Lifecycle carbon footprint assessment of biorefinery planned to Estonia

Final report

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1 Introduction

A group of Estonian investors with long forestry and wood processing experience is considering an option to establish a novel biorefinery in Estonia. The forecasts show that the planned investment of around one billion would be the biggest ever industrial investment in Estonia.

According to Est-For, the refinery, with its *ca.* 750,000-tonne planned production capacity, would raise the Estonian timber industry to a whole new level and contribute to its development. The estimated timber needed as raw material for the refinery is *ca.* 3.3 million cubic meters a year. The company is of the opinion that the refinery would be a next-generation biorefinery that would be the most advanced in all of Europe. Initial forecasts indicate that the refinery would start production in 2022.

The biorefinery would process timber into various components, such as pulp, hemicellulose and lignin. Depending on the technology chosen, these can be processed into different bioproducts. The processing by-products would be tall oil and renewable energy.

This assessment was commissioned by Est-For Invest OÜ. The company wanted to know the direct carbon footprint of the biorefinery. SEI Tallinn proposed the application of an internationally accepted methodology that can be used for the lifecycle carbon footprint assessment of the planned biorefinery. This also allows for assessing the impact of the refinery on climate change as well as the contribution of the factory to the achievement of national and international climate and energy policy objectives, such as the Paris Agreement goals, the General Principles of Estonian Climate Policy till 2050 and other relevant political guidelines.

The assessment was conducted in 2017.

2 Methodology

The assessment used the carbon footprint definition given by the International Organisation for Standardisation (ISO) in its standard. Pursuant to this, the carbon footprint of a product is the "sum of greenhouse gas (GHG) emissions and removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change".[1]

The carbon footprint of the biorefinery was calculated in compliance with the Confederation of European Paper Industries (CEPI) methodological framework for carbon footprint calculation with respect to paper and cardboard products.[2] This methodology was prepared in 2007 and updated in 2017 and takes into account other relevant carbon footprint protocols and methods.[3] The CEPI methods are widely used in the wood processing industry, and among other things, it allows for assessment and comparison of carbon footprints of different biorefineries.

The CEPI framework for carbon footprint calculation of paper products is based on ten elements (so-called toes) that follow the main lifecycle stages:

1. biomass carbon removal and storage in forests
2. biomass carbon in paper products
3. greenhouse gas emissions from paper and/or pulp manufacturing facilities
4. greenhouse gas emissions associated with producing wood fibre
5. greenhouse gas emissions associated with producing other raw materials
6. greenhouse gas emissions associated with purchased and sold electricity, steam, heat, and hot and cold water
7. greenhouse gas emissions associated with transportation
8. greenhouse gas emissions associated with product use (e.g. printing)
9. greenhouse gas emissions associated with product end of life
10. avoided greenhouse gas emissions (mainly on account of renewable electricity sold, instead of electricity from fossil fuels)

[1] ISO (2013). *Greenhouse gases – Carbon footprints of products – Requirements and guidelines for quantification and communication.* Technical specification, International Organization for Standardization (ISO/TS 14067:2013).

[2] CEPI (2017). *Framework for Carbon Footprints for Paper and Board Products.* Confederation of European Paper Industries. http://www.cepi.org/node/21490

[3] For instance: *ISO (2013) Greenhouse gases – Carbon footprints of products – Requirements and guidelines for quantification and communication.* Technical specification, International Organization for Standardization (ISO/TS 14067:2013); JRC (2016) The *European Commission Product Environmental Footprint (PEF) Category Rules (PEFCR) for Intermediate Paper Products.* Final draft.

In compliance with the CEPI framework and background data supplied by the company, we calculated both biogenic carbon and fossil carbon emissions and removal and used these to determine the carbon balance of the refinery. Fossil CO_2 is mainly emitted in the process of fossil fuels combustion, and it directly contributes to the climate change. Biogenic CO_2 emissions are related to the natural carbon cycle as well as result from the combustion and decomposition of biomaterial, such as wood. In general, biogenic CO_2 is considered carbon-neutral from the climate perspective.[4]

As the final assortment of products of the biorefinery was not selected at the time of this assessment, the carbon footprint was calculated on the basis of its main output, i.e. wood pulp. The carbon footprint was determined as CO_2 equivalents per tonne air-dry pulp.

The carbon footprint calculation method used is based on the lifecycle approach. So, the carbon footprint calculations also covered various lifecycle stages associated with the product, such as the production of raw material (both wood fibre and process chemicals), the pulp production process, transport of raw material and the finished product, and use of the finished product. The calculations did not cover the CO_2 end-of-life emissions from final products made from pulp because making these calculations at this stage would involve too much uncertainty. The scope of this assessment is described in more detail in the following chapter.

The assessment also compared the situation, i.e. carbon footprint, when Estonia has such a refinery and the baseline scenario, where there is no biorefinery in Estonia. The comparison with the baseline scenario allows assessment of the impact of the refinery on climate change. This also allowed indirect assessment of the contribution of the biorefinery to the achievement of Estonian climate goals. In assessing the latter contribution, only fossil carbon footprint results were taken into account.

2.1 Scope and assumptions of assessment

The lifecycle stages covered in the carbon footprint calculation of the biorefinery are presented in Figure 1.

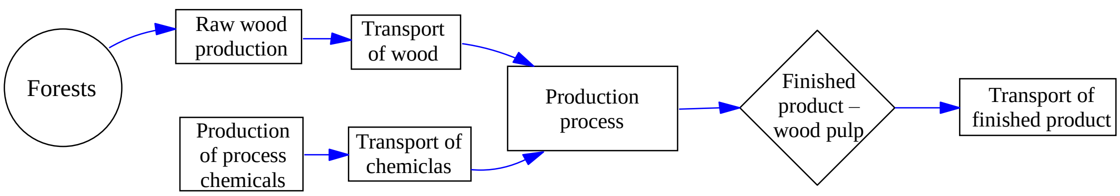

Figure 1: Lifecycle stages covered when calculating carbon footprint of biorefinery

[4] If biomass (wood) is used faster than it regrows, the future stock of carbon-neutral fuels and amounts of carbon stored by forests decrease.

The calculations of the carbon footprint were based on the following main assumptions:

- The raw wood will come from Estonia and northern Latvia. The current felling volumes and wood chip volumes in Estonia and Latvia are sufficient for the production capacity of the plant. No increase in felling volumes due to the refinery is foreseen.
- The refinery will use the best available techniques in its production.
- By burning lignin, bark and sewage sludge, the biorefinery will generate renewable energy, mostly for use in the biorefinery, but the excess will be sold to the transmission network operator. So, a part of fossil-based oil shale electricity will be replaced by renewable energy.
- One-third of the transport (both raw material and the finished product) will be by rail.

More detailed assumptions and explanations regarding each of the ten toes listed in the CEPI framework and used in the carbon footprint calculations are given below.

1. Biomass carbon removal and storage in forests
    - In consideration of the assumptions regarding raw material needed, as submitted by the company, no changes in carbon storage by forests are expected. The maximum annual amount of raw material the biorefinery will need is 3.3 million cubic meters of raw wood. Of this, one million will be acquired in the form of wood chips from Estonian and Latvian sawmills and 2.3 million cubic meters in the form of pulpwood Estonia and Latvia exported so far (where necessary, also from Lithuania and Belarus). Although the final share of raw wood obtained from Estonia and Latvia will be determined by the market situation, it is assumed that 1.6 million cubic meters will come from Estonian forests and 0.7 million from Latvian forests (assuming annual felling volumes of 10 million cubic metres in Estonia and 11 million m^3 in Latvia)[5]. This means that the wood exported from Estonia and Latvia would be used mainly as the raw material for the biorefinery. The company has stated that should the pulpwood available in Estonia and Latvia decrease significantly, the missing part would be acquired primarily from Lithuania and Belarus.[6] See also the description under "Greenhouse gas emissions associated with transportation".
    - The national inventory report on Estonian greenhouse gas emissions[7] indicates that in the period from 2012 to 2015 when the felling volumes were stable at around 10 million cubic metres, carbon removal amounted to *ca.* 2,000–3,000 tonnes of CO_2 a year. In view of the current felling volumes of Latvia, i.e. *ca.* 11 million cubic metres a year, their forest growing stock continues to increase and forests are removing carbon.[8] The CEPI method allows us to

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[5] The annual felling volumes assumed are based on the forestry statistics of Estonia and Latvia (Environment Agency (2017). Eesti Mets 2016 and Zaļās mājas (2017). *2017 Latvian forest sector in facts and figures*).

[6] The biorefinery would prefer certified raw wood, and to increase the amount of raw wood from certified forests, the refinery will cooperate with private forest owners and the state to promote certification of forests.

[7] *NIR Estonia* (2017). *Greenhouse gas emissions in Estonia 1990-2015. National inventory report to European Commission*.

[8] Zaļās mājas (2017). *2017 Latvian forest sector in facts and figures* and *NIR Latvia* (2017). *National inventory report 1990-2015*.

consider zero impact of the biorefinery on carbon removal by forests if the felling volumes required for the raw material used in the biorefinery do not exceed the carbon removal limit of forests.

2. Biomass carbon in paper products
   - Wood-based products store biogenic carbon. The carbon in the product at the gate of the biorefinery before entering into commerce was taken into account, which means that no GHG emissions outside the refinery, i.e. upon additional processing, were taken into account.
   - As it is yet unknown what final products will be further manufactured from the pulp, it was not possible to assess how long the carbon will stay in the product.

3. Greenhouse gas emissions from paper and/or pulp manufacturing facilities
   - The GHG emissions from fossil fuels and biomass fuels used in the production were calculated separately. The company presumes that it will not use any fossil fuels in the production process (generation of heat and electricity) or other technical processes. See also the following points.
   - The proposed biorefinery will be constructed using the currently best available techniques (BAT)[9]. These are much more advanced than similar biorefineries of the previous generations. The production process will make use of 100% renewable energy generated on site. When wood chips are treated with vapour and chemicals in the production process, black liquor will be produced as a byproduct. Its main ingredient is lignin. Lignin will be combusted after extracting the rosin soap from it in the production of tall oil. The activated sludge produced in the wastewater treatment plant will be combusted as well.[10] The combustion will produce heat and electricity to be used in the processes of the refinery. Thus, all the heat and electricity used by the biorefinery will be renewable energy because it will be produced from biomass on site. Biogenic CO_2 was calculated on the basis of CO_2 emission factors of paper and pulp mills.[11]
   - A small amount of fossil fuels (mainly diesel fuel) will be used in internal transportation to handle raw material and finished products.[12]

4. Greenhouse gas emissions associated with producing wood
   - The GHG emissions from raw wood production, primarily from forestry management, i.e. felling and afforestation, were taken into account. The data was obtained from the State Forest Management Centre (RMK).[13]

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[9] Suhr, M., Klein, G., Kourti, J., Gonzalo, M.R., Santonja, G.G., Roudier, S., Sancho, L.D. (2015). *Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board. Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)*. JRS Science and Policy Reports.

[10] The company is investigating opportunities to add value to the activated sludge produced in the waste water treatment plant, for example as a soil conditioner, but final choices will require additional.

[11] NCASI (2005). *Calculation Tools for Estimating Greenhouse Gas Emissions from Pulp and Paper Mills.* The Climate Change Working Group of The International Council of Forest and Paper Associations (ICFPA).

[12] The company is also investigating opportunities to substitute the diesel fuel with biogas produced on site.

[13] Urbel-Piirsalu, E. (2010). *The Estonian forest sector in transition to sustainability? Capturing sustainability with the help of integrated assessment.* Doctoral thesis, Lund University.

- The biorefinery will produce pulp only from virgin wood fibres, i.e. no recycled wood fibres will be used in the production. The carbon footprint assessment was made on the assumption that half of the output will be made from coniferous and half from deciduous wood. Wood fibre from conifers will come from pulpwood and wood chips, which is a by-product of sawmills. Wood fibre from deciduous trees will come from pulpwood only.

5. Greenhouse gas emissions associated with producing other raw materials
   - Emissions from the production of non-wood raw material used in production, mostly chemicals, were taken into account.
   - The technological core process of the biorefinery will be chemical pulping of wood (breaking it down into cellulose fibres). The various production process stages involve the use of process chemicals, the production, and use of which also generates GHG emissions. Sodium sulphate and lime will be added to the wood fibres to be processed; sodium oxide and chlorine dioxide will be added during boiling. The chlorine dioxide is elemental chlorine free. The chemicals will circulate in an 80–90% closed cycle, and the estimated amount of chemical additives needed for one tonne of pulp is 50–60 kg. The carbon footprint assessment considered input chemicals that are needed in amounts more than 5 kg per tonne of pulp. Thus, *ca.* 2.5% of the amounts of process chemicals were left out of the calculations. CO_2 emissions were calculated on lifecycle data.[14]

6. Greenhouse gas emissions associated with purchased and sold electricity, steam, heat, and hot and cold water
   - No heat or electricity will be purchased for production purposes. Any heat and electricity needed for production the company will produce on site, as a by-product, from black liquor, tree bark and activated sludge from its own wastewater treatment plant.
   - The water needed for production will be pumped from the river and the treated water will be returned to the river using electricity the company produces on site.

7. Greenhouse gas emissions associated with transportation
   - Calculations of transportation-related GHG emissions included transportation of raw materials (raw wood and process chemicals) and the finished product outside the territory of the biorefinery. Transportation analysis was based on transportation volumes and the assumptions made in the socio-economic impact analysis of the biorefinery.[15] The possible location of the biorefinery is next to the Suur-Emajõgi River near Tartu.
   - As for transportation of wood, it was assumed that 80% of the pulpwood and wood chips currently exported from Estonia will be redirected to the proposed biorefinery and 20% will still be exported. The missing raw material needed will be sourced from Latvia, in the form of wood chips and pulpwood.
   - Where necessary, the additional raw material could be obtained from Lithuania and/or Belarus. However, in the calculations of transport volumes, this option

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[14] Althaus, H-J., Hischier, R., Osses, M., Primas, A., Hellweg, S., Jungbluth, N., and Chudakoff, M. (2008). *Life Cycle Inventories of Chemicals.* Ecoinvent report no 8; EKA Chemicals (2005). *Certified Environmental Product Declaration (EPD) for Sodium chlorate ($NaClO_3$).*

[15] Centar (2017). Puidurafineerimistehase sotsiaal-majanduslike mõjude analüüs. Uuringu aruanne. *(Socio-economic impact analysis of biorefinery. Final report.)*

was not included because according to initial estimates this will not be necessary and additional amounts from Latvia would be enough. The amount of pulpwood exported from Estonia and Latvia in 2015 was 4.4 million cubic metres.[16] Thus, the amount of pulpwood on the markets of Estonia and Latvia twice exceeds the amount of raw material the refinery would need in addition to wood chips.

- As for transportation of the finished product, the calculations included transportation to Kunda and Muuga harbours. Any further transportation by sea was not included in the calculations because the destinations of the biorefinery products are yet unknown.
- The calculations of both the finished product transportation and raw material transportation assumed that two-thirds of it will be via roads and one-third via railways.
- As for process chemicals, transportation from the port to the biorefinery was included.
- The CO_2 emissions from transportation, including different means of transport, were calculated using LIPASTO coefficients.[17]

8. Greenhouse gas emissions associated with product use (e.g. printing)
   - The biorefinery would process timber into various components, such as pulp, hemicellulose and lignin. Depending on the technology chosen, these can be processed into various bioproducts. The carbon footprint was calculated on the basis of the main finished product of the biorefinery, i.e. wood pulp, which can be further processed and used in various ways. As the list of possible final products is yet unknown and may change in time, the calculations of GHG emissions from the use of possible products assumed that using products made of the pulp will not generate any GHG emissions.

9. Greenhouse gas emissions associated with product end of life
   - As there is no information on which products will be further manufactured from the pulp, no calculations of product end-of-life GHG emissions are possible. The biorefinery has no control of such emissions (e.g. arrangements for collection and management of paper products), and there is major uncertainty related to this. The final amounts of fossil and biogenic CO_2 emissions will depend a lot on how advanced the waste management practices are in the country of final use of the products, i.e. how much of it is recycled or combusted for energy, what construction and technical requirements the landfills meet, etc. The carbon footprint of recycling is usually negative, i.e. no CO_2 will be produced because recovery of the material allows CO_2 emissions from the production of new material to be avoided. The biggest contribution to fossil CO_2 emissions at the product end-of-life will be landfill gas, mostly methane. Collection and use of landfill gas in modern landfills considerably reduce GHG emissions. So, the share of product end-of-life GHG emissions in the carbon

[16] *Ibid.*
[17] LIPASTO - calculation system for traffic exhaust emissions and energy use in Finland. Accessible at www.lipasto.fi (last accessed on 25 Sept 2017).

footprint will be relatively low. [18] Due to the above reasons, this assessment did not consider product end-of-life GHG emissions.[19]

10. Avoided greenhouse gas emissions (mainly on account of renewable electricity sold, instead of electricity from oil shale)
    - The estimated amount of electricity produced by the biorefinery from lignin, bark and activated sludge is 682 GWh/y. Of this, 63% i.e. 427 GWh/y, will be used in the production process and the remaining 37%, i.e. 255 GWh/y, will be sold to the public power transmission network, where it will presumably replace the long-term marginal source of electricity in Estonia, i.e. oil shale electricity.[20] Thus, the biorefinery will have a positive impact on the renewable electricity balance of Estonia. The avoidance of GHG emissions refers to such emissions from oil shale to produce the same amount of electricity, i.e. 255 GWh.
    - The calculations of CO_2 emissions from oil shale were based on the CO_2 factor provided in the Environmental Product Declaration of Eesti Energia.[21]

In the carbon footprint balance sheet the generation of GHG emissions are marked with a plus sign and removal of GHG with a minus sign (in CO_2 equivalents).[22]

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[18] Hanna Pihkola, Minna Nors, Marjukka Kujanpää, Tuomas Helin, Merja Kariniemi, Tiina Pajula, Helena Dahlbo & Sirkka Koskela (2010). *Carbon footprint and environmental impacts of print products from cradle to grave. Results from the LEADER project (Part 1)*. VTT Tiedotteita – Research Notes 2560.

[19] The entity that commissioned this assessment is planning an additional assessment to determine the carbon footprint of its possible products. That assessment will also cover product end-of-life CO_2 emissions. That survey will be conducted after the possible products have been selected.

[20] Marginal sources of energy are mostly fossil fuel-based power plants that have the highest variable costs and the share of which will be the first to increase/decrease upon fluctuations in energy demand. For further information see Moora, H; Lahtvee, V (2009). *Electricity Scenarios for the Baltic States and Marginal Energy Technology in Life Cycle Assessments – a Case Study of Energy Production from Municipal Waste Incineration.* Oil Shale, 26(3 Special), 331 – 346.

[21] Eesti Energia (2008). *Certified Environmental Product Declaration (EPD®) for Oil Shale Electricity from the Circulating Fluidized Bed Combustion (CFB) Blocks of the Narva Power Plants*.

[22] The emissions of CO_2 and other GHGs will be converted into CO_2 weight units, and the calculations take into account the relative scale of global warming potential (GWP). The aggregate result will be given in CO_2 equivalents as a single unit of measurement.

3 Assessment results

3.1 Carbon footprint of the proposed biorefinery

The results of the biorefinery carbon footprint calculations are given in Table 1 below.

Table 1 Carbon footprint of the proposed biorefinery

Carbon footprint "toes"	**Fossil CO_2**	**Biogenic CO_2**
	kg CO_2 eqv per tonne of the finished product	
1. Biomass carbon removal and storage in forests[23]	–	0
2. Biomass carbon stored in the finished products of the biorefinery	–	−1 659.31
Total removal of biogenic carbon	**0**	**−1 659.31**
3. Greenhouse gas emissions from pulp manufacturing in the biorefinery	1.89	330.88
4. Greenhouse gas emissions from the production of raw wood (felling and afforestation)	24.01	0
5. Greenhouse gas emissions associated with purchased and sold electricity, steam, heat, and hot and cold water	0	0
6. Greenhouse gas emissions associated with transportation	21.77	0
7. Greenhouse gas emissions associated with producing other raw material	8.04	0
8. Greenhouse gas emissions associated with product use	0	0
9. Greenhouse gas emissions associated with product end of life[24]	–	–
Total CO_2 emissions[25]	**55.71**	**330.88**
10. Avoided GHG emissions (on the account of renewable electricity instead of oil shale electricity)	−444.01	0
Carbon footprint	**−388.30**	**−1 328.43**

Source: calculations made by SEI Tallinn

From the climate change perspective, it is important that the biorefinery does not affect the carbon sequestration in forests. It would be possible to cover the expected production volumes of the biorefinery, i.e. 750,000 tonnes a year, with raw wood within the current felling limits of Estonia and Latvia, without losing the carbon sequestration in forests.

Carbon footprint calculations indicate that in total 55.7 kg fossil CO_2 (in CO_2 equivalents) is emitted per tonne of the finished product, the biggest part of which will

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[23] The assessment assumes that the raw material needs of the biorefinery will remain within the limits of 2.3 million cubic metres from Estonia and Latvia, and the overall felling volumes will not increase in these countries.

[24] Accurate calculations are not possible at this stage as the final list of products to be manufactured from the finished product is yet unknown.

[25] The actual amount might be slightly higher because there is yet no data on the product end-of-life GHG emissions. However, the estimated share of such emissions will be relatively low compared to the whole carbon footprint.

come from the production of raw materials. Around 43% of the fossil CO_2 will come from raw wood production, i.e. primarily from fuel consumption during forest management and felling, and 14% will come from the production of other raw materials, especially process chemicals. Another big part of CO_2 (39% of fossil CO_2) will be emitted during transportation of raw materials, i.e. raw wood and process chemicals, as well as that of the finished product. A marginal share (3%) of the fossil CO_2 will come from diesel-fuelled machinery used for transporting raw material and the finished product within the biorefinery.

No fossil CO_2 will be emitted from the production of heat and electricity used in the production processes of the refinery because these will be generated from the combustion of black liquor and bark, i.e. the by-products of the main production process. During combustion, however, 331 kg of biogenic CO_2 is generated. A large share of the renewable electricity produced in the biorefinery will be used up in its production processes, but a considerable part (37%) of it will be in excess. This excess amount will be sold to the public transmission network of Estonia, where it will replace oil shale electricity (see 10th toe under assessment assumptions). The estimated amount of oil shale electricity to be replaced will be 371 kWh per tonne of the finished product. Producing this amount of electricity from oil shale would generate 444 kg of CO_2 per tonne of the finished product. The biorefinery would allow this to be avoided.

As for the biogenic carbon footprint, the calculations show that, on average, one tonne of the finished product[26] will store 1,659 kg or 1.6 tonnes of biogenic CO_2. The production of renewable energy, however, generates 331 kg of biogenic CO_2. So, it can be said that, on average, the biorefinery would allow for storing of 1,328 kg of biogenic CO_2.[27] In view of the whole production volume (presumably 750,000 tonnes of pulp a year), the estimated amount of CO_2 bound a year would be 1 million tonnes. Depending on the further lifecycle stages of the product, carbon could be stored in, for example, a paper product for up to 6 years (various sources indicate that paper and cardboard products have a useful life of 1 to 6 years[28]). Thus, the finished product of the refinery would not store carbon for long. Nevertheless, some paper products, such as books, can exist for a long time. In addition to paper and cardboard, the finished product of the biorefinery can be used for making other products as well, e.g. viscose products, and their lifespan is longer. As the company is yet unsure which products will be made from the pulp, we cannot calculate the lifespan of the products and the related carbon storage and CO_2 emissions.

Thus, in conclusion, it can be said that, the carbon footprint of the proposed biorefinery will be neutral as much as climate change is concerned. The biorefinery will have a considerable role in increasing the renewable energy share of Estonia's energy balance and in replacing oil shale electricity because it will allow a considerable part of fossil

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[26] The carbon footprint was assessed on the basis of the main output of the refinery, i.e. pulp.

[27] The calculations assumed that the raw material needs of the biorefinery will remain within the limits of 2.3 million cubic metres from Estonia and Latvia, and the overall felling volumes will not increase in these countries.

[28] IPCC (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan; Skog, K., and Nicholson, G. (1998). *Carbon cycling through wood products: the role of wood and paper products in carbon sequestration.* Forest Products Journal vol. 48, no. 7/8; CEPI (2003). *Wood and Paper Products Store Greenhouse Gases. The story of carbon in wood and paper products.* CEPI.

CO_2 emissions going into the atmosphere to be avoided. The calculations show that the biorefinery would contribute to the prevention of 0.39 tonnes, i.e. 388 kg, of fossil CO_2 per tonne of the finished product. Thus, it could be estimated that the total amount of renewable electricity to be sold to the transmission network would allow the prevention of 291,000 tonnes of fossil CO_2 a year. In addition, one tonne of the finished product of the factory allows for storage of 1.3 tonnes of biogenic CO_2, thus allowing the prevention of 1 million tonnes of CO_2 emissions a year. The total impact of the biorefinery on the carbon balance of Estonia will be discussed in more detail under "Impact of the biorefinery on climate change".

3.2 Comparison with the current situation

The assessment included an estimation of the possible carbon footprint change in Estonia, caused by the biorefinery in comparison with the baseline scenario, where there would be no such refinery in Estonia and raw wood would still be exported from Estonia for further processing abroad.

When comparing the carbon footprint of the biorefinery with the baseline scenario, where Estonia would not have such a biorefinery, the following GHG emissions were taken into account:

- Transport-related GHG emissions. These were calculated on the assumption that if Estonia does not have the biorefinery the amount of raw wood the refinery would need is exported (in the form of pulpwood or wood chips) to Finland or Sweden. The baseline scenario would not include transport of process chemicals and the finished product.
- Emissions from the production of electricity the biorefinery would replace. The calculations assumed that the amount of electricity the biorefinery would sell to the public transmission network would still be produced from oil shale if there were no biorefinery. Thus, the same amount of fossil CO_2 emissions that the refinery would replace, would be generated in Estonia in case of no biorefinery (added as a positive value under the 10^{th} "toe" of the CEPI method).

The following GHG emissions directly linked to the biorefinery, however, were not taken into account:

- emissions from the production process of the biorefinery;
- emissions from the production and transport of process chemicals;
- emissions from the transport of the finished product;
- emissions from the use and end of life of the product.

The "toes" related to biomass carbon storage are left out of the comparison as well. These include carbon that is stored in the finished product of the biorefinery and carbon sequestration in forests because it is assumed that whether there is a biorefinery of not, the volume of trees felled would be the same.

The comparison with the baseline scenario indicates that the carbon footprint of the proposed factory differs by two main aspects:

First, as it was already mentioned earlier, the excess renewable electricity the biorefinery produces and does not consume itself can be sold to the public transmission network, where it would replace the oil shale electricity and thus prevent in total 333,000 tonnes of CO_2 emissions. If there were no such biorefinery in Estonia, the same amount of fossil CO_2 emissions, i.e. 333,000 tonnes a year, would be generated because that electricity would be produced from oil shale.

Second, the biorefinery would reduce the transportation-related GHG emissions (the estimated reduction would be approximately one-third). This is due to three main facts:

1) Currently (in the baseline scenario), the pulpwood and chipped wood are transported mainly by road, but the biorefinery would allow for around one-third of the raw material to be transported by rail, which emits relatively less CO_2.
2) In the baseline scenario, the raw wood transport distances would be slightly longer because the wood is transported mainly to Riga Port, which is further away than the biorefinery in Estonia (assuming it will be near Tartu).
3) Were there no biorefinery, both Estonian and Latvian wood would be transported by sea to foreign (mostly Nordic) biorefineries and pulp mills.

While the Estonian biorefinery would contribute to reducing transport-related fossil CO_2 emissions, its production process, including construction, process chemicals and internal transport, would still generate some fossil CO_2 emissions. Nevertheless, these would be around 5% lower than in the baseline scenario.

In addition, as for the Estonian carbon balance, the biorefinery would allow biogenic carbon to be stored in the product, while in the baseline scenario, it would be taken out of Estonia.

To summarise, it can be said that in consideration of the assumptions the construction of the biorefinery into Estonia would have a positive impact from the perspective of the carbon footprint. There are three main reasons for this:

- The renewable electricity the biorefinery would produce would allow for the prevention of fossil CO_2 emissions in Estonia.
- Without the biorefinery, the road transport volumes would be slightly higher, especially in Latvia.
- With the biorefinery, the wood and the finished product would be transported more by rail, which has lower CO_2 emissions.

4 Impact of biorefinery on climate change

In December 2015, at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21), 195 countries adopted a global legally binding agreement to stop global warming. The main aim of the Paris Agreement, which took effect on 4 November 2016, is to mitigate climate change, and pursuant to this the parties must start active reduction of GHG emissions.

The European Union (EU) has devised a climate and energy package that covers all Member States and sets specific objectives for 2020, plus a climate and energy policy framework until 2030, which is in accordance with the Paris Agreement. By 2020, the EU, including Estonia, must achieve 20% cut in greenhouse gas emissions (from 1990 levels), 20% improvement in energy efficiency and ensure that 20% of EU energy from renewables. The goals of the EU by 2030 include cuts in GHG emissions by at least 40% below 1990 levels, increase energy efficiency by at least 27% and to boost the share of renewables to at least 27% of EU energy consumption. The long-term climate goal of the EU is to cut in greenhouse gas emissions 80–95% below 1990 levels.

Estonia as an EU Member State also contributes to the resolution of the climate change problem and has set its own objectives in consideration of the EU climate and energy package. To achieve the objectives, Estonia adopted "General Principles of Climate Policy until 2050", a long-term climate policy, in 2017. The adoption of this document is the first agreement on the long-term vision of our climate policy in Estonia. By 2050, Estonia wants to reduce its GHG emissions 80% compared to 1990. To achieve this, Estonia has a long-term objective of a low-carbon economy. This means gradual purposeful rearrangement of the economic and energy systems to make them more resource-efficient, productive and eco-friendly. The climate policy goals show that the biggest reduction of GHG emissions must be achieved in energetics, manufacturing and transport.

Similar objectives are included in the Estonian National Development Plan of the Energy Sector until 2030:

- Electricity generated from renewable sources will account for 50% of the domestic final electricity consumption.
- 80% of the heat will be generated from renewable sources.
- By 2050, Estonia will meet its energy demand (both electricity and heat) by domestic resources.
- GHG emissions in the energy sector will be reducedat least 70% by 2030.

The impact of the biorefinery on climate change was assessed mainly in view of fossil CO_2 reduction in Estonia. Biogenic CO_2 removal or emissions were not taken into account. Considering the carbon footprint of the biorefinery with respect to fossil CO_2 emissions and extending the result to total production volumes, it can be said that the biorefinery will contribute to all three main climate goals: (1) reduction of GHG emissions; (2) improvement of energy efficiency; and (3) increased share of renewable energy. This is primarily due to the renewable electricity produced for its own needs as well as for selling to the public transmission network.

As mentioned under the assumptions above, the annual renewable electricity is 682 GWh of which 427 GWh/y will be used in the biorefinery and the remaining 255 GWh/y will be sold to the transmission network. Sales of excess renewable electricity to the transmission network allows replacement of the current mainly fossil, i.e. oil shale, electricity. The amount of renewable electricity to be sold to the transmission network would allow the prevention of 333,000 tonnes of oil shale CO_2 a year. The amount of fossil CO_2 generated in the operation of the biorefinery, i.e. 55.7 kg per tonne of the finished product a year, which is *ca.* 42 000 tonnes of fossil CO_2, was deducted to get the net amount of fossil CO_2 to be prevented by the biorefinery. The calculations indicate that the biorefinery would reduce the amount of fossil CO_2 in Estonia by 291,000 tonnes. This amounts to *ca.* 1.6% of our current GHG emissions (*ca.* 18 million tonnes in 2015[29]). Thus, it can be said that the proposed biorefinery would directly contribute to the main objective of Estonian climate policy, i.e. reduction of GHG emissions. The biorefinery would also directly contribute to the reduction of GHG emissions from the energy sector (Estonian National Development Plan of the Energy Sector Until 2030).

As *ca.* 37.5% of the electricity resulting from the production process would be sold to the transmission network, the biorefinery will be a net producer of electricity not a net consumer, whereas the electricity would be generated from renewable sources. Estonia's consumption of electricity in 2016 was 7664 GWh[30], the share of renewable electricity being 18% or 1,414 GWh[31]. As mentioned, the consumption of renewable electricity would increase by 682 GWh with the biorefinery. So, the share of electricity from renewable sources would increase by 8% up to 26%. Thus, the biorefinery would significantly contribute to the objectives of the climate package and of Estonian National Development Plan of the Energy Sector until 2030 to increase the share of renewable energy.

The biorefinery will be constructed using the best currently available techniques (BAT). These are much more energy efficient than similar biorefineries of the previous generation. This improves the average energy efficiency of manufacturing in Estonia. Thus, it can be said that the biorefinery would also contribute to the third climate package objective, i.e. improved energy efficiency. The share of this contribution can be assessed after the final choice of technology has been made.

Furthermore, the biorefinery also contributes to the mitigation of climate change because the pulp and paper industry differs from other industries (except other wood processing industries) in that it allows for storage of carbon in the product. The available data show that the amount of carbon stored in paper and cardboard products amounts to 7% of the initial carbon.[32] Storing carbon in products is an important part of the carbon balance of the paper industry. How long the carbon will be stored in the products depends on their composition, use and the share of their recycling. The more paper is recycled the longer the carbon will be stored in paper products and not be emitted into the atmosphere. When paper is no longer used, either by combustion or decomposition at a landfill site, the CO_2 stored in it is usually released into the atmosphere. The amount of CO_2 emissions generated in the landfills depends on the construction and technology of the landfill. The share of CO_2 emitted from paper

[29] *NIR Estonia* (2017). *Greenhouse gas emissions in Estonia 1990-2015*. National inventory report to European Commission.
[30] Statistics Estonia database 2017.
[31] Elering's data on renewable electricity.
[32] CEPI (2017) *Framework for Carbon Footprints for Paper and Board Products.* Confederation of European Paper Industries.

products in modern landfills is marginal.[33] Depending on the landfill, some of the carbon in paper products does not decompose in anaerobic conditions and is locked in the product for a long time.[34]

The analysis shows that the biorefinery would improve carbon balance in Estonia as it allows for the carbon to be stored in the product. However, it might be argued that even now, when there is no such refinery, carbon is stored in products. This is done mostly outside Estonia, in Finnish and Swedish pulp mills where Estonian wood is exported. Nevertheless, the biorefinery in Estonia would contribute to the mitigation of climate change because it would reduce the amount of global fossil CO_2 emissions.[35] This has two main reasons. First, most of the Nordic pulp mills where Estonian pulpwood is exported are first-generation mills. Their technology is not as energy efficient as that which the proposed biorefinery would use.

The biorefinery in Estonia would allow for prevention of a higher amount of fossil CO_2 emissions compared to a new biorefinery in the Nordic countries. This is because different regions and countries have a different share of renewable sources in electricity generation. The renewable electricity to be produced by the biorefinery in Estonia would replace mostly oil shale electricity, both today and in 20 to 30 years. So, the biorefinery in Estonia would prevent the bigger amount of fossil CO_2 emissions.

Thus, in addition to the decrease in transport-related GHG emissions and oil shale electricity GHG emissions, the global CO_2 emissions will decrease as well. This is because there is no fossil CO_2 emitted in the production process of the Estonian biorefinery. Instead, it would sell renewable electricity to the transmission network, which will reduce CO_2 emissions more in Estonia that it would do in Nordic countries, where the share of renewable energy is quite high.

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[33] Pihkola, H., Nors, M., Kujanpää, M., Helin, T., Kariniemi, M., Pajula, T., Helena Dahlbo, H. and Koskela, S. (2010). *Carbon footprint and environmental impacts of print products from cradle to grave. Results from the LEADER project (Part 1)*. VTT Tiedotteita – Research Notes 2560.

[34] CEPI (2017) *Framework for Carbon Footprints for Paper and Board Products.* Confederation of European Paper Industries.

[35] The final impact of the biorefinery on the global GHG reduction can be estimated after the products to be manufactured have been chosen and the lifecycle carbon footprint of these has been assessed.

5 Summary

This work assessed the **carbon footprint** of a proposed biorefinery in Estonia. This allows for assessment of the contribution of the biorefinery to the climate objectives of Estonia. The carbon footprint was assessed by viewing **fossil and biogenic CO_2 emissions** separately, also taking into account **carbon removal.**

The carbon footprint was assessed **from the lifecycle perspective and in accordance with the internationally recognised CEPI method.** In view of the objective of the assessment and the available data and assumptions, the carbon footprint assessment focussed primarily on the following lifecycle stages that affect the carbon footprint the most:

- carbon sequestration in forests;
- CO_2 emissions from the production process of the biorefinery and from the inputs and outputs;
- CO_2 emissions from the transport of raw wood and the finished product;
- carbon stored in the finished product.

The carbon footprint was calculated on the basis of pulp because the final assortment of products of the biorefinery was yet unknown at the time. This is the reason why other lifecycle stages (e.g. product end of life) were not included in the assessment.

It is presumed that the raw material needed for the biorefinery can be obtained without increasing the felling volumes of Estonia and Latvia. Based on this assumption, **the biorefinery would not increase Estonian felling volumes.** In view of the fact that Estonian and Latvian forests are storing carbon at current felling rates, **the impact of the biorefinery on carbon sequestration in forests will be zero.**[36]

The fossil CO_2 emissions from the production process and transport of raw material and the finished product of the proposed biorefinery will be 0.056 tonnes per tonne of finished product. It is assumed that the biorefinery will use only the heat and electricity it produces itself. The excess renewable electricity (255 GWh a year) will be sold to the transmission network, where it will replace oil shale electricity. As a result, **it would be possible to prevent in total 333,000 tonnes of fossil CO_2 emissions that would otherwise be generated in the production of oil shale electricity.** This is indicated as a negative amount (−0.44 tonnes per tonne of the finished product) in the calculations of the fossil carbon footprint of the biorefinery.

As the fossil CO_2 emissions to be prevented by the sales of renewable electricity produced by the refinery are higher than the fossil CO_2 from the production and transport related to the refinery, the fossil carbon footprint of the biorefinery is also negative (−0.39 tonnes of fossil CO_2 per tonne of the finished product). **The total amount of fossil CO_2 the biorefinery would help prevent would be 291,000 tonnes a year**. Thus, the biorefinery would have a positive effect on climate change mitigation.

The proposed biorefinery also has a biogenic carbon footprint as regards CO_2 emissions and removal.

[36] Should the felling volumes increase significantly in Estonia and/or Latvia, this would affect the carbon footprint and increase the impact of the biorefinery on climate change.

Wood-based products store carbon. The carbon footprint calculations show that a tonne of **finished product (pulp) of the biorefinery stores 1.6 tonnes of CO_2.**[37] The renewable energy production of the biorefinery generates **0.33 tonnes of biogenic CO_2 per tonne of the finished product**.

The calculations of biogenic carbon footprint indicate that the proposed biorefinery would allow for **storage of 1.3 tonnes of biogenic CO_2** per tonne of the finished product. This, in turn, would help prevent additional CO_2 emissions being released into the atmosphere.

Thus, in summary, it can be said that **the carbon footprint of the proposed factory has an impact on climate change.** In addition, the biorefinery would contribute considerably to the three main Estonian climate objectives:

(1) The biorefinery would contribute to **decreasing GHG emissions in Estonia by *ca.* 1.6% compared with the current situation**.

(2) **The share of renewable electricity in electricity consumption would increase to 26%.**

(3) The proposed biorefinery would **improve the average energy efficiency of manufacturing** in Estonia.

[37] Depending on the final product made from the pulp, the carbon storage period may be longer or shorter. This, in turn, affects greenhouse gas emissions associated with product end-of-life. As the final assortment of products of the biorefinery was yet unknown at the time of the assessment, these were not taken into account.

6 Bibliography

Althaus, H-J., Hischier, R., Osses, M., Primas, A., Hellweg, S., Jungbluth, N., and Chudakoff, M. (2008). *Life Cycle Inventories of Chemicals.* Ecoinvent report nr 8. Accessible at https://db.ecoinvent.org/reports/08_Chemicals.pdf

Centar (2017). Puidurafineerimistehase sotsiaal-majanduslike mõjude analüüs. Uuringu aruanne. *[Socio-economic impact analysis of biorefinery. Analysis report.]* Accessible at http://www.centar.ee/uus/wp-content/uploads/2017/03/Puidurafineerimistehase-sotsiaalmajanduslik-analüüs.pdf

CEPI (2003). *Wood and Paper Products Store Greenhouse Gases. The story of carbon in wood and paper products.* CEPI.

CEPI (2017). *Framework for Carbon Footprints for Paper and Board Products.* Confederation of European Paper Industries. Accessible at http://www.cepi.org/node/21490

Eesti Energia (2008). *Certified Environmental Product Declaration (EPD®) for Oil Shale Electricity from the Circulating Fluidized Bed Combustion (CFB) Blocks of the Narva Power Plants.*

Environmental Agency (2017). Eesti Mets 2016.

EKA Chemicals (2005). *Certified Environmental Product Declaration (EPD) for Sodium chlorate ($NaClO_3$).* Accessible at http://www.dantes.info/Publications/Publication-doc/EPD%20NaClO3.pdf

IPCC (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

ISO (2013). *Greenhouse gases – Carbon footprints of products – Requirements and guidelines for quantification and communication.* Technical specification, International Organization for Standardization (ISO/TS 14067:2013).

Johnson, E. (2009). *Goodbye to carbon neutral: Getting biomass footprints right.* Environmental Impact Assessment Review 29, 165–168.

JRC (2016). *The European Commission Product Environmental Footprint (PEF) Category Rules (PEFCR) for Intermediate Paper Products.* Final draft.

LIPASTO (2017). LIPASTO – calculation system for traffic exhaust emissions and energy use in Finland. Accessible at www.lipasto.fi

NCASI (2007). *The greenhouse gas and carbon profile of the global forest products industry.* Special Report No. 07-02. Research Triangle Park, N.C.: National Council for Air and Stream Improvement, Inc.

NCASI (2005). *Calculation Tools for Estimating Greenhouse Gas Emissions from Pulp and Paper Mills.* The Climate Change Working Group of The International Council of Forest and Paper Associations (ICFPA).

NIR Estonia (2017). *Greenhouse gas emissions in Estonia 1990-2015.* National inventory report to European Commission.

NIR Latvia (2017). *Latvia's National inventory report 1990-2015.*

Miner, R. (2007). *Clearing the air about biomass carbon neutrality.* Paper 360.

Moora, H; Lahtvee, V (2009). *Electricity Scenarios for the Baltic States and Marginal Energy Technology in Life Cycle Assessments – a Case Study of Energy Production from Municipal Waste Incineration.* Oil Shale, 26(3 Special), 331 – 346.

Pihkola, H., Nors, M., Kujanpää, M., Helin, T., Kariniemi, M., Pajula, T., Helena Dahlbo, H. ja Koskela, S. (2010). *Carbon footprint and environmental impacts of print products from cradle to grave. Results from the LEADER project (Part 1).* VTT Tiedotteita – Research Notes 2560.

Skog, K., and Nicholson, G. (1998). *Carbon cycling through wood products: the role of wood and paper products in carbon sequestration.* Forest Products Journal vol. 48, no. 7/8.

Statistics Estonia (2017). Statistical database.

Suhr, M., Klein, G., Kourti, J., Gonzalo, M.R., Santonja, G.G., Roudier, S., Sancho, L.D. (2015). *Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board. Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).* JRS Science and Policy Reports. Accessible at http://eippcb.jrc.ec.europa.eu/reference/BREF/PP_revised_BREF_2015.pdf

University of Tennessee Center for Clean Products (2008). *Limestone Quarrying and Processing: A Life-Cycle Inventory.*

Urbel-Piirsalu, E. (2010). *The Estonian forest sector in transition to sustainability? Capturing sustainability with the help of integrated assessment.* Doctoral thesis, Lund University.

Zaļās mājas (2017). *2017 Latvian forest sector in facts and figures.*