XXIII. Model and algorithm for supply chain analysis in energy-wood industry

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Abstract

Short rotation coppices are a renewable energy concept based on renewable raw material. This paper proposes a model and calculation method which generates valid supply chains using quantified technological and infrastructural constraints.

1 Introduction

In Europe and particular in Germany the change in energy supply plays currently a dominant role. The EU-directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources defines a target for share of energy from renewable sources in gross final consumption of energy of 18 % for Germany in 2020 (from 2005: 5,8 %). By 2013 already 11,7 % of the consumption was generated from renewable sources, which constitutes a raise of 4,7 % within 3 years. In turn, this also supports the growing relevance of logistics related research in the renewable-energy domain.

Besides energy generation from wind, water and sun the use of renewable raw material is intensified, too. Short rotation coppices (SRC) represent such an energy wood concept, i.e. cultivation of fast growing wood, such as poplar, willow and locust, for the generation of woodchip for heat generation and electric power generation. Compared to "classical" energy plants, such as corn or rapeseed, the renewable source SRC are

- more profitable (SRC yield a double energy result per acre) and
- less critical to their ecological impact (SRC require a less fertilizer and herbicide treatment and produce synergies towards a natural balance and landscape [1].

Currently, the federal cultivation size equals approximately 1400 acre [2]. Compared to Sweden (cultivation size 2006: 6.000 acre), Italy (1.400 acre) or Poland (2.800 acre) the cultivation area looks quite small, nevertheless it doubled since 2008 [3].

Due to longer growth cycles it takes 10+ years for SRC to reach economical attractiveness. Such periods are however uncommon in typical agriculture (and are rather typical for silviculture). Hence, limited knowledge on the potentials of SRC in combination with a rather high market entry risk, the renewable energy source SRC is quite not yet developed as it could be in Germany.

In this context logistics owns a special role: the supply chain needed for harvested wood in short rotation coppices accounts for up to 60 % of the total production costs [4]. Therefore logistics in agriculture industry faces a new challenge caused by an increasing number of short rotation coppices.

There is a lack of significant analyses dealing with factors such as harvesting methods, drying and chopping processes, transport and handling procedures. These factors have an important influence onto the possible application of technologies related to the energy wood industry. Furthermore, all probable sequences of the used technologies are defined by the mentioned factors. In order to get authentic results for structure, costs and length of such possible supply chains, the above mentioned factors should be quantified and their relationships modeled parametrically.

The aim of this research is to develop a model and to propose a calculation method which generates valid supply chains using quantified technological and infrastructural constraints. The suggested approach shows how an estimation of needed time and costs can be automatically derived for each chain, independent of the particular cultivation area[1].

2 State of the art

The term „Biomass Logistics“ (also: „Agrologistik“, German synonym für agricultural logistics) so far addresses the organization of transport processes. On the other hand, comprehensive views onto the entire process with its multitude of possible process alternatives are academically oriented ([5], [6], [7], and [8]) and did not yet produce applied methods or software tools for decisions support systems.

The challenge is a concept that automatically generates process chains for the linkage of harvesting, chopping, drying, transshipment, storage and transport which are technically possible and economically beneficial. So far, the selection of an optimal supply chain required lengthy calculations for a specific case.

In agricultural sciences possible supply chains of SRC are defined visually or verbally and in particular their impact factors are specified qualitatively only. A frequent

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[1] **Notification:**
If wood properties are changed through usage of technologies we call this a process. A sequence of processes therefore is a process chain. If an admissible connection between source (short rotation coppice) and sink (e.g. communal heating station) was found, we take this as our (analyzed) supply chain.

illustration is shown in Figure 1. Parametric modelling of these chains was less sophisticated. Reasons are hard to quantify organizational and political frame conditions (among others: field-sink-relations, tenancy agreement vs. life span of plantation, public funding). The data was due to low harvest volume quite limited: relevant research on harvesting technologies, drying and chopping processes as well as transport and transshipment processes and their interrelationship was ongoing. These interdependencies have direct impact onto the application and sequence of certain processing steps.

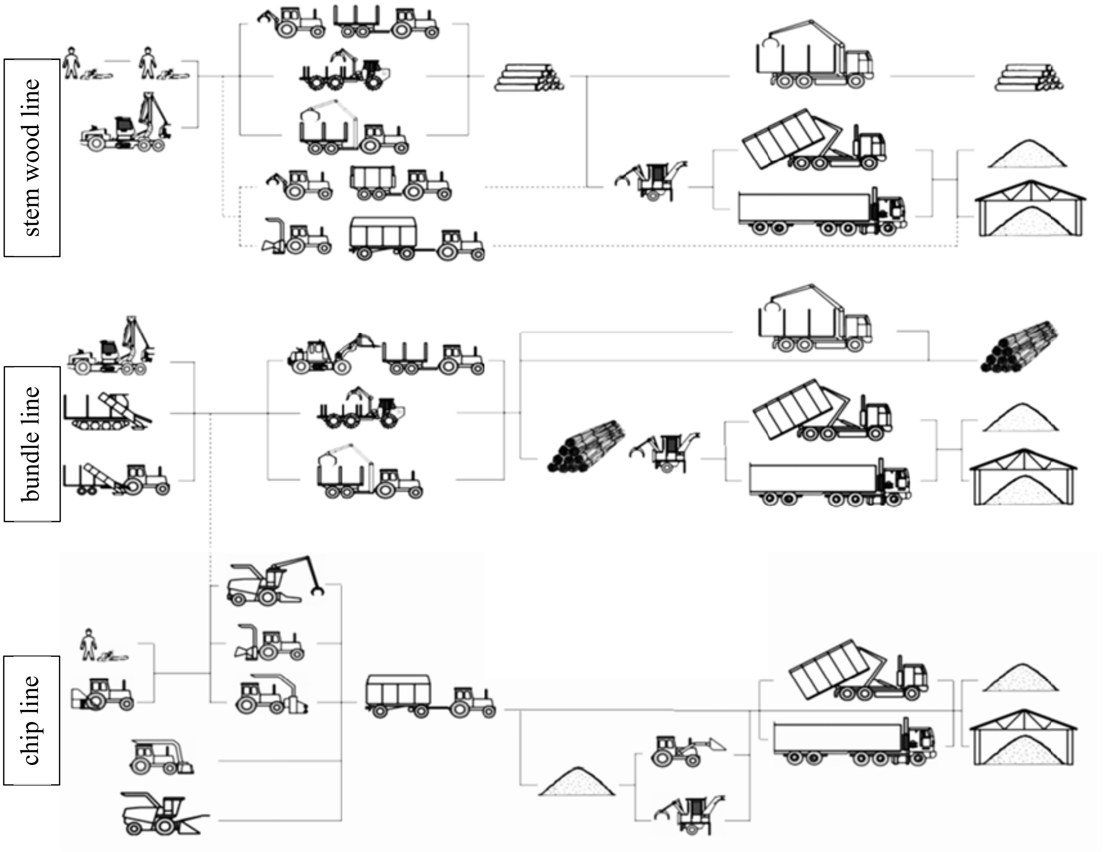

Figure 1: Harvesting and post-harvesting methods of short rotation trees (cf. [9])

There exists a varying number of process steps depending on the process line. In each process step there are several alternatives for the wood manipulation. This yields a huge combinatorial multitude to the user, whereas not all combinations are technically valid or economically attractive. For the single user the design of an optimal process chain was quite a challenge. So far no decision support tools were available that provided guidance in selection a proper supply chain. Hence, the selection so far was not always soundly proven. Within the underlying research project, a decision support tool was developed to ease the situation.

3 Model and algorithm

The developed model consists of two primary components. First are the product properties which basically influence the usability of manipulating and transport technologies. Second is the topography, which consists of the area under crops, location of consumers and the infrastructure.

3.1 Product properties

Energy wood has only a few properties that are relevant for modelling supply chains and their related processes. For example these are moisture (therefrom depending heat value), fraction size, bulk density and ash content. Special attention is paid to the inherent properties: moisture and fraction size because they are directly related to logistic processes as they influence density and volume which influences the weight of the wood.

Furthermore, some important restrictions for the use of technologies are derived from the product properties, in particular the sequence of their usage. For example, in order to dry some wood, it not should be enrooted (property type: fraction size) on the plantation, instead it must be cut at first. In the model, especially fraction size and moisture are allowed only to decrease while being manipulated by technologies. This restriction is useful because increasing the moisture (and therefore decreasing the heat value) or fraction size does not have any relevance in reality. Table 1 shows how inherent product properties are quantified in the model.

Fraction size restricted technologies are not able to manipulate wood which current parameter set includes a higher fraction size class. The same applies to moisture restrictions.

Non-inherent parameters, which are also needed for modelling logistics processes, are the actual position of the wood in supply chain, the current mass which depends on the process losses, a timestamp and the accumulated costs. Inherent and non-inherent properties are manipulated by technologies during each process step.

Table 1 - Specification of inherent product properties similar to [10]

Parameter	Class	Range
Fraction size **P**	P16 P45 P63 P100 P200 P300 whole tree – disrooted whole tree – enrooted	$0 \leq P \leq 16$ mm $16 \leq P \leq 45$ mm $45 \leq P \leq 63$ mm $63 \leq P \leq 100$ mm $100 \leq P \leq 200$ mm $200 \leq P \leq 300$ mm $300 \leq P \leq$ disrooted $P \geq$ disrooted
Moisture **M**	M10 M15 M20 M25 M30 M35 M40 M45 M50 M50+	≤10% ≤15% ≤20% ≤25% ≤30% ≤35% ≤40% ≤45% ≤50% ≥50%

3.2 Technologies

Technologies are divided into two categories: technologies that change inherent wood properties (e.g. harvester, chipper and woodpile) and others that only modify non-inherent properties (e.g. transport technologies). The parameterization of the chosen technologies is based on well-funded literature search (e.g. [11], [12]) in addition to cooperate research with energy wood farmers prior to this project. Therefore our algorithm is able to calculate realistic chain structures, timeframes and total costs for each identified supply chain.

It is assumed that processes are not allowed to happen simultaneously but step-by-step. Furthermore, at each step, there is always only one technology that manipulates the wood. These simplifications are acceptable because of the behavior of drying technologies. These will always be the time bottleneck in e-wood supply chains and can only be used one after another.

As an example, whether one chopper needs ten days for harvesting the SRC plantation or 10 harvesters need one day is not that important in reality while it takes 180 days to dry the wood. It is more important that all the costs of the technologies in use increase linearly depending on “time in use”.

Table 2 - Parameterization of technologies in e-wood industry

Type of technology	Parameter class	Parameter and quantity unit
Harvester/ Chipper	costs/ performance	Ø - fix costs in €/use Ø - variable costs in €/h Ø - performance in t/h Ø - loss of material in %
	restrictions	maximum fraction size in P minimum fraction size in P
	manipulations	manipulating fraction size
Drying technologies	costs/ performance	Ø - drying duration in d Ø - stack height in m Ø - costs in €/m² Ø - loss of material in %
	restrictions	maximum fraction size in P minimum fraction size in P
	manipulations	manipulating moisture level

3.3 Algorithm

For an extensive comparison of different supply options and thereon based optimized selection of the favorite supply chain it is necessary to determine all (!) process chains that fit to the wood properties in combination with the technologies and their restrictions. Therefore needed calculations cannot be done manually due to large number of possible solutions. In order to increase efficiency through automated computation we present a dynamic search tree approach.

Referring to graphs (consisting of vertices and edges [13]) like they are used very often in logistics it is proposed to generate a dynamic search tree. The search algorithm for possible sequences of technologies is similar to a procedure that is called “depth-first search” in computer sciences. In our algorithm implementation each vertex consists of:

- current wood parameter values,
- valid successor manipulating technologies (depending on the current parameter values, that’s why we call it “dynamic tree”),
- actual chosen technology in the current vertex (depending on step of the algorithm)
- link to predecessor vertex
- and the chosen predecessor technology in the predecessor vertex.

The following pseudo-code presents the approach that leads from an initial state of wood parameters to a selected final state by using manipulating technologies and therefore generates valid supply chains.

[Initialization]

- ➔ *if* no manipulating technology, caused by their restrictions, for initial wood properties exists: *terminate*
- ➔ *else*: build initial vertex, manipulate wood with first technology and check if final wood parameters reached (if true then save supply chain)

[Build Search Tree]

```
repeat
        while (SuccessorTechnologyForManipulatedWoodParametersExists = TRUE) do
                GenerateSuccessorVertex
                ManipulateWoodParameters
                if (CurrentWoodParameters = FinalWoodParameters) then
                        SaveSupplyChain
                        exit while
                end if
        end while
        repeat
                if (AnotherManipulatingTechnologyInCurrentVertexExists = TRUE) then
                ChoseNextTechnology
                ManipulateWoodParameters
                        if (CurrentWoodParameters = FinalWoodParameters) then
                                SaveSupplyChain
                        end if
                        exit repeat
                else
                CurrentVertex = PredecessorVertex
                end if
        until CurrentVertex<InitialVertex
until CurrentVertex<InitialVertex
```

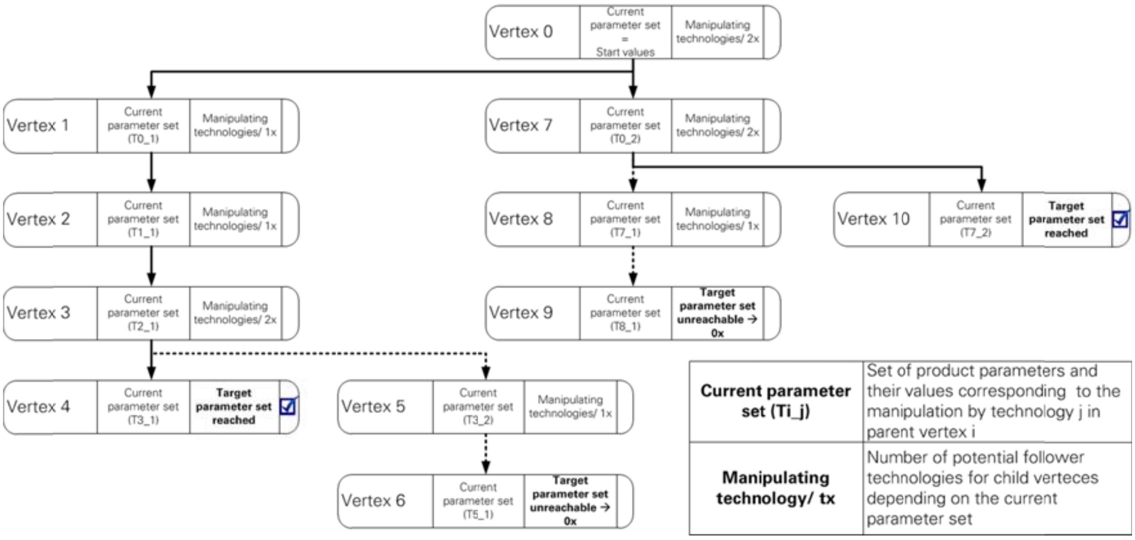

Figure 2: Principle of the "dynamic-search-tree" algorithm

4 Results and outlook

A parametrical model was developed including an algorithm to derive the optimal process chains for supplying the wood according to the demands of the customers.

In future, especially the organization of harvest rhythms and needed storage capacities may influence the costs of energy wood supply. For example, on the one hand only for a short term each year energy wood will be harvested and dried. On the other hand, there is a nearly constant level of wood demand over the whole year. In order to balance supply and demand of energy wood, storage will be needed. However, one should avoid storing short rotation coppices for longer than one year as problems with degradation will be the result. Thus in order to guarantee a high-level security of energy wood supply, new concepts are needed for delivering the right quantity of energy wood at the right time. In addition, the regional dimension of the crop areas (source to sink distances) will influence transport efforts, the level of energy efficiency and therefore the resulting total costs. In this regard methods of logistics research are able to support the search for optimal supply chains in energy wood industry.

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