MS-E2177 - Seminar on Case Studies in Operations Research

Team UPM Carbon

System Dynamics Modelling of Forests as Carbon Sources and Sinks

Project Plan

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Background

Forests, most broadly defined as large land areas dominated by trees, are "the dominant terrestrial ecosystem on Earth", accounting for 80% of the total plant biomass and a habitat for the majority of species on the Earth [Pan et al., 2013].

Not surprisingly, forestry, silviculture, and the use of wood have a long history intertwined with the history and development of the human race. Wood has been an integral for developing the craftsmanship of modern humans, and wooden tools dating back as far as 400 000 years ago have been discovered [Radkau, 2012].

The modern forest industry grew alongside a developing world and new raw material requirements. The Finnish forest industry, started in the 16th century, grew out of an increasing need to control the use of forests, as well as their preservation [Tasanen et al., 2004]. Our client organisation, UPM, has its roots in multiple different forest industry companies dating back to the 18th century [UPM, 2019]. Today, the forest industry is mainly divided into two parts, the mechanical and chemical forest industries [Forest.fi]. The mechanical forest industry includes products made directly from wood, whereas the chemical forest industry refers to products (pulp and paper) made using wood raw materials and chemicals.

The forest industry and its products are becoming increasingly interesting due to their possible impact on climate change. The "warming of the climate system is unequivocal" and "unprecedented", with the impact of agriculture, forestry and other land use (AFOLU) being significant source of emissions. In 2010 24% of greenhouse gases released came from AFOLU [Pachauri et al., 2014].

The forest industry, and its products' impact on climate change, can be viewed both directly and indirectly. Although forestry's direct impact is significant and it has been said that in forestry the "most cost-effective [climate change] mitigation options are afforestation, sustainable forest management and reducing deforestation" [Pachauri et al., 2014]; forestry and the forest industry can have a positive impact indirectly through substitution. This is when forest industry products are used instead of products made by fossil fuels or other greenhouse gas (GHG) intensive materials.

In order to truly compare the climate change effects of different industries and products, one has to look at the whole life cycle of a specific product: from raw materials and production, to its use and possible recycling, then finally to its disposal as waste. To assess the climate change impact of such a life cycle, one can calculate the total CO_2 emissions (or CO_2-equivalent (CO_2-eq) emissions, i.e. the amount of CO_2 "emission[s] that would cause the same integrated radiative forcing, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs" [Pachauri et al., 2014], where radiative forcing (RF) is used to quantify the strength of climate change drivers).

Forestry, the forest industry, and the use of the industry's products make up a complicated dynamic system, therefore system dynamics (SD) is well-suited for this task. SD is used to model the behaviour of complex systems over time through its feedback processes, i.e. positive and negative feedback loops, different relationships (e.g. flows) and elements of complexity (e.g. stocks, delays) [Sterman, 2001]. Due to their ability to model complex systems, SD methods have already been successfully used to model the climate change impacts of forests (e.g. Härkönen et al. [2019]; Bonan et al. [2003]; Machado et al. [2015]) as well as for carbon footprint modeling of different products and processes (e.g. Trappey et al. [2012]; Shrestha et al. [2012]). SD methods are especially well-suited for modeling processes and supporting decision-making in matters as complicated and important as environmental decisions (e.g. Stave [2002]).

Objectives

UPM is one of the biggest operators in the Finnish forest industry [Metsäteollisuus, 2019]. Forests can be used as massive carbon stocks and understanding the climate effects of forestry, or any other industry for that matter, is now more important than ever. The objective of this project is to use system dynamics to model the carbon cycle in forestry. The idea is to model the entire Finnish forest industry using biological forests (apposed to political forests) by creating an interactive tool to help us understand what kind of effects different features, parameters and products have on the net impact of carbon emissions.

There are plenty of open questions related to forestry and the carbon cycle: To what extent is using forests more efficient than conserving them? What is the net impact of different actions? In which cases are forest based products better than their substitutions? These are only a few examples of the questions our model tries to answer.

The objective of this project is to educate UPM - to improve conceptual understanding and support the sustainable aims of the company. As mentioned above the tool will be interactive, with the possibility to compare products and scenarios. The interactivity and visual figures of the model support the educational aspect of the project. The target audience for the model is a layman or a UPM worker. However, this could be sacrificed later to take it towards a forest expert audience.

Some key rules and parameters should be included in the model, for example substitution effects, although further development could be made afterwards. Some of the potential additional features of the model include lengthening the time span, adding a product inventory to the model, or considering price dynamics or supply and demand rules as additional parameters. However, it is important to realise that the model cannot increase infinitely, because of the constraints of forestry. Consequently, another objective is to understand these constraints and their impacts in forestry.

Tasks

1. Familiarizing with the topic

The first task is to familiarise ourselves with the topic by reading material related to system dynamics and the carbon cycle of our model (including forest dynamics and product life cycles). This also includes planning the project, meeting with the client and presenting our initial ideas to them.

2. Writing the project plan

Project plan report will be written and presented during the first excursion.

3. First proof of concept

Building the first proof of concept (PoC) includes testing different softwares, programming languages and mathematical methods, building the model and its dynamics and ensuring that the model makes sense. The first PoC should be as simple as possible and use dummy data. The model will be improved after receiving comments for the first PoC from the client.

4. Improved proof of concept

The improved PoC should be built after receiving feedback for the first PoC. This will include e.g. choosing the details that will be included in the model, improving the model dynamics and finding more relevant data.

5. Writing the interim report

Interim report will be written and presented during the second excursion. The interim report will include the current status of the project and possible changes in the project plan.

6. Building the simulation tool

Besides modeling the carbon cycles of forests, the objective is to build an interactive simulation tool that allows to change parameter values and test different scenarios etc. This can be done when the improved PoC is satisfactory.

7. Writing the final report

The final report will include everything made for the project, and it will be presented during the third excursion.

8. Running the simulations

The simulations will be run after the model and the simulation tool are finished.

Schedule

The Gantt chart in Figure 1 shows the scheduling of the tasks in this project. The green bars represent completed tasks and the grey bars represent remaining tasks. The course meetings and deadlines are marked in red above the tasks.

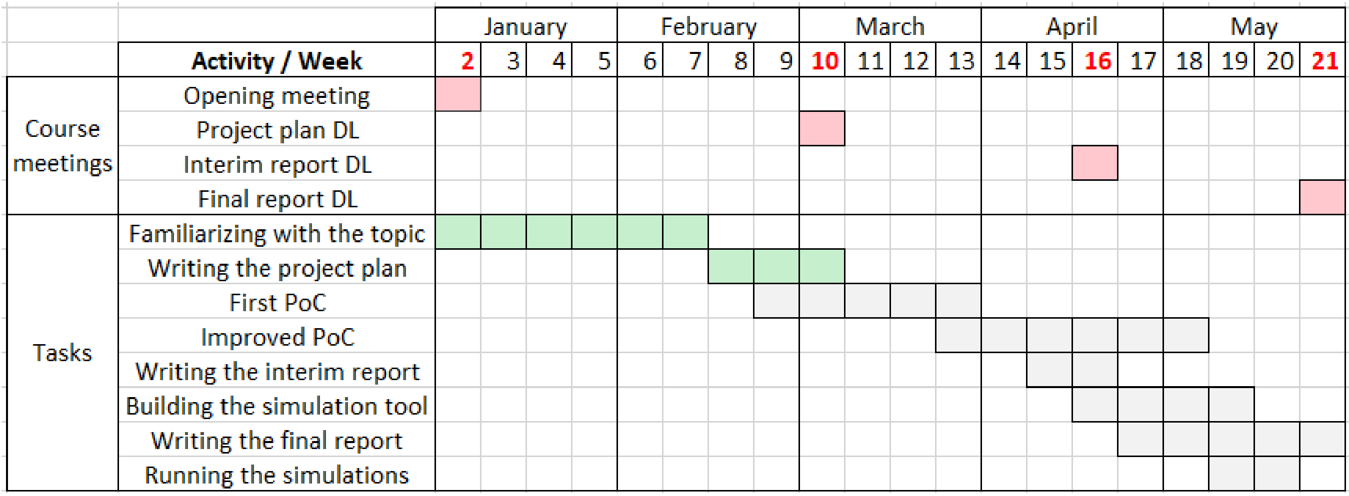

Figure 1: Gantt chart of the project schedule.

Resources

In terms of internal resources our team consists of four Operations Research Masters students who will split the workload equally, aside from the allocation of the bulk of the admin to our project manager Roni to fulfill his extra credits for the course. Although we were all drawn to this project by interest, we have limited knowledge ourselves of forest systems and their production lines. To rectify this we have built a Google Drive library of literature. This is a rich area in terms of forest systems and dynamic systems which is complemented by a team of varied UPM contacts: Anssi Käki (Vice President, Pulp Supply Chain and Tools & Processes), Sami Oksa (Director, Stakeholder Relations at UPM Wood Sourcing and Forestry), Sauli Järvenpää (Manager, Fibre Business Forecasting and Analytics at UPM) and Tuomas Niemi (Manager, Reporting and Standards) with whom we are having approximately tri-weekly meetings. Although UPM has extensive and open data on their product materials, emission impacts and manufacturing processes, product data for the substitution effects is hard to find and possess a resource challenge as we will need this data to complete the model.

To make the model we have no limits for programming language, which means we have the chance to trail many languages and softwares to find the most suitable. However, after prototypes on Simulink and Vensim (industry standard) to check results, we would prefer an open source option for the final product to make it easier for everyone to access.

Risks

Forest industry is a dynamic system and modeling the climate impacts of forests and forest based products can be very complex. Evaluating the key rules and uncertainties in forestry is therefore important. The main risks of the project are listed in Table 1.

Table 1: Risks related to the project.

Risk	**Likelihood**	**Effect**	**Impact**	**How to avoid**
Overly complex model	Medium	Workload too large, lack of motivation & time, mistakes	High	Sufficient project plan & realistic schedule
Overly simple model	Low	Model is not useful	Low	Research, managing expectations, allow future developments
Unreliable or non-realistic model	Medium	Overconfidence, false conclusions	High	Sensitivity analysis, critical thinking, avoid oversimplifications, use reliable data
Incomplete data	High	Difficulties in creating the model, mistakes	Medium	Research, scoping
Insufficient team work, team member inactive	Low	Uneven workload, inefficiency, project delayed	Medium	Good communication, project managing

The risk of an overly simple, overly complex or unreliable model can mean that the model will not fill its educational purposes. To avoid this we should consider the educational level and learning pathways carefully and create a user friendly interface.

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