A Spatial Agent-based Model for Assessment and Prediction of Woodchips Availability for Heating Plants in Austria

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1. Introduction

Energy from renewable sources is a growing trend in Europe and all over the world, as a reduction of greenhouse gases by a certain percentage is a political goal according to the Kyoto Protocol. In order to achieve the goals envisaged in the treaty – a reduction of greenhouse gas emissions by 20% (base year 1990) during 2013-2020 – the propagation of renewable energy sources is one of the strategies followed by politics and administration.

Though in every country the increased usage of renewable energy sources is favoured and sponsored. There is rarely a study that evaluates the effects of the consumption of renewable energy resources with respect to the spatio-temporal dimension on a fine grained level of detail. So far only studies exist that evaluate renewable energy projects on a global/local level - e.g. for a whole country or province (e.g. Arbeitsplattform Wald und Holz in Kärnten 2007, Möller and Nielsen 2007).

The work presented in this paper focuses on effects of wood chip heating plants on the availability of lumber for wood chip production on a fine spatial and temporal granularity. In order to model the "consumption" of timber for heating purposes, an agent-based model coupled with a GIS is employed (Crooks and Heppenstall 2011, Johnston 2013, Van Berkel and Verburg 2012, Mandl 2003). In a generic way the model mimics the competition of several heat plants for biomass. In addition, it includes a basic forest growth model as well as a sequence of forest operations that result in lumber for wood chip production. The scientific question of this paper tries to answer if a spatio-temporal effect of competition for renewable energy resources exists. The paper evaluates the question in the context of the wood chip market which serves as energy source for heating plants in a given test area. The theoretical model is applied to a data set of Carinthia, a province of Austria.

The paper is organized as follows: section 2 elaborates on the test area, the data used in the study and the general approach of the study. The theoretical model, following an agent-based approach, is described in section 3. The first results are given in section 4, followed by a discussion and conclusions.

2. Test Area and Approach of the Study

This section elaborates on the study area and the necessary data for conducting some experiments using an agent-based model. The scientific approach of this study is given in a subsequent subsection.

2.1 Study area: Province of Carinthia and data used

The test area of this study is the province of Carinthia - the southernmost federal state of Austria. The test area is chosen due to the fact that 57.6 % of the area is covered by forests and several heating plants are existing which compete for the available biomass (i.e. wood).

The data necessary for this study are a road network, spatial raster data indicating forest according to the Austrian Forest Act with 300 m resolution (source: Austrian Ministry for Agriculture & Forestry), forest type map raster data (source: Austrian Ministry for Agriculture & Forestry), growing stock raster data (source: Austrian Ministry for Agriculture & Forestry), a digital elevation model with 25 m resolution and data on of the position and yearly lumber consumption of heating plants in Carinthia (see Figure 1).

The road network and the DEM with 25 m resolution are used to model the distance between heating plants and forest stands – i.e. the biomass to be harvested. The forest data – forest, forest type, growing stock – are necessary to reason about the forest type, tree age, the forest growth and the potential biomass to be extracted from the forest (either as thinning or clear cut, depending on the age of the standing trees). The data on the heating plants – position and yearly biomass consumption are created for the study by the authors.

2.2 General Approach of the Study

In order to model the effects of wood chip heating plants on the availability of wood chips based on the available data sources we defined the following spatio-temporal model that is based on an agent-based approach. The model is given in Figure 1 and described hereafter.

In order to model the biomass supply chain a source and a sink has to be defined. The source is the forest, where timber is growing constantly with respect to a forest growth model and the current growing stock. Lumber for wood chip production can only be extracted from the stands based on a given forest operations plan which is based on schedule for thinning operations and clear cuts based on the age of the trees. The sinks are represented by heating plants which generate energy from wood chips.

The reason for modelling the biomass supply with agents traveling in space to collect biomass is explained as follows. The system should model a dynamic “market situation” for a given time period of several decades. This shall give evidence if there is a spatio-temporal effect on the biomass availability – i.e. the market – for heating plants. Hence, each agent is able to interact and alter the environment accordingly – by collecting the timber of thinning and clear cut operations and converting them into biomass for energy purposes. To mimic the behaviour of heating plant managers – whose primary target is to minimize the transport costs of biomass – we assume that each manager collects available timber close to the location of the heating plant with respect to the street network. Due to the fact that there are a number of different heating plants in the province of Carinthia, there is a market situation where heating plants compete for close available biomass, we follow an agent-based approach to mimic the market situation present in the universe of discourse. In this paper we intentionally do not model the real market as such, as there are no studies on the behaviour of the biomass market as such. Thus, we model the market by agents, with a given behaviour, which follow the basic rationale any market participant follows. In addition, the study focuses on modelling agents on a fine grained level of detail, but restricts the analysis to the macro-level which gives a global overview of the outcomes of the biomass market.

Each heating plant gets a “prospector” - i.e. an agent - that searches for available biomass, which is produced in the forest with respect to the forest operations schedules. The general rule is that the agent tries to find biomass as close as possible to the heating plant in order to keep the transport distances and overall costs as low as possible. If two agents are longing for the same timber stand at a given raster cell, the agent visiting the cell earlier gets the available wood – the other one gets biomass that is left. Each agent searches until the yearly wood chip demand for the associated heating plant has been collected. In addition, the transport distance - based on the generated transport distance raster - is monitored for each gathered m³ of timber and evaluated thereafter.

The evaluation of the transport distances as well as the pattern of collected timber over the given simulation period of several years shall give evidence for the spatio-temporal availability of biomass for energy purposes.

3. Agent-based Model for Collecting Wood for Heating Plants

The innovations of this model are not only the spatial resolution and the coupling of a GIS and an agent-based modelling environment using the Agent Analyst of ArcGIS (Johnston 2013) but also the subject matter which checks the hypothesis that the support of wood chips as fuel for heating plants is not a sustainable solution for renewable energy source projects in Central Europe. In this approach four specific procedures (indicated by the numbers 1 to 4 in Figure 1) were developed to model the universe of discourse accordingly.

The first procedure (# 1 in Figure 1) is a forest growth model based on empirical forest inventory data and a DEM, which represents the annual growth of the dominant two tree types (spruce and European beech) with respect to different altitude. This is done for all forest stands in Carinthia, which have an area of 580.000 ha of the complete 953.301 ha land area.

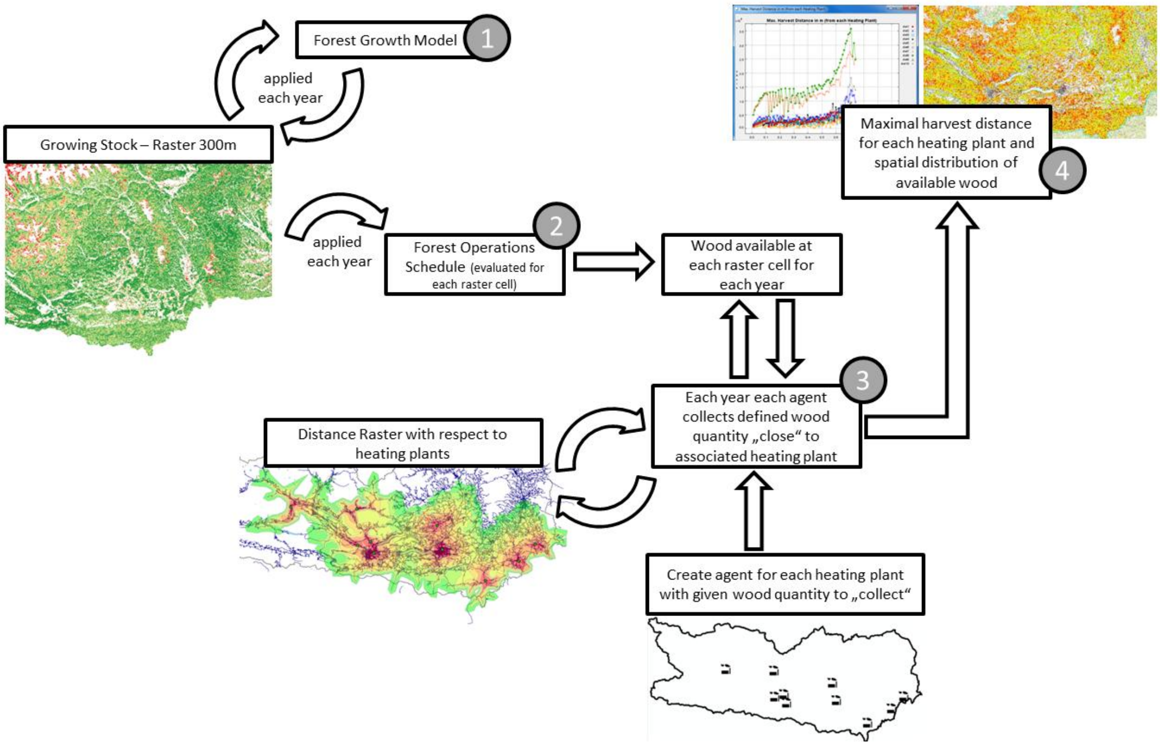

Figure 1. Approach to evaluate the wood chip availability with a given consumption of lumber by heating plants. The numbers in the circles define the sequence of operations carried out each year that is modelled.

The second procedure (# 2 in Figure 1) is an estimation model for the amount of available wood chips per raster cell (300m by 300m). Here the data of the forest inventory is essential to define a forest operations schedule, based on the standing timber and the "history" of the standing timber (i.e. prior forest operations, age of forest). In 2013 13% of the forest trees were under 20 years old, 60% between 20 and 100 years and 17% older than 100 years (10% were bushes etc.). The trees between 20 and 70 years of age were used for wood removal and that only every 10th year. So the forests in Carinthia are relatively old, which is similar all over Central Europe. This fact and the decreasing maintenance of the forests are the main reasons for the decreasing supply of wood chips as fuel.

The third procedure (# 3 in Figure 1) is the simulation of the collection process for the prospector agents, which is based on a round trip concept to scan the landscape and collect wood chip material as needed by each heating plant. The prospectors collect wood in a systematic way as long as there is a demand of the supplied heating plant. When the collecting areas are overlapping, the prospector who is at a certain stand first, gets the wood. Further criteria for collecting the wood are a maximum of 20% removal of biomass per stand, 25% crop loss, removal only in stands having an age of 20 to 70 years and at an age of 100 years the stands are fully harvested and the amount of biomass is reset to zero.

The fourth and final procedure (#4 in Figure 1) is the calculation of different statistical parameters like the maximum harvest distance for each heating plant and of maps of the spatial distributions of available wood for each of the simulation years (Figure 2). Further ouput parameters of the simulation process are the amount of the total, the available and the not available wood for all of Carinthia (see Figure 3 Left) and the average age and percentage of the harvestable forest stands (see Figure 3 Right). In these figures the proposition that the age of the stands is the main reason for a massive decrease in wood chips availability during the next decades is confirmed.

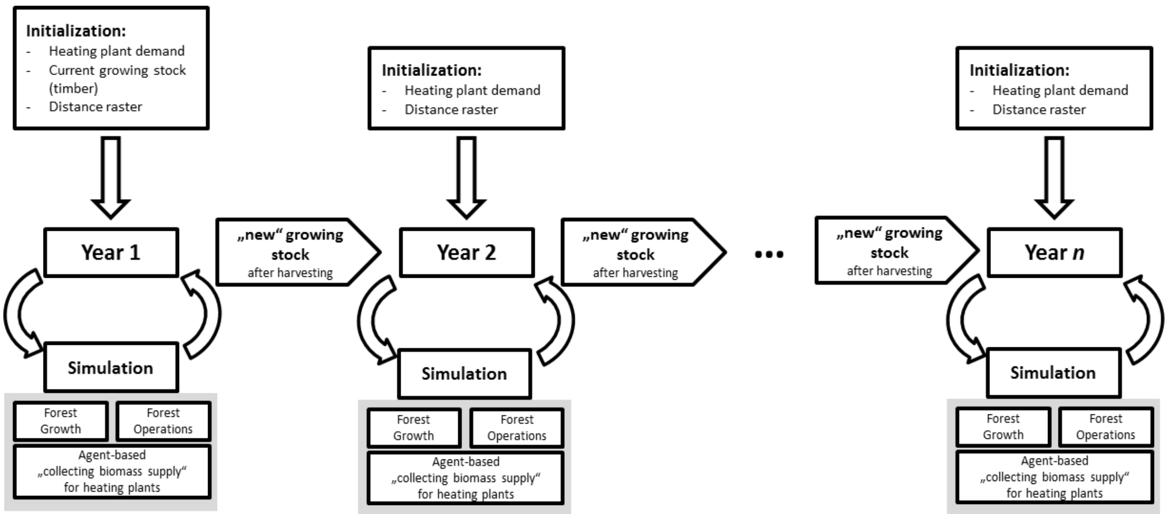

Figure 2. Agent-based simulation approach for each simulation year. This graphic depicts the temporal sequence of the simulation process and the necessary data for each yearly simulation.

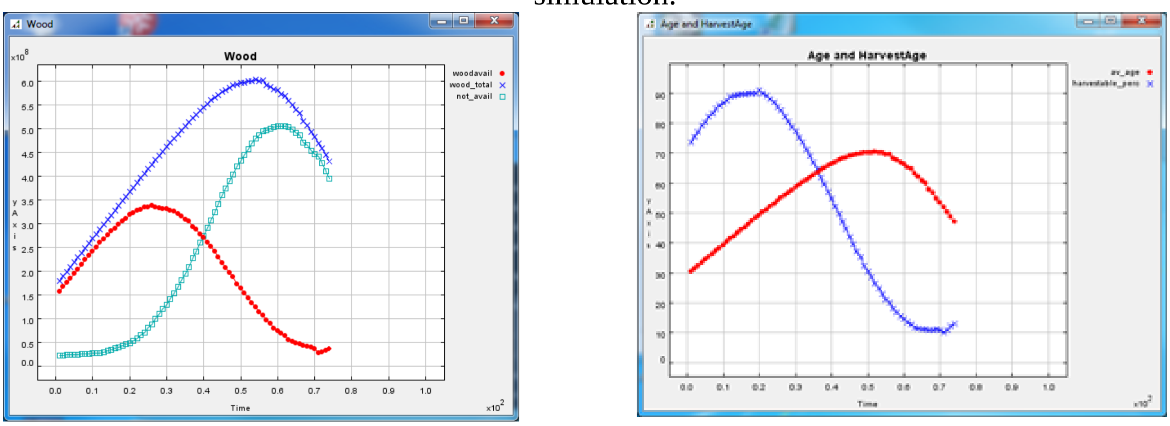

Figure 3. Results of the simulation process for Carinthia. Left. Amount of the total (blue), the available (red) and the not available wood (light blue), Right. Average age (red) and total percentage of the harvestable forest stands (blue).

4. First Results for Two Scenarios

The results of the spatial agent-based model are maps of the available amount of wood chips and statistics for the distance of timber haulage at each time step (from forest to heating plant). A prototypical implementation is applied to two scenarios to model the wood chip demand for heating plants in Carinthia. The first scenario models ten operational heating plants and the second one includes a fictional new heating plant for Klagenfurt.

The results of the agent-based spatio-temporal simulation processes for both scenarios are presented in Figure 4 and 5. Figure 4 shows the maximum transport distance from the forest to every heating plant of scenario 1 for each simulation year. The graph reveals that the maximum transport distance increases the longer the simulation runs. This is due to the fact that forests in the vicinity of a heating plant cannot supply the heating plants accordingly, and timber has to be transported over longer distances. This can also be justified by the increasing number of moves of each agent until the biomass supply for each heating plant is collected (see Figure 5). For scenario 2 the situation is similar to scenario 1 with an additional heating plant in Klagenfurt that increases the demand of fuel by a factor of 4.3.

The results of the scenarios indicate that the model is capable of modelling the timber usage of heating plants and the effects of heating plants on the "environment" – i.e. the forest, standing timber and transport distances – over a time frame of 50 years accordingly.

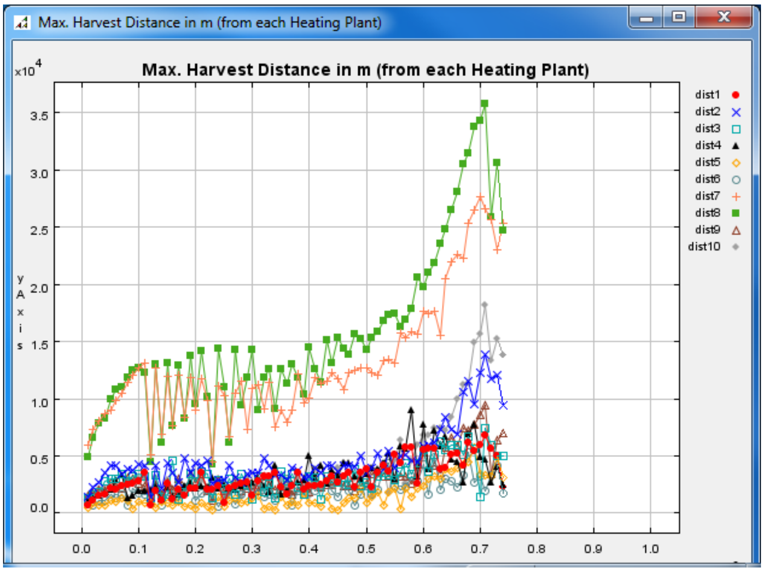

Figure 4. Results of the agent-based spatial simulation process for scenario 1. The results depict the transport distance to the last biomass collection point of each heating plant under review for each year of the simulation period (74 years for scenario 1).

5. Conclusion, Discussion and Future Work

The paper describes an approach to model the impact of wood chip heating plants on the availability of lumber for wood chip production. The model operates on a fine spatial and temporal granularity. In order to model the "consumption" of timber for heating purposes, an agent-based model coupled with a GIS is employed. The model is applied to two scenarios that include ten operational heating plants (scenario 1) and an additional high-demand heating plant located in Klagenfurt, Austria (scenario 2). The results reveal that the approach is capable of modelling the impacts of heating plants on forest and transport distances. Additionally, the results indicate, that, within the test area Carinthia one cannot fully rely on wood chips from local forests in order to fulfil the heating energy demand.

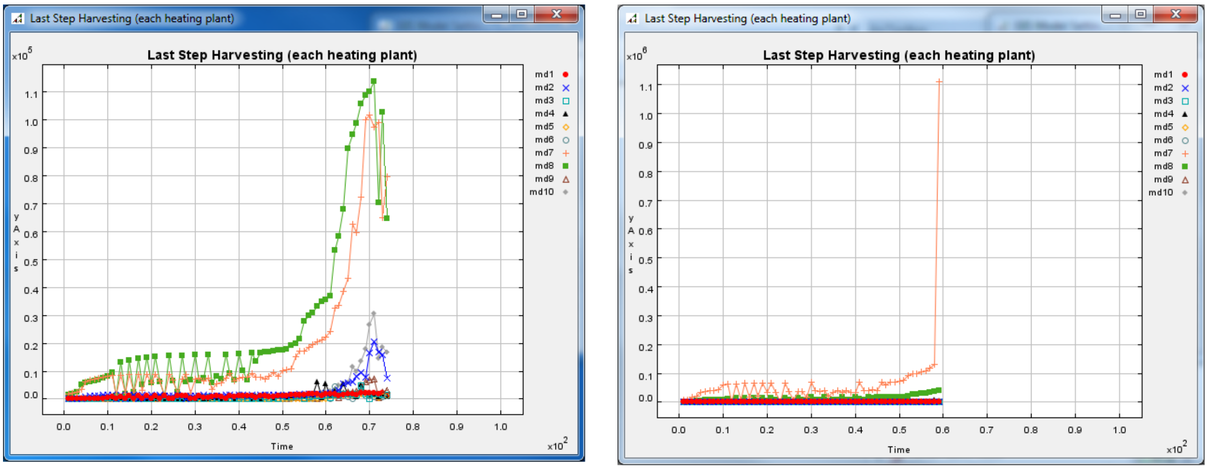

Figure 5. Results of the agent-based spatial simulation process for scenario 1 (left) and scenario 2 (right). The results depict the number of moves of each agent – i.e. prospector – until the timber demand for a heating plant for one year is collected.

In further projects the presented model can be used to simulate additional scenarios. The problems which will be worked on are the change of the types of forest operations and their timing, the influence of wood chip imports from other countries on the model results, the optimum of the number and the location of power stations which get along with the available amount of timber in Carinthia as well as the combination of the biomass power plants with other renewable energy sources. Furthermore the development of a simulation methodology supporting the Energy Master Plan for Carinthia (http://www.energie.ktn.gv.at/) is in progress.

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