schedule. First, the natural goal is to fulfil the plant's orders; that is, the group of procurement tasks should be completed on time. Second, the monetary goal is to minimise the total procurement cost. Third, the most important schedule property from a practical procurement perspective is that the setup times for the energy-fuel mixtures are minimised and an efficient delivery sequence is guaranteed. However, these objectives are contradictory in most cases. For example, in order to meet the confirmed due dates, it is often necessary to use more quality changes before release dates (change aspects of the energy-fuel mixture) than would otherwise be required. In practice, a short-term scheduling work involves a continuous balancing of the three goals. For example, quality changes can be compensated for by paying additional procurement costs. To support large-scale and long-term planning, energy-fuel flows, intermediate storage times, and transition times must be included in the optimisation methodology, because there is a sufficiently large supply area and a sufficiently long planning horizon that delivery deadlines are unlikely to be missed.

In this study procurement costs and a procurement rate of non-renewable fuels are included in the methodology. These are also crucial to an actual sustainable energy production with forest fuels, in which task *n* (a specific energy-fuel mixture) happens during period *t*. Procurement of energy fuels operates based on a monthly order-driven policy according to an energy production schedule. The energy-flow model of Palander and Vesa (2009) can be further developed and converted into software to solve this multi-objective task. In mathematical terms, the model can be described using the following equations:

$$\begin{aligned}\text{Minimise } Z = \Bigg[ & \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T}\left(cl_{ijt}L_{ijt} \times (1+(p/13))^{t}\right) \\ & + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T}\left(cyh_{ijkt}YH_{ijkt} \times (1+(p/13))^{t}\right) \\ & + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T}\left(cyh_{ijkt}YH_{ijkt} \times (1+(p/13))^{t}\right) \\ & + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{t=1}^{T}\left(cmh_{ikt}MH_{ikt} \times (1+(p/13))^{t}\right) \\ & + \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{t=1}^{T}\left(cp_{nkt}P_{nkt} \times (1+(p/13))^{t}\right) \\ & + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T}\left(X_{ijt} \times (1+(p/13))^{t}\right) \\ & + \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{t=1}^{T}\left(ce_{nkt}E_{nkt} \times (1+(p/13))^{t}\right) \\ & + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{t=1}^{T}\left(cm_{ikt}M_{ikt} \times (1+(p/13))^{t}\right) \Bigg] \end{aligned} \tag{1}$$

Subject to the following restrictions:

- Energy fuel demands

$$Y_{ijkt} + YH_{ijkt} + MH_{ikt} + M_{ikt-1} \leq D\max_{ikt} \tag{2}$$

$$Y_{ijkt} + YH_{ijkt} + MH_{ikt} + M_{ikt-1} \geq D\min_{ikt} \tag{3}$$

- Heating energy and electricity production

$$E_{nkt-1} + P_{nkt} - E_{nkt} \geq PT\min_{nk} \tag{4}$$

$$Y_{ijkt} + YH_{ijkt} + MH_{ikt} + M_{ikt-1} \geq E_k \quad (5)$$

- Dynamic equations

$$X_{ijt-1} - Y_{ijkt} - YH_{ijkt} + L_{ijt} = X_{ijt} \quad (6)$$

$$M_{ikt-1} + Y_{ijkt} - MH_{ikt} = M_{ikt} \quad (7)$$

$$E_{nkt-1} + P_{nkt} = E_{nkt} \quad (8)$$

- Roadside chipping

$$X_{ijt} - YH_{ijkt+1} \geq 0 \quad (9)$$

- Purchase and harvesting

$$L_{ijt} \leq L\max_{ijt} \quad (10)$$

$$L_{ijt} \geq L\min_{ijt} \quad (11)$$

- Roadside inventories

$$X_{ijt=0} = XI_{ij} \quad (12)$$

$$X_{ijt=12} = XB_{ij} \quad (13)$$

- Transportation

$$Y_{ijkt} + YH_{ijkt} \leq Y\max_{ij} \quad (14)$$

$$Y_{ijkt} + YH_{ijkt} \geq Y\min_{ij} \quad (15)$$

- Plant inventories

$$M_{ikt} \leq M\max_{ikt} \quad (16)$$

$$M_{ikt} \geq M\min_{ikt} \quad (17)$$

$$M_{ikt=0} = MI_{ik} \quad (18)$$

$$M_{ikt=12} = MB_{ik} \quad (19)$$

- Non-negativity

$$Y_{ijkt}, YH_{ijkt}, MH_{ikt}, L_{ijt}, P_{nkt}, E_{nkt}, X_{ijt}\ M_{ikt} \geq 0 \quad (20)$$

The scheduling problem was formulated using an objective function subjected to both allocation and technical constraints (Dantzig, 1951). The dynamics of the model were based on 12 monthly planning periods with no periods during which energy was not produced. Unit costs for purchase, harvesting, electricity procurement, non-renewable fuel procurement, wood procurement, chipping, transportation and production in the objective function were determined from the materialised average unit costs. Peat's fuel tax was used as an additional coefficient in the model. Data were provided by an energy plant of Stora Enso Fluting Mill in southern Finland. According to data, plant inventory costs were calculated to be 1€ $MWh^{-1}$. The annual interest rate (8%) was applied to value of the wood to determine the unit cost for the roadside inventory. To simplify our calculations and make the use of the model clearer, our analysis was confined to a single plant (i.e., $k = 1$).

Allocation constraints were formulated at the plant level. Using them the main objectives were included in the solution methodology incorporated in the computer software. The maximum procurement energy content (MWh $m^3$) was determined for every team from the materialised procurement volumes ($m^3$) for the subject plant in 2006. The profitability of energy production by a plant depends on two factors; maximising the energy production (thus, the profits) and minimising the total operating cost. The model minimises the costs according to heating energy and electricity required at the plant during the decision-making horizon. To estimate the profits and permit a calculation of profitability, the energy equivalent provided by each volume of energy fuel was calculated.

Initial levels were determined for the roadside and plant inventories using data from the same plant. Roadside inventory levels were set to correspond *a priori* to the weekly energy-fuel requirement for the plant at the beginning of the planning horizon, and changed linearly to reflect *a priori* the weekly energy-fuel requirement for the plant at the end of the planning horizon. Roadside inventory levels were scaled to reflect the proportion of the total harvest allocated to each of the harvesting teams. The minimum plant inventory was defined as 50% of the *a priori* weekly energy-fuel requirement for the plant; the maximum level was set 10% higher than this weekly requirement. All plant inventories were set at their minimum levels at the beginning of the planning horizon. In this specific case, initial levels were also determined for the purchased and logged forest fuels.

The optimisation runs of the model were performed using three examples on a standard desktop computer (2,393 MHz × 86 processor) with 4 GB RAM running the Windows XP Professional operating system. The scheduling algorithm was implemented using the C programming language and the user interface was created using Microsoft Visual Basic from version 6.0 of the Microsoft Visual Studio suite. We decoded the dynamic linear optimisation programme and we used version 5.0 of the Lindo API software (http://www.lindo.com/), with its standard settings, as the linear programming solver. The user interface of our software was designed to make it easier for users to adapt the model to changing decision environments simply by changing the constraints and the parameter values for each of the parameters described in the model.

## 3 Results and discussion

### *3.1 Evaluation of planning model*

We used the results of our modelling to evaluate the quality of the planning mdel in terms of its technical performance and differences in the scheduled decision alternatives. We calculated the differences by analysing the total operating costs for each example during the planning horizon (Table 1). We assumed that the presence of a clear difference indicated good quality of the methodology. Furthermore, if the differences are reasonable and acceptable, they also reveal the importance of procurement planning for renewable fuels by the energy plant. Moreover, if the solutions are global optimums, the methodology can be considered to have reached a good-quality solution (Taha, 2010). Table 1 shows that changes of the total operating costs of the used model are reasonable and acceptable.

**Table 1** Increase of the total operating costs of CHP plant: A = increase of peat's unit procurement costs (€), A1 = 0, A2 = 1.9, A3 = 3.9; B = decrease of peat's procurement volumes (%) in the energy fuel mixture (MWh); B1 = 100%, B2 = 75%, B3 = 50%, B4 = 25%, B5 = 0%; < = Optimum peat use of CHP plant; > = Minimum peat use of CHP plant

| *Production, MWh / Unit costs, €* | *B1* | | *B2* | | *B3* | | *B4* | | *B5* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | < | > | < | > | < | > | < | > | < | > |
| A1 | 2.6 | | 1.9 | | 1.2 | | 0.5 | | 0 | |
| A2 | 2.7 | 2.6 | 2.0 | 2.9 | 2.1 | 3.2 | 2.0 | 3.7 | 1.9 | 4.2 |
| A3 | 2.7 | 2.7 | 2.6 | 3.4 | 2.6 | 4.3 | 2.6 | 5.2 | 2.6 | 6.3 |

General optimisation model can be developed for solving research problems in hand. The energy-flow model in the present study proved to be more effective than the materials-flow models developed by Palander (1995, 1998), because the new model more precisely accounts for both delivery of the forest fuels and their energy contents. The energy-flow model used in the previous research by Palander and Vesa (2009) did not account for the profitability of integrated procurement of the electricity and energy fuels. Furthermore, the previous energy-flow model allocated only a volume (MWh) of fuels to ensure that the best possible fuel mixture was selected by the model, but it did not ensure that this solution was profitable in energy production. Therefore some of the delivery alternatives would presumably have decreased rather than increased the manager's ability to achieve a profitable mixture of energy fuels. Although we did not calculate the profits from sales of energy produced by the plant (Palander, 2011a, 2011b), it is clear that minimising the total operating cost will increase profitability.

Computer programming work was useful as the optimisation method was decoded and models were adapted to changed objectives of the decision environment. The methodology successfully used dynamic linear programming decoding approach for energy fuel planning taking into account both production and procurement considerations in single objective model. The results are accordance with the general optimality theory (Dantzig, 1951; Taha, 2010). Further, the software that we developed was sufficiently flexible that it could be adapted easily to a changing decision environment without requiring the users to learn sophisticated programming skills. These results should not be confused with the works by Hongtao et al. (2006, 2010), Palander (2011a, 2011b), studying the multi-objective heating optimisation problems when goal programming is used. In the present study, the handling different goals are relatively insignificant, compared to the other planning activities. Managers require the software for their daily work, as well as to solve larger multiple objective procurement problems, because it is too laborious to formulate such models manually (Palander et al., 2002; Eriksson et al., 2003).

The examples achieved global optimality, with total number of linear programming iterations increasing from 173 to 313 as a result of adding the peat fuel tax cost to the model. The resulting objective function value (annual operating costs) increased 4.2% when the actual peat tax cost (+1.9 € $MWh^{-1}$) was included (Table 1). In this decision environment the operating costs decreased by 3.3% in the examples when the peat procurement rate was decreased from 100% to 80% and forest technology rate was increased. The operating costs increased by 6.3% if the peat tax cost was 3.9 € $MWh^{-1}$ (Table 1). In this decision environment the production costs decreased by 3.7% in the examples when the peat procurement rate was decreased from 100% to 0%. The software clearly performs well and the methodology guaranteed a global optimal solution within a realistic range of values for the study area and within the normal computational possibilities. The objective function values are also reasonable based on available data for the energy plant whose data we used in our modelling. Moreover, including the peat tax cost increased the total production costs for the produced energy, which could not be compensated by increasing the forest fuel procurement.

### *3.2 Energy production with renewable fuels*

To clarify the differences between the procurement chains in the examples, we summarised the energy flows from electricity and different energy-fuel assortments for the 12 monthly planning periods in a one-year decision horizon. Including the peat taxes and the peat procurement rates in the examples clearly affected the levels of the various energy flows. Changes in the characteristics of the energy-fuel mixture throughout the year in the optimal solution can be seen in the Figures 4 and 5; the increase in the volumes of forest energy fuels (MWh) resulted from decreased volumes of peat fuels from peat procurement rate of 0% to 100%. Discussions with the manager of the energy plant that provided the data used in our models indicated that the differences revealed by the optimal solutions are reasonable based on the actual long-term energy production environment for the plant; all available wood-based energy sources as renewable fuels are currently being used by the plant. Therefore, the remainder of the discussion concentrates on differences in primary forest energy sources and peat energy sources, although all wood-based fuels have a neutral $CO_2$ balance. Oil is only used in energy production, if renewable fuels are not available in CHP plant.

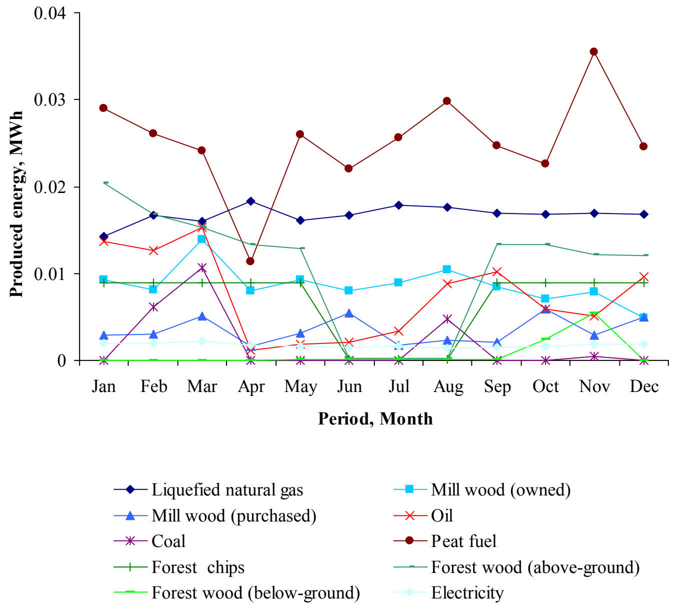
In the least cost solution the relationship between the procurement levels for peat and forest fuels without including the peat fuel tax costs (Table 2) was 58/42 (peat = 58%, forest fuels = 42%). Table 2 shows all annual procurement levels of forest fuels for decreasing use of peat fuel.

**Table 2** Comparison of the CHP plant's annual fuel procurement relationships between peat and forest fuels: A = increase of peat's unit procurement costs (€), A1 = 0, A2 = 1.9, A3 = 3.9; B = decrease of peat's procurement volumes (%) in the energy fuel mixture (MWh), B1 = 100%, B2 =75 %, B3 = 50%, B4 = 25%, B5 = 0%; < = optimum peat use of CHP plant; > = minimum peat use of CHP plant

| *Production / Unit costs* | *B1* | | *B2* | | *B3* | | *B4* | | *B5* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | < | > | < | > | < | > | < | > | < | > |
| A1 | 0/100 | - | 14/86 | - | 28/72 | - | 42/58 | - | 45/55 | 58/42 |
| A2 | 0/100 | 5/95 | 14/86 | 15/85 | 28/72 | 29/51 | 41/59 | 43/57 | 46/54 | 57/43 |
| A3 | 0/100 | 0/100 | 0/100 | 14/86 | 0/100 | 28/72 | 0/100 | 46/54 | 0/100 | 57/43 |

Because customers purchase varying volumes of heat and electricity during different seasons of year, the annual average procurement levels do not describe adequately dynamics and competition of peat and forest fuels. Therefore we calculated the procurement levels for monthly fuel mixtures (Figure 4). During summer the difference of the procurement levels (97/3) was largest and peat procurement was more important than forest fuel procurement. During autumn forest fuel procurement increased and during spring the procurement volume of peat even decreased to under the volumes of forest fuels, which resulted the procurement level 34/66.

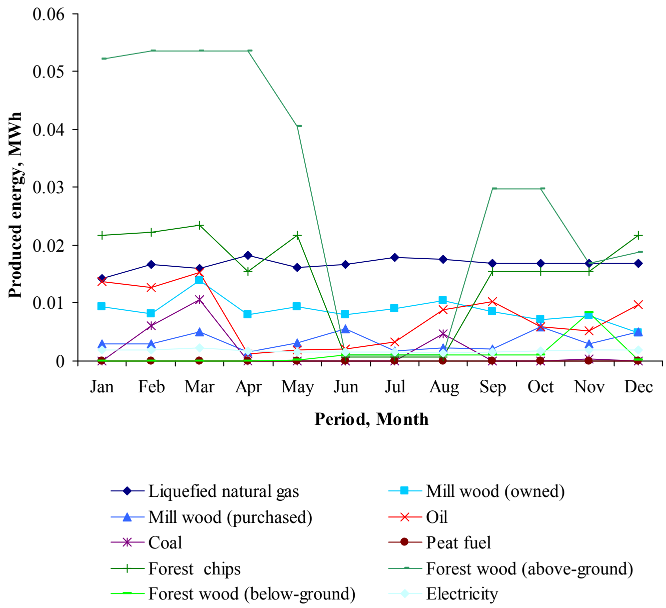
**Figure 4** Energy fuel and electricity procurement volumes (MWh) in the example that includes the peat fuel (see online version for colours)




The Finnish peat fuel tax system was launched shortly before we wrote this paper. Therefore, reliable data on how this system will work is not yet available, and we were forced to examine the impacts of the peat tax cost at a relatively high level of abstraction, especially in our determination of the unit costs that we used as basic data in the procurement problem. Obviously, the assumed costs will differ from the real costs, but the analysis remains relevant because the purpose was to model the natural variations in these costs in the energy industry for optimisation of the total operating costs.

Figure 5 shows the electricity and energy-fuel procurement levels of fuel mixtures in example that does not include the peat fuel. The differences between the scheduled decision alternatives resulted from the potential increase of the forest fuels. The relationship between the annual procurement levels for peat and forest fuels was 0/100. It seems that competition for forest fuels appears likely to significantly intensify in the near future. The proposed Finnish investments in energy production using renewable resources will further increase the demand for wood biomass. In this context, the present study provides a simple tool that plant managers can use to analyse the optimal fuel mixture as the prices of fuels and procurement rates are changing.

**Figure 5** Energy fuel and electricity procurement volumes (MWh) in the example that does not include the peat fuel (see online version for colours)




The differences between the monthly procurement levels of the various forest fuels resulted from the increased forest technology rates of teams. In this respect the optimal solutions were analysed by calculating changes in teams' procurement volumes in the examples. The changes were positive and negative and there were large differences in deliveries of forest wood to the CHP plant in many teams. The annual procurement volumes of forest fuels could range by 240% between examples as a result of the equal changes of the levels of peat procurement rates. However, forest fuel procurement is spatially dependent on harvesting areas and the annual procurement volume increased only by 78% as the peat procurement level was decreased by 100%. According to these results, it is difficult to achieve renewable energy target of Finland without the implementation of additional policy measures.

A direct outcome of this study can be the improvement of plans for supply chain scheduling to plant managers. Discussions with the manager of the energy plant who used the system indicated that the computer solutions are reasonably based on the plant's actual long-term energy production environment. Therefore, the optimum delivery schedule increased the manager's ability to achieve a profitable mixture of energy fuels. Indirect outcome can be the improvement of guidelines and advise on forestry operations designs to team managers and entrepreneurs. In order to optimise local wood procurement, they should be aware of the main energy fuels to be demanded by the plant before making the harvesting-related decisions. This research problem can be analysed in future, when more efficient management planning method is developed for sustainable energy production.

## 4 Conclusions

The results of this study illustrate the advantages of the potential impacts of optimisation of renewable forest fuel supply for more sustainable energy production of CHP plant in Finland. Using the encoded dynamic linear programming methodology made it possible to efficiently solve the fuel procurement problems. Further, the methodology can be used as a powerful core for future decision-support systems, and has high potential to significantly improve the efficiency of the forest operations in respect to the planning of renewable supply chain.

The illustrative examples we discuss in this paper, which are based on the same real-life data from the energy-production industry, allowed us to assess the impacts for the industry of including the peat fuel tax costs. The results show procurement relationships for peat and forest fuels, which indicate that meeting peat tax targets may not be adequate for the future success of renewable energy production in Finland, because energy production costs are increasing and it is difficult to achieve forest fuel targets. The energy industry as a whole in Europe is subject to policy decisions regarding incentive-based policies including carbon taxes and use of price drives. Further studies are needed to demonstrate the cost-efficiency of the energy policies for decision makers in various real-life production and procurement environments.

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