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From forest to wood product: comparing the carbon flux effect of naturally generated birch and planted Norway spruce in western Norway

Documentation of a life cycle analysis of CO2-emissions relating to harvesting of wood to production of selected wood products, and an analysis of the theoretical CO2-reduction effect of substituting selected CO2-intensive products with selected wooden products

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1 Introduction

Forest management is an important tool for mitigation of CO_2-emissions. Forests have a sink function; they retrieve CO_2 from the atmosphere during photosynthesis. They are also harvested, and a properly managed forest will have a near carbon balance while the sink that is removed is replaced by growing trees which have a larger carbon uptake. The balance is reached over a rotation period which is how long it takes for new trees to sequester the same amount of carbon as the ones that were harvested.

Forest management is not only about finding the right volume to harvest, but also about using harvested wood for the right products. Wood products store carbon that otherwise would have been released into the atmosphere through combustion or decay. They may also substitute non-wood or lower-wood materials produced by consuming fossil fuel, given that the products have the same function. Thus, by substituting fossil-based materials such as cement, concrete and steel, wood products are contributing to avoided emissions of CO_2. Also, the longer the rotation period, the more important it is for carbon from harvested wood to be stored in products with longer lifetime rather than being burnt for energy production. This shortens the time it takes for new trees to achieve carbon balance.

This report presents an LCA analysis for wood harvesting in Western Norway. The analysis is very much based on a previous analysis for Eastern Norway by Timmermann & Dibdiakova[1]. The analysis presented here uses input specifically for Western Norway. This region is characterized as more mountainous as the rest of Norway with long fjords carved out by glaciers still active. The landscape is steep and, in many parts, not very suited for wood harvesting. Transport of harvested wood often takes place on narrow, winding

[1] Timmermann, V., & Dibdiakova, J. (2013). KLIMAGASSUTSLIPP I SKOGBRUKET – FRA FRØ TIL INDUSTRIPORT Vugge-til-port livsløpsanalyse (LCA). Rapport fra Skog og Landskap, 20/2013. Norwegian Forest and Landscape Institute. ISBN 978-82-311-0198-7.

roads that do not accommodate the largest timber trucks. Three quarters of all wood harvested in Western Norway is exported, most often by boat transport to Denmark and Germany. The wood is therefore mostly transported by trucks to the nearest timber quay.

The LCA analysis presented here is for wood harvested and delivered to timber quay in Western Norway. It is a cradle-to-gate analysis where the timber quay is a proxy for production gate. The analysis is therefore based on the precondition that production takes place in Western Norway. As such, the purpose of the analysis is to show the potential for local use of resources in mitigation of climate gas emissions.

The data presented in this report is the basis for the following article: Simonsen, M., Kjønnaas, J.O, Aall, C. (2022): Substitution of fossil-energy intensive building materials by wood products – does it matter? A case study from Western Norway. Journal of Cleaner Production, 134941, https://doi.org/10.1016/j.jclepro.2022.134941

2 LCA Wood harvesting

Estimates for wood harvesting are usually normalized to 1 m^3. It is therefore appropriate to ask what the unit measures, what is contained in different applications of it. Is it the volume of standing trees, the volume delivered at forest road, or the volume delivered from sawmill gate?

In German [2], there is a distinction between Vfm ("Vorratsfestmeter") and Efm ("Erntefestmeter"). They are both measurement of a volume of 1 m^3. One Vfm ("Vorratsfestmeter") is defined as the volume of wood containing of standing trees with a diameter of 7 cm at a height of 1.3 meter. This includes bark and residual tree loss. One Efm is the volume of harvested wood exclusive bark and residual wood. 1 Efm = 1 m^3 of piled logs exclusive bark without air space between them. A rule of thumb is that 1 Efm = 1 Vfm -0.1 Bark-0.1 Residual loss.

When logs are loaded on a truck, there is in German a measurement called Raummeter (Rm) which is 1 m^3 of timber logs inclusive air space between logs. A rule of thumb: 1 Rm with bark= 0.75 m3 with bark (but with air spaces) [3].

The residual losses may be hacked into chips. These are measured in heaps like sawdust and bark. A Schüttraummeter (Srm) is 1 m^3 of residual wood resources and it is roughly assumed that 1 Srm = 0.4 Fm.

The volume of timber with bark delivered to a sawmill is called gate-entrance volume (German: "Werkseingangmass", or Wfm). This is a bit smaller than Efm ("Erntefestmeter") since some of the wood with inferior quality is left behind at the harvest site. Also, logs are transported with bark to the gate entrance of

[2] Rohstoffmonitoring Holz:Erwarungen und Möglichkeiten. Bundesministerium für Ernährung und Landwirtschaft. https://www.charta-fuer-holz.de/fileadmin/charta-fuer-holz/dateien/service/mediathek/Broschuere_Rohstoffmonitoring_Holz_Web_neu.pdf

[3] Umrechnungsfaktoren Waldholz und Restholz. Schweizerische Interessengemeinschaft Industrieholz. http://www.holz-bois.ch/fileadmin/his/Dokumente/Verband/FG_Industrieholz/Umrechnungsfaktoren-IGIH08_D.pdf , see also https://de.wikipedia.org/wiki/Festmeter

the sawmill or pulpwood mill, but the bark itself is not included in the volume delivered at this gate. A rule of thumb is that 1 Wfm=0.6Vfm.

Timber leaving a sawmill is called product volume (German: "Produktmass"). This is timber logs cut into boards or plank. This is the volume leaving the production gate.

This discussion shows that the unit 1 m^3 is far from unambiguous. When comparing different estimates for energy use and emissions from wood harvesting or wood production it is therefore important to carefully document what volume energy use and emissions are related to. Is the volume measured with or without bark? With or without residual harvest loss? Is the volume related to gate entrance or to leaving the production gate as finished product from e.g. a sawmill?

It is assumed that the Norwegian concept of "avvirket tømmer" is identical to the German concept of Vorratsfestmeter, the volume of standing trees harvested.

Timmermann & Dibdiakova [4] present an LCA analysis of logs with bark delivered to production plant gate. This analysis includes transport from wood harvesting site to the production gate. The estimates are made with the software SimaPro. Input for the different activities are obtained from Norwegian research literature (e.g. hours spent using machines, type of machines used, average transport length etc.). The analysis includes the activities shown in Table 1. The table also shows emissions of CO_2-eq. per m^3. The emissions are weighted with how much each activity contributes towards the total volume of wood harvested in Norway. This volume was 8 396 000 m^3 in 2010 [5]. 13% of the final volume was allocated to thinning while 85% was allocated to clearfell and 2% was allocated to harvesting with crane and cableway in steep terrain. Of the harvested timber, 52% was used for production of sawed logs while 48% was used for pulpwood. All estimates are

[4] Timmermann, V., & Dibdiakova, J. (2013). KLIMAGASSUTSLIPP I SKOGBRUKET – FRA FRØ TIL INDUSTRIPORT Vugge-til-port livsløpsanalyse (LCA) Prosjektrapport fra KlimaTre. Table 16.

[5] "Avvirkningsvolumet i 2010 var på 8 396 000 m3". Timmermann & Dibdiakova, page 3

normalised to clearfelled volume or "Vorratsfestmeter", the volume of standing trees harvested [6].

Table 1 Energy use and emissions per activity in cradle-to-gate entrance LCA

Activity	kWh per m^3	MJ per m^3	kg CO_2-eq per m^3 [7]
Planting	0.68	2.46	0.22
Seed and seeding production	0.04	0.14	
Site preparation	0.40	1.44	0.093
Reforestation	0.04	0.13	
Tending	0.20	0.73	0.14
Spraying	0.003	0.0118	0.0032
Fertilization	0.01	0.0396	0.089
Pruning	0.01	0.0247	0.001
Forest road construction	1.65	5.93	0.19
Forest road reconstruction	1.90	6.83	0.22
Thinning	3.91	14.07	1.08
Terrain transport while thinning	2.16	7.79	0.56
Clearfell	11.46	41.25	2.87
Terrain transport while clearfelling	10.22	36.78	2.79
Harvesting with cable crane/ cableway	1.80	6.48	0.29
Timber transport, road	28.85	103.86	8.49
Timber transport, rail	2.00	7.21	0.81

[6] The volume calculations are based on a) Spruce: Bauger, E., 1995: Gran med bark, b) Birch: Braastad, 1995: Bjørk med bark,c) Bauger, E., 1995: Tree volume functions and tables. Scots pine, Norway spruce and Sitka spruce in western Norway. Norsk Institutt for skogforskning og institutt for skogfag NLH, Ås. Rapport fra Skogforsk 16/95.(In Norwegian with English summary), d) Braastad, H. 1966. Volumtabeller for bjørk. Meddelelser fra Det norske Skogforsøksvesen 21:23-78

7 Taken from Timmemann & Dibdiakova, page 11.

Sum	65.33	235.18	17.85
For sawn logs	33.97	122.29	9.28

The last column is taken from Timmermann & Dibdiakova [8]. The columns for energy use are calculated using input from Timmermann & Dibdiakova and energy use factors from Appendix A including upstream energy use, e.g. energy required for transforming the energy source into the energy carrier. The energy content is called the embedded energy, this is the energy source transformed into some useful energy carrier. The upstream energy required for that transformation is called the embodied energy. We may refer to it as the energy's energy. The "embodied energy of a material is the primary energy that is associated with the extraction, processing and transportation of that material from the cradle to the factory gate" [9]. The embedded energy of a wood product is the energy recovered when the product is incinerated.

All energy use and emissions are normalised to total harvested volume which was 8 396 000 m^3 in 2010.

According to Table 1, transport from forest road to production gate is the activity with the largest emission of CO_2 per m^3. This is followed by clearfell and terrain transport for clearfell.

The LCA analysis from Timmermann & Dibdiakova will be a reference case in the following. This is a transparent and well documented analysis. In addition to this analysis, several other LCA analysis with roughly the same system borders will also be presented for comparison. This allows for triangulation, assessing the validity and soundness of different analysis and their assumptions by contrasting them with other roughly identical analysis.

The LCA analysis from Timmermann & Dibdiakova does not distinguish between different type of trees (spruce, pine, birch etc).

[8] Emissions for planting include seeds and seeding production. Emissions for harvesting with cable crane include "heltreavvirkning"

[9] Hill, C and Zimmer, K.: The environmental impacts of wood compared to other building materials, NIBIO RAPPORT VOL 4, NR 56, 2018, page 29

2.1 Activities defined per hectare

Some energy and emissions are calculated per decare [10] and not per m3. Table 2 shows these activities as given by Timmermann & Dibdiakova [11] with the given number of hectares per activity.

Table 2 Activities defined per decare

Activity	Hectares
Site preparation	4309
Reforestation	11938
Tending (ungskogpleie)	27233
Spraying	658
Fertilization	572
Pruning	420
Total decare	45131

Equation 1 Calculation of energy use for reforestation per total harvested m3

$$\frac{Energy-use_{reforestation}}{Total-harvested\ volume\ m^3} = \frac{Energy-use_{reforestation}}{Harvested\ area\ _{reforestation}-hectare} * \frac{Harvested\ area\ _{reforestation}-hectare}{Total-harvested\ volume\ m^3}$$

For these activities, the total energy use (and emissions) are calculated using relevant area use as shown in Table 2 and then divided by total harvested volume. This calculation is shown in Equation 1 using reforestation as an example.

[10] One decare is one tenth of a hectare and is a area measurement used in Norway, see https://en.wikipedia.org/wiki/Hectare#Deciare

[11] Timmermann & Dibdiakova, page 4-6.

2.2 Energy use by activity

In the following section, the estimates for energy use for different wood harvesting activities will be presented. The input is taken from Timmermann & Dibdiakova. Their report does not report energy use, but emissions of CO_2-equivalents for the same activities are reported. The input will also be used for estimation of energy use and emissions for the same activities in Western Norway with relevant revision of input adjusted to harvesting in that area. The energy use factors applied are presented in Appendix A. All factors used include upstream energy, that is energy required to transform the energy source to a usable energy carrier.

Table 3 Input, output and energy use by activity

Type	Activity	Value	Unit	Energy use	Remark
Output	**Seed and seeding production**	**1**	**kg**	**kWh**	
Input	seeds production	1	kg		
Input	electricity	833	kWh	833.0	
Input	heating oil	20	litre	278.5	
Output	**Planting**	**1000**	**pieces**		
Input	seeds	0.02	kg		
Input	electricity	40	kWh	40.0	
Input	heating oil	20	litre	246.6	
Input	fertilizer	0.5	kg		
Input	insecticides	0.1	kg		
Output	**Site preparation**	**1**	**ha**		
Input	forwarder, production	2.3	kg		use of a machine (including the production of the machine)
Input	forwarder, operation time	2	hours		
Input	forwarder, fuel usage	48	litre	668.3	
Input	forwarder, transport machine displacement	68	tkm (tonnxkm)	103.3	
Input	Transport, personal car	11.4	car km	9.7	

Output	**Reforestation**	**1**	**ha**		
Input	workers, time used	4.5	hours		
Input	workers, transport (to the site)	22.7	car km	19.3	
Input	plants	1700	pieces		
Input	transport of plants to the forest site (van)	1.7	tkm	5.7	
Output	**Tending (ungskogpleie)**	**1**	**ha**		
Input	workers, time used	5	hours	10.0	Assuming gasoline as fuel for chain saw
Input	workers, transport (to the site)	40	car km	34.0	
Input	time spent on cleaning site (ryddesagbruk)	6	hours	12.0	Assuming gasoline as fuel for chain saw
Product	Spraying	1	ha		
Input	Helicopter, usage time	0.04	hours	40.9	
Input	Pilot, personal transport	0.3	car km	0.26	
Input	pesticide	3.5	kg		
Input	transportation of the pesticide to the forest (van)	0.2	tkm	0.67	
Output	**Fertilization**	**1**	**ha**		
Input	Helicopter, usage time	0.05	hours	51.1	
Input	Pilot, personal transport	0.3	car km	0.26	
Input	fertilizer	550	kg		
Input	transportation of the fertilizer to the forest (van)	33	tkm	110.13	
Output	**Pruning**	**1**	**ha**		
Input	workers, time used	20	hours	40.0	Assuming workers using chain saw
Input	workers, transport (to the site)	100	car km	85.1	
Output	**Forest road building**	**1**	**km**		
Input	clearfell including terrain transport	92	m3		
Input	Machines usage	102	hours	41310.0	Assumed diesel

Input	Machines transport (displacement)	3221	tkm	4893.6	Assumed truck <18 tonne
Input	gravel	1800	tonne		
Input	gravel transport til forest (van)	36000	tkm	120140.1	
Input	Transport, personal car	478	car km	406.836	
Input	area change (from forest to the road)	0.4	ha		
Output	**Forest road reconstruction**	**1**	**km**		
Input	Machines usage	31	hours	12555.0	
Input	Machines transport (displacement)	515	tkm	782.430	Assumed truck <18 tonne
Input	gravel	600	tonne		
Input	gravøl transport til forest (van)	12000	tkm	40046.7	
Input	Transport, personal car	120	car km	102.1	
Output	**Thinning**	**1**	**m3**		
Input	harvester (harvesting machine), production	0.3	kg		
Input	harvester, working time	0.2	hours		
Input	harvester, fuel usage	1.9	litre	26.5	Assumed diesel
Input	harvester transport, displacement	1.6	tkm	2.4	Assumed truck<18 tonne
Input	transport, personal car	1.4	car km	1.19	
Output	**Terrain transport while thinning**	**1**	**m3**		
Input	forwarder, production	0.1	kg		
Input	forwarder, operation time	0.1	hours		
Input	forwarder, fuel usage	1	litre	13.92	Assumed diesel
Input	forwarder, transport machine displacement	1.4	tkm	2.13	Assumed truck<18 tonne
Input	Transport, personal car	0.7	car km	0.596	
Output	**Clearfell**	**1**	**m3**		
Input	harvester (harvesting machine), production	0.1	kg		

Input	harvester, working time	0.1	hours		
Input	harvester, fuel usage	0.9	litre	12.53	Assumed diesel
Input	harvester transport, displacement	0.4	tkm	0.61	Assumed truck<18 t
Input	transport, personal car	0.4	car km	0.34	
Output	**Terrain transport while clearfelling**	**1**	**m3**		
Input	forwarder, production	0.1	kg		
Input	forwarder, operation time	0.1	hours		
Input	forwarder, fuel usage	0.8	litre	11.14	Assumed diesel
Input	forwarder, transport machine displacement	0.3	tkm	0.46	Assumed truck<18 t
Input	Transport, personal car	0.5	car km	0.43	
Output	**Harvesting with cable crane/ cableway**	**1**	**m3**		
Input	Chain saw usage	0.1	hours	0.20	Gasoline
Input	cable crane, fuel usage	1.7	litre	23.67	Diesel, assumed being run by a tractor
Input	Harvester, fuel usage	2.1	litre	29.24	Diesel
Input	forwarder, fuel usage	0.8	litre	11.14	Diesel
Input	Machines production	0.6	kg		
Input	Machines, usage time	0.1	hours		
Input	Machines, displacement	15.3	tkm	23.25	Assumed truck<18 t
Input	Transport, personal car	2.8	car km	1.84	Gasoline
Output	**Timber transport, road**	**1**	**m3**		
Input	saw logs transport	23.1	tkm	14.4	Assumed truck >18t
Input	pulp wood transport	25.3	tkm	15.77	Assumed truck >18t
Input	loading and unloading, diesel usage	0.3	litre	4.18	
Output	**Timber transport, rail**	**1**	**m3**		
Input	saw logs transport electric train	7.4	tkm	0.37	Energy use factor based on Austria

Input	saw logs transport, diesel train	0.8	tkm	0.13	Energy based on transport.vestforsk.no, emissions on diesel property
Input	pulp wood transport, electric train	161	tkm	8.05	Energy use factor based on Austria
Input	pulp wood transport, diesel train	16.3	tkm	2.58	Energy based on transport.vestforsk.no, emissions on diesel property
Input	loading and unloading, diesel usage	0.1	litre	1.39	

It is assumed that 1 m3 is not the same unit for all activities in Table 3. For instance, 1 m3 transported timber is not the same as 1 m3 of thinning. Energy use for some activities is also reported per hectare. Therefore, in the following, all activities will be normalised to the same unit, 1 m3 of harvested or clearfelled volume.

Thinning

Equation 2 shows the energy use is normalized to total harvested volume in Norway 2010. For clearfelling, terrain transport for clearfelling, transport by road and rail, harvesting with crane and cable way the same approach is applied.

Equation 2 Calculation of energy use for thinning per total harvested m3

$$\frac{Energy - use_{thinning}}{total - harvested - volume\ m^3} = \frac{Energy - use_{thinning}}{Harvested\ volume\ _{thinning}\ m^3}$$

Table 4 shows the estimate for energy use for thinning normalised to total harvested volume in Norway 2010.

Table 4 Energy use for thinning normalised to total harvested volume Norway 2010

Thinning	Value	Unit	kWh
Sum per 1 m3			30.07638
Total volume thinning	1091000	m3	32813330
Total volume harvested Norway 2010	8 396 000	m3	3.9

Table 5 shows the estimate for energy use for terrain transport while thinning normalised to total harvested volume in Norway 2010.

Table 5 Energy use for terrain transport while thinning normalised to total harvested volume Norway 2010

Terrain transport while thinning	Value	Unit	kWh
Sum per 1 m3			16.6
Total volume thinning	1091000	m3	18160694
Total volume harvested	8396000	m3	2.16

2.3 Site preparation

Table 6 shows the estimate for energy use for site preparation normalised to total harvested volume in Norway 2010.

Table 6 Energy use for site preparation normalised to total harvested volume in Norway 2010

Sum per ha	1	ha	781.3
Total ha	4309	ha	3366727
Total harvested volume	8396000	m3	0.40

Tending

Table 7 shows energy use for tending normalized to 1 m3 of clearfelled volume in Norway 2010.

Table 7 Energy use for tending normalised to total harvested volume Norway 2010

Tending	Value	Unit	kWh
Sum per ha	1	ha	62.6
Total ha activity Norway	27233	ha	1705067
Total harvested volume Norway 2010	8396000	per m3	0.20

Reforestation

Table 8 shows the energy use for reforestation normalised to total harvested volume in Norway 2010.

Table 8 Energy use for reforestation normalised to total harvested volume

Reforestation	Value	Unit	kWh
Sum per ha	1	ha	24.99374
Total ha Norway 2010	11938	ha	298375.3
Total harvested volume Norway 2010	8396000	m3	0.035538

Pruning

Table 9 shows the energy use for pruning normalised to total harvested volume in Norway 2010.

Table 9 Energy use for pruning normalised to total harvested volume

Pruning	Value	Unit	kWh
Sum per ha	1	ha	137.1
Total ha	420	ha	57560.7
Total harvested volume	8396000	m3	0.007

Fertilization

Table 10 shows the energy use for fertilization normalised to total harvested volume in Norway 2010.

Table 10 Energy use for fertilization normalised to total harvested volume

Fertilization	Value	Unit	kWh
Sum per ha	1	ha	161.5

Total ha	572.3	ha	92433.8
Total harvested volume	8396000	m3	0.011

Spraying

Table 11 shows the estimate for energy use for spraying normalised to total harvested volume in Norway 2010.

Table 11 Energy use for spraying normalised to total harvested volume

Spraying	Value	Unit	kWh
Sum per ha	1	ha	41.8
Total ha	658.4	ha	27538.31
Total harvested volume	8396000	m3	0.00328

Transport

Timmermann & Dibdiakova state that almost all transport of timber to saw mills is done by truck. This is equivalent to almost 4.4 million m3. One third of timber for pulp mills was transported using rail [12]. The rest is assumed to be transported by truck. This gives a total of 7.05 million m3 of harvested timber transported by road and 1.34 million m3 transported by rail. The energy use and emissions given per m3 for road by Timmermann & Dibdiakova are normalised to total harvested volume using Equation 3. The same procedure is used for rail.

Equation 3 Calculation of energy use for road transport per total harvested m3

$$\frac{Energy-use_{road-transport}}{Total-harvested\ volume\ m^3} = \frac{Energy-use_{road-transport}}{m^3} * \frac{Volume\ _{road-transport}-m^3}{Total-harvested\ volume\ m^3}$$

[12] ibid., page 9.

Table 12 shows the estimate for energy use for road transport normalised to total harvested volume based on Equation 3.

Table 12 Energy use for road transport normalised to total harvested volume

Transport by road	Value	Unit	kWh
Sum per 1 m³			34.3
Total volume by road Norway	7052640	m3	242218764.6
Total harvested volume Norway	8396000	per m3	28.8

Planting

Energy use and emissions of CO_2-equivalents for activity planting is given per 1000 plants. A total of 20 million plants were produced in Norway in 2010. The energy use and emissions for 1000 plants are multiplied with number of plants and then divided by the total harvested volume. Equation 4 shows the calculation for energy use and emissions from activity planting.

Equation 4 Calculation of energy use for planting transport per total harvested m³

$$\frac{Energy-use_{planting}}{Total-harvested\ volume\ m^3}=\frac{Energy-use_{planting}}{1000\ plants}*\frac{Plants\ 1000's}{Total-harvested\ volume\ m^3}$$

Table 13 shows the estimate for energy use for planting normalised to total harvested volume in Norway 2010.

Table 13 Energy use for planting normalised to total harvested volume Norway 2010

Planting	Value	Unit	kWh
Sum	1000	Pieces	286.6
Plants (1000)	20000	Plants	5732058
Total harvested volume Norway 2010	8396000	m3	0.68

Seed and seeds production

Energy use and emissions for activity seeds are given per kg. A total of 300 kg seeds was produced in Norway in 2010. Equation 5 shows how energy use and emissions for this activity is normalised per total harvested volume.

Equation 5 Calculation of energy use for seeds per total harvested m3

$$\frac{Energy - use_{seeds}}{Total - harvested\ volume\ m3} = \frac{Energy - use_{seeds}}{kg} * \frac{Total\ kg\ seeds}{Total - harvested\ volume\ m3}$$

Table 14 shows the estimate for energy use for seed and seed production normalised to total harvested volume in Norway 2010.

Table 14 Energy use for seed and seed production normalised to total harvested volume Norway 2010

Seed and seed production	Value	Unit	kWh
Sum for kg	1	kg	1111.5
Total kg seed	300	kg	333438.8
Total harvested volume Norway 2010	8396000	m3	0.039714

Crane harvesting

Table 15 shows the estimate for energy use for crane harvesting normalised to total harvested volume in Norway 2010.

Table 15 Energy use for crane harvesting normalised to total harvested volume Norway 2010

Crane harvesting	Value	Unit	kWh
Sum per 1 m3			89.9
Total harvested volume crane/cableway	168000	m3	15108955
Total harvested volume Norway 2010	8396000		1.8
Fraction harvested by crane	2.0%		

Clear-fell

Table 16 shows the estimate for energy use for clearfelling normalised to total harvested volume in Norway 2010.

Table 16 Energy use for clearfelling normalised to total harvested volume Norway 2010

Clearfell	Value	Unit	kWh
Sum per 1 m3			13.5
Total volume clearfell	7137000	m3	96199510
Total volume harvested Norway 2010	8396000	m3	11.5

Table 17 shows the estimate for energy use for terrain transport while clearfelling normalised to total harvested volume in Norway 2010.

Table 17 Energy use for terrain transport while clearfelling normalised to total harvested volume Norway 2010

Terrain transport while clearfelling	Value	Unit	kWh
Sum per 1 m3			12.02
Total volume clearfell	7137000	m3	85785702
Total volume harvested	8396000	m3	10.2

Forest road

Equation 6 shows the equation for estimating energy use for forest construction. The values for km and harvested volume are for Norway 2010. The same equation is used for forest road reconstruction.

Equation 6 Energy use for forest construction normalised to total harvested volume

$$\frac{kWh}{m^3} = \frac{kWh}{km} * km * \frac{1}{totalharvested - volume - m^3}$$

Table 18 shows the estimate for energy use for forest road construction and reconstruction in Norway 2010.

Table 18 Energy use for forest road construction and reconstruction normalised to total harvested volume Norway 2010

Forest road	Value	Unit	kWh
Sum per km construction			166750.5
Sum per km reconstruction			53486.3
Total length new forest roads Norway 2010	83	km	13840293
Total length forest road reconstruction Norway 2010	298	km	15938905
Forest road building per m3	8396000	m3	1.65
Forest road reconstruction per m3	8396000	m3	1.9

2.4 Comparison of different estimates for wood harvesting

Table 19 shows different estimates for production of 1 m^3 of wood. The last column to the right explains what is included in these estimates. The purpose of this section is to validate the estimates for energy use and emissions from Timmermann & Dibdiakova by contrasting them with other corresponding estimates.

The estimate closest to Timmermann & Dibdiakova is the first estimate from ProBas [13], but this estimate contains no information on transport from forest road to production gate. Still, this estimate is about 1.6 times higher than the estimate from Timmermann & Dibdiakova.

The functional unit in Timmermann & Dibdiakova is 1 m^3 of harvested timber [14].

[13] ProBas=Prozessorientierte Basisdaten für Umweltmanagementsysteme, Online database from German Environment Agency, http://www.probas.umweltbundesamt.de/php/index.php

[14] "Funksjonell enhet (FU) er 1 m3 avvirket tømmer under bark." Timmermann & Dibdiakova, page 3.

The functional unit in estimates from ProBas is 1 kg of different wood products. The estimates are recalculated with m^3 as functional unit using the wood products' density as shown in Equation 7. The densities differ for different products as shown in Table 19.

Equation 7 Recalculating from kg to m^3 as functional unit

$$\frac{MJ}{m^3} = \frac{MJ}{kg} * \frac{kg}{m^3}$$

Table 19 Different estimates for production of 1 m^3 of wood

	MJ/ m^3	CO_2-eq/m^3	Density kg/m^3	Explanation
ProBas I [15]	379.0	7.4	430	Cradle-to-forest road. Logs delivered for transport to production gate. With bark. Logs not stacked on truck.
ProBas II [16]	1808.0	50.66	731	Produced timber from sawmill. Unplaned. No information on transport to production gate.
ProBas III [17]	2846.5	123.3	495	Planed timber from sawmill.
CORRIM [18]	258.0	17	168	Hardwood at forest road. No information on forest road construction or reconstruction.
González-García et al. [19]	370.0	36.1	765	Embodied energy of 370 MJ/m3 under bark for spruce production in Sweden. Assumed cradle-to-gate-entrance. No information on forest road building or transport.

[15] Internal reference Forst-D&EStamm-Fichte-atro-DE

[16] Internal reference HolzWirtschaftSchnittholz-Fichte

[17] Internal reference HolzWirtschaftHobelware-Fichte

[18] Puettmann, M., Bergman, R., Oneil, E.:Cradle-To-Gate Life Cycle Assessment of North-American Hardboard and Engineered Wood Siding and Trim Production, https://www.fs.usda.gov/treesearch/pubs/52618

[19] Taken from Hill, C and Zimmer, K.: The environmental impacts of wood compared to other building materials NIBIO RAPPORT VOL 4, NR 56, 2018.

Lumber ("Skurlast") [20]	2955	43	450	Sawn, unplaned timber from spruce or pine. Gradle-to-gate. EDP from Norwegian Wood Industries Association.
Schnittholz Fichte [21].	2120.1	29.9	482	Sawn, unplaned timber from spruce. Gradle-to-gate. Estimate from Ökobau [22].

The EPD from Norwegian Wood Industries Association does not differ between activities A1-A3. A1 is harvesting the wood, A2 is transporting it to production gate and A3 is manufacturing timber at the sawmill. These activities are aggregated together in the EPD. Also, the EPD gives a negative estimate for Global Warming Potential of -672 kg CO_2-equivalents for 1 m^3 of sawed timber. This represents the CO_2 calculated from carbon stored in the wood minus emissions of CO_2-equivalents from harvesting, transport and production. The estimate for CO_2 storage is given as 715 kg CO_2 in the EPD [23]. This number represents the amount of CO_2 that would be released into the atmosphere if the carbon stored in the wood would oxidise through combustion of it.

Adding 715 kg CO2 to the -672 kg CO_2-equivalents gives 43 kg of CO_2-equivalents for harvesting, transporting and manufacturing the sawn timber in the EPD. This estimate is the gross emissions for these activities, not considering any carbon store in the produced timber.

One problem with *Table 19* is that the estimates are not normalized to the same definition of m^3. The volume has different definitions as discussed in the introduction. The densities in the table also shows that the definition of volume is not identical for different estimates. Some densities are for dried

[20] https://www.moelven.com/globalassets/certificates-and-policies/epd/epd-moelvenwood-skurlast-g-f-nepd-307-179-no-skurlast-av-gran-eller-furu-gk.pdf

[21] The carbon fraction is given as 195.5 kg. Using atomic mass weight of CO2 vs weight of carbon, this gives 724 kg CO_2 stored per m^3. Net emissions of CO2-equivalents are given as -694.1 allowing for carbon storage in product. Adding stored CO_2 to net emissions give gross emissions of 29.9 kg CO_2 per m^3.

[22] https://oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=3057d7c0-7bee-4ba2-9edf-517d4cd97a14&stock=OBD_2019_III&lang=de

[23] This assumes a carbon fraction of 0.5 of produced dry mass. The density is set to 390 kg/m^3 which gives 195 kg carbon. This figure is multiplied with 44/12 which is atomic mass of CO_2 relative to atomic weight of carbon. This gives 715 kg CO_2 stored per m3.

wood while other are for raw wood from forest ("green state", prior to shrinking [24]). The density for the Probas I estimate is for dried timber.

The estimate from Timmermann & Dibdiakova is distributed on total harvested volume, including branches, treetops and other residual harvest mass that is not converted into logs. The volume used in the estimate from ProBas is the volume of logs at forest road. The volume used in the EPD is based on sawn logs. These volumes presumably do not take residual losses into consideration.

In order to make the estimates comparable, we need a volume-equivalent measurement that takes account of how much volume (m^3) of standing trees ("green state") that is necessary in order to produce 1 m^3 of logs delivered at forest road or sawn timber. The UN agency UNCE specifies a conversion factor of 1.67 m^3 of roundwood to 1 m^3 of sawn wood [25] for Germany. By using this conversion factor, volume of sawn wood is converted to roundwood or "green state" equivalents. This approach is used for the EPD where all energy use and emissions are presumably allocated on 1 m^3 of finished product ("Produktmass"). The estimate for " Schnittholz Fichte" is corrected in the same way, where the original estimates for energy use and gross emissions of CO_2 are divided by the conversion factor.

The ProBas estimates are given in mass. They are converted to volume by using the density given for the estimates. According to ProBas, 2.33 m^3 of harvested spruce wood with bark (Efm with bark) is required for 1 tonne of dried wood from spruce ("Absolut trocken"). This factor corrects for different humidity in wood when going from "green state" to finished product. The volume Efm ("Erntefestmeter") does not normally include 10% bark and 10% residual harvest loss [26]. In this case, bark is included but presumably not residual harvest loss. The factor is therefore corrected for this fraction as described in Equation 8 where f' is corrected factor, f is the uncorrected factor (2.33) and rf is the residual harvest loss fraction which is 10% or 0.1 used in the equation.

[24] United Nations Economic Commission For Europe: Forest Product Conversion Factors For The UNCE Region, Geneva Timber And Forest Discussion Paper 49, Geneva 2010, page 8

[25] ibid., page 12.

[26] https://www.charta-fuer-holz.de/fileadmin/charta-fuer-holz/dateien/service/mediathek/Broschuere_Rohstoffmonitoring_Holz_Web_neu.pdf

Equation 8 Correction of volume factor for residual harvest loss

$$f' = f * \frac{1}{1-rf}$$

The corrected volume factor is then 2.59. This correction factor is applied both on energy use and emissions of CO_2-equivalents to convert from mass-based to volume-based estimate.

This factor accounts for volume of residuals in addition to volume of logs delivered at forest road (Efm). This should make log volume at forest road equivalent to harvested volume. Estimates from ProBas may then be compared to estimates from Timmermann & Dibdiakova who distributes energy use and emissions on total harvested volume in Norway in 2010.

This gives the following procedure for converting from energy use per kg to corresponding energy use per m3 of harvested timer ("Vorratsfestmeter").

The last term in the equation below is the inverse of the volume factor (f') obtained for spruce from ProBas described above.

Equation 9 Converting from energy use per mass to energy use per volume

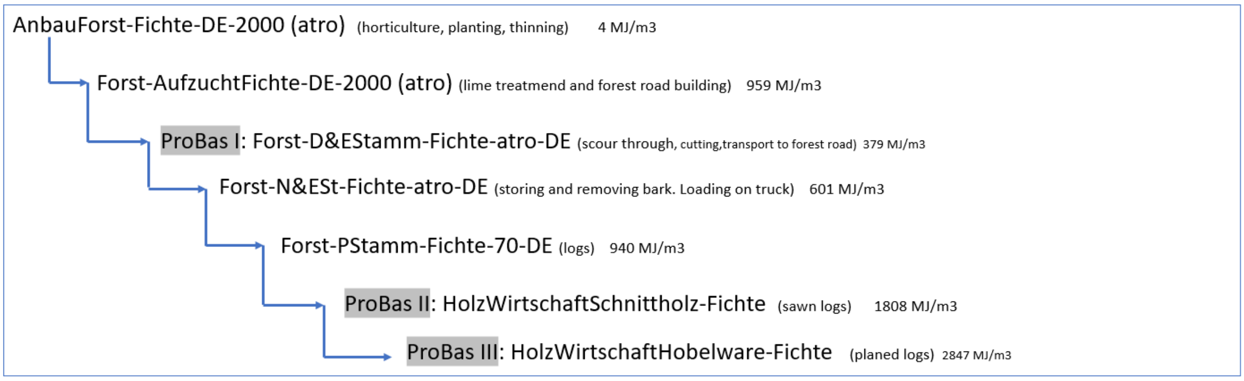
$$\frac{MJ}{m^3} = \frac{MJ}{tonne} * \frac{tonne}{m^3}$$

The functional unit for the ProBas estimates is 1 kg. We convert MJ/kg to MJ/tonne and divide by the volume required to produce that tonne of dried wood. The volume is found by multiplying 1 tonne with the factor above. This gives us the estimate in MJ/tonne which is converted into MJ/kg with volume corrected for density of dry wood and harvest residuals.

The ProBas estimates are nested in a hierarchy where estimate I is input for estimate II which again is input for estimate III. Figure 1 shows all involved ProBas estimates all up to ProBas II estimate. The figure shows what activities are included in each estimate and the energy use per m3 for each of them. The volume is calculated by using energy per kg and dividing by given density of wood for that estimate.

The estimates II and III may be corrected by subtracting the old value for estimate I and adding the new corrected value for it.

Figure 1 ProBas estimates



This conversion to volume-equivalents is important for interpretation of EPDs. Activities A1-A3 (extraction of raw materials, transport to production site, manufacturing) are normally reported as one sum. The emissions related to the activity A1, extraction of raw materials, are not known. With a model allowing for splitting energy use and emissions on activities A1-A3, it is possible to properly account for the effect of changes in stored carbon or effects from storage of carbon in soil or the finished product. Estimates of carbon storage will have a direct impact on the net emissions of GWP (Greenhouse Gas Potential in CO2-eq) in A1.

Net emissions consider potential CO_2 storage in wood in addition to gross emissions which are emissions related to activities A1-A3. The potential CO_2 storage is given as a negative number since emissions are avoided. Adding the gross emissions give the net emissions for any given unit such as e.g. kg or m^3 as shown in Equation 10.

Equation 10 Definition of net emissions for any given unit

$$Net - emissions - CO_{2-eq} = Potential - storage\ CO_2 + Gross - emissionsCO_2 - eq$$

It may be objected to the Timmermann & Dibdiakova analysis that they do not consider forest roads already established, only the ones constructed or maintained in 2010. The energy use and emissions for forest road construction and maintenance in 2010 is divided on the whole volume of harvested wood, 8.4 million m^3 for that year. This may underestimate the effect of road building since roads already constructed are not taken into the calculations at all. An alternative approach is suggested by Kraler et al in their LCA analysis of mountain wood from Tyrol [27]. Forest road building is considered in a seven-year interval and the energy and emissions related to that activity is allocated on the volume of wood required to be felled to open the forest area for road building. The volume used for normalization of energy use and emissions is therefore not harvested wood, but wood cleared for road building activities.

This approach is used here to assess the impact of forest road building. It is assumed that every year, 83 km of road is constructed. This corresponds to the amount built in Norway 2010 and it is the figure for forest road construction used in Timmermann & Dibdiakova. This road length is accumulated over seven years. This interval, as well as other numbers presented here, is taken from the Tyrol report. It is assumed that 21-meter forest road is built on a hectare. Further, 5 m^3 wood is felled per hectare per year for clearing area for the forest road. Equation 11 shows area required to build 581 (83*7) km forest road in 7 years. Equation 12 shows calculation of volume required for building that forest road length over the whole interval. This volume is divided by the total harvested volume in 2010 and the fraction is used as weight for normalizing energy use and emissions from forest road building and reconstruction for one year. This approach ensures that all energy use and emissions related to wood harvesting is normalised to the same unit, the total volume harvested in 2010.

Equation 11 Forest area in hectare required to build a given forest road length

$$forest - area_{hectare-interval} = \frac{road - length_{km-year} * \frac{m}{km} * years_{interval}}{meter_{hectare}}$$

Equation 12 Forest volume for road building per year

[27] Kraler, A., Krismer, V.,Wieland, G.: Gebirgsholz -Wald ohne Grenzen, Universität Innsbrück 2011, https://www.proholz-tirol.at/files/interregiva-gebirgsholz_oekobilanz-uibk.pdf

$$forest - volume_{m^3-interval} = \frac{m^3}{hectare_{year}} * years_{interval} * forest - area_{hectare-interval}$$

This correction gives 262 MJ/m3 and 27.2 kg CO_2-equivalents per m3 for the Timmermann & Dibdiakova estimate.

Table 20 Corrected estimates for production of 1 m3 of wood

	MJ/ m³	CO2-eq/m³	Density kg/m³	Explanation
ProBas I [28]	340	6.6	430	Cradle-to-forest road. Logs delivered for transport to production gate. With bark. Logs not stacked on truck.
ProBas II [29]	1770	49.9	731	Produced timber from sawmill. Unplaned. No information on transport to production gate.
ProBas III [30]	2808	122.6	495	Planed timber from sawmill.
Timmermann & Dibdiakova	235.10	17.9	765	Logs with bark delivered at production gate entrance. With road building. No allocation between sawn wood and pulp wood. Transport specified. Forest road construction/reconstruction as reported by the authors.
Timmermann & Dibdiakova	262.1	27.2	765	Same as above, but with forest road construction energy use and emissions distributed on volume for clearing road area in a 7-year interval.
Skurlast [31]	1769	25.7	450	Sawn, unplaned timber. Gradle-to-gate. EDP from Norwegian Wood Industries Association.

[28] Internal reference Forst-D&EStamm-Fichte-atro-DE

[29] Internal reference HolzWirtschaftSchnittholz-Fichte

[30] Internal reference HolzWirtschaftHobelware-Fichte

[31] Volume corrected by assuming av factor of 1.67 from roundwood to sawn wood.

Schnittholz Fichte	1270	17.9	482	Sawn, unplaned timber from spruce. Gradle-to-gate. Estimate from Ökobau.

2.5 Wood harvesting in Western Norway

This section presents a separate analysis of wood harvesting in Western Norway. The analysis uses the same model as Timmermann & Dibdiakova but with revised input specifically for Western Norway. The LCA analysis is for logs with bark delivered to production plant gate or to quay for export. The revised input is obtained from ATSkog which is a company that runs district organizations for the Association of Norwegian Forest Owners (Norsk Skogeierforbund) dated October 16th, 2019.

The following assumptions are made for the model:

- Western Norway comprises the counties Rogaland, Hordaland and Sogn og Fjordane.
- There is no thinning activity in Western Norway. This means that weights for other activities are modified accordingly. The weight for thinning in Timmermann & Dibdiakova was 13% [32].
- The proportion of saw timber of total harvested volume is 0.58. The national figure for Norway is 0.52. Accordingly, the proportion for pulp is set to 0.42.
- There is no rail transport of timber in Western Norway. Some regions do not have railways at all (e.g. Sogn og Fjordane county).
- 90% of the timber is transported per boat, most of it abroad. Of total harvested volume, 75% is exported, 15% is used in Western Norway and the rest goes to other locations in Norway [33]. Transport distance by truck is the distance from the harvested areas to the most frequently used quays. This average distance is 38 km according to ATSkog. The most important destinations for boat transport are Rostock in Germany and Kolding in Denmark.
- Harvesting with crane and cable way is performed on 7% of total harvested volume in Western Norway. The corresponding figure for Norway was 2% [34].

[32] Total volume for thinning was 1 091 000 m^3 in 2010. The total harvested volume was 8 396 000 m^3 according to Timmermann & Dibdiakova, page 3.

[33] Personal communications with K. A. Rødland, Vestskog, July 2017.

[34] Personal communication AtSkog, October 16th, 2019.

- Based on Statistics Norway, the total clearfelled volume in Western Norway was 450 874 m^3 in 2015 [35].
- The average area use factor is given as 23 m^3 per daa in Timmermann and Dibdiakova [36]. We assume the same area use factor for Western Norway.
- Figures for energy use and emissions related to forest road construction and reconstruction are estimated assuming the same km per harvested m^3 as the national figures from Timmermann & Dibdiakova [37]. In 2010, 83 km forest road were constructed for 8,4 million m^3 harvested volume. The same volume for Western Norway was 0,45 million m^3. Consequently, we have assumed that 4.5 km forest road were constructed for Western Norway that year. For reconstruction, the national figure was 298 km and the revised figure for Western Norway was 16 km.
- Planting. According to Statistics Norway [38], 1989 plants were planted in Western Norway in 2018. This figure includes all tree sorts.
- According to Statistics Norway [39], a total of 137 hectare was used for tending in Western Norway in 2018. In the county Sogn og Fjordane there was no tending.
- Site preparation. None of the counties had site preparation in 2018. Therefore, no energy use and emissions are assumed for site preparation [40].
- Fertilization. Only Rogaland had any fertilization in 2018 according Statistics Norway. The figure was 6.8 hectare for that county. We have chosen not to include any energy use or emissions from this activity in Western Norway [41].
- Pruning. About 1% of total harvested area in hectare was used for pruning [42]. We assume the same figure for Western Norway. This gives 18 hectares used for pruning in 2010.
- Reforestation. A total of 779 hectares were used for reforestation in Western Norway 2018 [43].

To arrive at estimates for energy use and emissions of CO_2-equivalents, energy use factors and emission factors are applied. These factors include chain effects. For energy use factors, this means that the factors include energy use related to

[35] https://www.ssb.no/276974/skogavvirkning-for-salg-etter-fylke-og-eiendomsstorrelse.kubikkmeter

[36] Timmermann and Dibdiakova, page 8.

[37] ibid., Table 8.

[38] Skogkultur, Tabell 1, https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/skogkultur

[39] Skogkultur, Tabell 2, https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/skogkultur

[40] Skogkultur, Tabell 3, https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/skogkultur

[41] Statistics Norway https://www.ssb.no/statbank/table/05543/tableViewLayout1/

[42] Timmermann and Dibdiakova, page 8.

[43] Skogkultur, https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/skogkultur , Tabell 1

production of one unit of energy with different fuels. Or correspondingly, the emissions factors include emissions upstream of the actual point of emissions.

The following algorithm is used:

- Find the energy content of an energy carrier in MJ per some unit, e.g. litre.
- Find the energy in MJ required to transform the energy content into that energy carrier. As an example, how much energy is required to transform 1 MJ of oil into 1 MJ of diesel. This is expressed as a ratio, the extra energy required for the transformation.
- Multiply the two together to get an estimate of the energy content for a fuel per unit, including the energy's energy, that is the energy required to produce it.

Equation 13 shows the algorithm expressed as a formula.

Equation 13 Energy use factors including chain effect

$$\frac{Energy - fuel_{MJ}}{litre} = \frac{Energy - content - fuel_{MJ}}{litre} * \frac{Energy - fuel - content_{MJ} + Energy - fuel - production_{MJ}}{Energy - fuel - content_{MJ}}$$

The first term after the equal sign is obtained from different sources. The second term is mostly taken from the German LCA web portal ProBas.

As an example, the energy content of 1 litre of diesel is 38.6 MJ per litre [44]. This is the *embedded or inherent* energy [45], the energy stored in diesel from the natural resource it is based on. According to ProBas, it takes 1.3 TJ to produce 1 TJ of diesel, including the energy content of the oil which diesel is based on [46]. This sum includes the energy required for extracting, transportation and transformation of oil to diesel. It will be used as an energy transformation factor for diesel. The energy content is multiplied with this transformation factor yielding an estimate of 50.12 MJ of primary energy in 1 litre of diesel including the *embodied* energy required to transform diesel from oil. This embodied energy is the difference between the total energy content, including

[44] The Physics Factbook, https://hypertextbook.com/facts/2006/TatyanaNektalova.shtml
[45] Hill and Zimmer, page 29.
[46] Raffinerie Diesel-generisch

transformation energy, and the embedded energy, in this case 11.52 MJ pr litre diesel.

For emissions, we use this algorithm.

- Find the direct emissions of burning a unit of fuel, e.g. 1 litre of diesel.
- Find the indirect emissions related to extract the natural energy source and transform it into some useful energy carrier, e.g. from oil to diesel.

The ProBas [47] estimate for production of 1 TJ of diesel contains "Vorkette" emissions of CO_2-equivalents, these are upstream emissions in the production chain for diesel. They include emissions for extracting and transporting oil and for producing diesel at the refinery. Since no diesel is burned at the refinery, all emissions are upstream emissions, or chain emissions required to produce 1 TJ of diesel.

Combusting 1 litre of diesel emits 2640 grams [48] of CO_2. According to ProBas, it requires 21345 kg CO_2-equivalents to produce 1 TJ of diesel. Since 1 litre contains 38.6 MJ, 1 TJ contains 25907 litres of diesel. This gives 824 grams of upstream CO_2-equivalents emissions per litre diesel. Adding this to the direct emissions, we get 3464 grams CO_2-equivalents per litre diesel. In this example, it is assumed that only CO_2 is emitted by combustion of diesel [49]. This corresponds to 249 gram CO2-equivalents per kWh of diesel.

For gasoline, the numbers are 672.4 gram CO_2-equivalents per litre for upstream emissions. For combustion, 2393 gram per litre is used, which gives a total of 3064 gram CO_2-equivalents per litre of gasoline. This corresponds to 269 gram CO_2-equivalents per kWh of gasoline.

Emissions of CO2-equivalents for a given activity is calculated by the following algorithm:

- Find the energy in kWh required for some activity in diesel or gasoline, including the energy required to produce the energy content used,

[47] ibid.

[48] https://ecoscore.be/en/info/ecoscore/co2

[49] https://www.dieselnet.com/tech/emi_intro.php

- use the corresponding emission factor for the fuel in kg CO_2-equivalents per kWh
- calculate the total emissions of kg CO_2-equivalents normalised to some unit, e.g. per m^3.

The emission factor for the fuel in kg CO_2-equivalents per kWh is a weighted factor of direct and indirect emissions per kWh where the weights are the proportion of direct and indirect energy for the fuel. The direct energy is the *inherent* energy, the energy content or the physical property of the fuel. The indirect energy is the energy use required to make that physical property useful.

Equation 14 Emission factor per kWh

$$\frac{kgCO_{2-eq}}{kWh} = \sum_{j=1}^{2} \frac{kgCO_{2-eq-j}}{kWh} * w_j$$

Equation 14 shows the formula for emission factor per kWh for diesel or gasoline. The subscript j is for direct and indirect emissions and w is the weight for these emissions based on proportion of direct and indirect energy for that fuel [50].

Equation 15 Calculating emissions of kg CO_2-equivalents for a given activity

$$\frac{kgCO_{2-eq}}{m^3} = \frac{kWh}{m^3} * \frac{kgCO_{2-eq}}{kWh}$$

As an example, consider use of harvester for clearfelling 1 m^3. This requires 0.9 litre of diesel which corresponds to 12.5 kWh. Using the emission factor per kWh for diesel, emissions of CO_2-equivalents are estimated to 6.3 kg per m^3 for use of harvester for clearfelling.

All energy factors and emissions factors used in this document are reported in Appendix A.

[50] For emissions related to 1 litre of the fuel the emission factor per litre will give the same result. For emissions related to 1 tonne-km the formula using emissions per kWh is the better choice and is therefore generally used.

Extra transport in Western Norway because of municipal road restrictions

In Norway, the total allowed carrying capacity for log trucks with trailer has been extended twice since 2017 [51]. In 2007 it was raised from 50 to 56 tonnes and in 2013 it was raised again to 60 tonnes. This has an impact on how logs are lifted onto trucks since not all municipal roads in Western Norway can accommodate trucks with trailer of the maximum size. Municipal roads usually make up the first part of the road network from harvesting site to further processing site for the logs. When these roads are inaccessible for the largest trucks, logs must be transported by the truck in several trips before loading them on to the trailer, thereby increasing the amount of transport from harvesting site to the transport site. In the county of Sogn and Fjordane in Western Norway, 78% of the municipal road network can only accommodate trucks without a trailer. This means additional transport by the truck which is called "kipping".

According to a report by the Norwegian Institute for Bioeconomy, the total yearly volume that must be handled with additional transport is 34294 m^3 in the county of Sogn og Fjordane [52]. This is calculated as an average for the years 2016-2018. The total harvested volume in the county is 99812 m^3 in 2015 [53], so a substantial part of the volume must be transported over longer distances. Using a density of 765 kg/m^3 [54], this represents 26235 tonnes for all 24 municipalities in Sogn og Fjordane [55].

A report from the Norwegian Association of Forest Owners [56] shows the percentage of municipal roads in each municipality in Sogn og Fjordane that can be accessed with trucks of different sizes. There are three relevant categories

[51] Fjeld,D., Vennesland, B., Bjørkelo, K.:Flaskehalser i det kommunale vegnettet, NIBIO-rapport nr 97, 2019. Page 5.

[52] ibid., page 16.

[53] Statistics Norway

[54] Ecoinvent 2007, from Timmermann & Dibdiakova (2013), page 3

[55] There are 26 municipalities, but there are no records for two of them, Årdal and Vågsøy.

[56] Molstad, O., Skjølaas, D.: Klassifisering av offentlig veinett etter tillatt totalvekt for tømmervogntog, Norges Skogeierforbund, 2019.

of trucks, less than 40 tonnes, over 40 tonnes but below 50 tonnes and over 50 tonnes but below 56 tonnes. For each category, the truck must make an extra number of trips to load the logs on the trailer. For the first category, 5 extra trips are required, for the middle category 4 extra trips are required and for the last category 3 number of trips are required. The average extra transport distance is 3 km [57].

The report contains a table which shows how many km these roads with limited access represent [58] for each municipality in Sogn og Fjordane. The total weight that requires extra transport for each of them can then be distributed on different distances and this allows for calculation of tonne-km for each municipality for this extra transport. Equation 16 shows how this is done. In the equation, i is subscript for municipality and j is subscript for each truck category that requires extra transport. The letter w denotes the weight of logs that requires extra transport in each municipality, the letter t denotes number of trips for each truck category and d is average transport distance (3 km). The result of these calculation for each municipality is shown in Appendix B.

Equation 16 Calculation of tonne-km for extra transport per municipality

$$Tonne - km_i = \sum_{j=1}^{3} w_i * p_j * t_j * d$$

Summing all tonne-km over all municipalities in Sogn og Fjordane gives a total of 359592 tonne-km of extra transport. This is equal to 3.6 tonne-km per m^3 of harvested volume [59] for the whole county. The energy use factor for trucks above 18 tonnes, 0.623 kWh per tonne-km [60], is used for the truck doing the extra number of trips. This gives 2.25 kWh per harvested m^3 for extra transport. Applying the emission factor in kg CO_2-equivalents per kWh (0.249 [61]) gives a total of 0.56 kg

[57] ibid., page 8
[58] ibid, page 31.
[59] Energy use and emissions for all activities are normalized to total clearfelled volume
[60] Austrian Environment Agency for direct energy use, ProBas for indirect (energy for energy production).
[61] ibid. for emission factors fir direct and indirect energy use

CO_2-equivalents per harvested m³ for extra transport. In Western Norway, all harvested volume is transported by road.

In addition, 0.3 litre diesel is used for loading the truck per m³. This input is taken from Timmermann & Dibdiakova and is the same quantity used for loading trucks for road transport. This means 4.18 kWh and 1.04 kg CO_2-equivalents additionally per m3 for loading in connection with extra transport because of lower truck accessibility on municipal roads in Western Norway.

The input for estimates for energy use per activity in Western Norway is the same as the input used for the national estimates presented in Table 3. There is one exception, transport by road. The average transport distance from harvest site to mill gate or to quay for further transport is different in Western Norway. This means the amount of tonne-km which is input for estimation of energy use for transport is different. Table 21 shows the revised input for estimate of energy use for road transport in Western Norway.

Table 21 Input for estimate of energy use for road transport in Western Norway

Type	Timber transport, road	1	m3	kWh	kg CO2-eq.
Input	saw logs transport	30.4	tkm	18.95	4.71
Input	pulp wood transport	30.4	tkm	18.95	4.71
Input	loading and unloading, diesel usage	0.3	litre	4.18	1.04

Energy use by activity

In this section, the estimates for energy use and emissions of CO2-equivalents are normalised to harvested volume in Western Norway 2015. Activities site preparation, thinning, fertilization, spraying and transport by rail are not used in Western Norway.

Tending

Table 22 shows energy use for tending normalized to 1 m3 of clearfelled volume in Western Norway 2010.

Table 22 Energy use for tending normalised to total harvested volume in Western Norway 2015

Tending	Value	Unit	kWh	kg CO2-eq.
Sum per ha	1	ha	62.6	16.9
Total ha Western Norway 2015	137	ha	8590.1	2314.3
Total harvested volume Western Norway 2015	450 874	m^3	0.019	0.005

Reforestation

Table 23 shows the energy use for reforestation normalised to total harvested volume in Western Norway 2015.

Table 23 Energy use for reforestation normalised to total harvested volume

Reforestation	Value	Unit	kWh	kg CO2-eq.
Sum per ha	1	ha	25	6.62
Total ha Western Norway 2015	779	ha	19467.6	3431.0
Total harvested volume Western Norway 2015	450 874	m^3	0.043	0.011

Pruning

Table 24 shows the energy use for pruning normalised to total harvested volume in Western Norway 2015.

Table 24 Energy use for pruning normalised to total harvested volume Western Norway 2015

Pruning	Value	Unit	kWh	kg CO2-eq.
Sum per ha	1	ha	137.1	36.9
Total ha Western Norway 2015	18	ha	2500.2	673.6
Total harvested volume Western Norway 2015	450 874	m3	0.006	0.0015

Transport

According to e-mail from ATSkog, 58% of harvested volume in Western Norway is used for sawn timber, 29% for pulp and 13% for packaging. The same average transport distance, energy use and emission factors, as well as energy use and emissions for loading and unloading, are assumed for all wood applications. These are given in Table 25.

Table 26-Table 28 show calculations of tonne-km, energy use and emissions for transport of sawn logs, pulp and packaging from Western Norway. The figures are normalized to total harvested volume in Western Norway 2015.

Table 25 Common factors for calculating tonne-km, energy use and emissions for transport in Western Norway

	Transport	Value	Unit
A_0	Average transport distance	38	km
B_0	Density	0.765	tonne/m3
C_0	Energy use factor	0.623	kWh/ tonne-km
D_0	Emission factor	0.2488	kg CO2-eq/kWh/ tonne-km
E_0	Loading and unloading per harvested m3	0.3	litre diesel
F_0	Loading and unloading per harvested m3	4.2	kWh/m3
G_0	Loading and unloading per harvested m3	1.0	kg CO2-eq./m3

Table 26 Tonne-km, energy use and emissions for sawn logs

	Transport sawn logs	Value	Unit
A	Total harvested volume	450 874	m3
B	Sawn log fraction	58	%
C=A*(B/100)	Volume sawn logs	261 507	m3
$D=C*C_0*D_0$	Tonne-km sawn logs	7 602 006	tonne-km
E=D/A	Tonne-km per total harvested volume	16.86	tonne-km /m3

$F_1=E*C_0$	Energy use per total harvested volume	10.5	kWh/m3
$G_1=F_1*D_0$	Emissions per total harvested volume	2.6	kg CO2-eq/m3

Table 27 Tonne-km, energy use and emissions for pulp

	Transport pulp	Value	Unit
A	Total harvested volume	450 874	m3
B	Pulp fraction	29	%
C=A*(B/100)	Volume pulp	130 753	m3
$D=C*C_0*D_0$	Tonne-km pulp	3 801 003	tonne-km
E=D/A	Tonne-km per total harvested volume	8.43	tonne-km /m3
$F_2=E*C_0$	Energy use per total harvested volume	5.3	kWh/m3
$G_2=F_2*D_0$	Emissions per total harvested volume	1.3	kg CO2-eq/m3

Table 28 Tonne-km, energy use and emissions for packaging

	Transport packaging	Value	Unit
A	Total harvested volume	450 874	m3
B	Packaging fraction	13	%
C=A*(B/100)	Volume packaging	58 614	m3
$D=C*C_0*D_0$	Tonne-km packaging	1 703 898	tonne-km
E=D/A	Tonne-km per total harvested volume	3.78	tonne-km/m3
$F_3=E*C_0$	Energy use per total harvested volume	2.4	kWh/m3
$G_3=F_3*D_0$	Emissions per total harvested volume	0.6	kg CO2-eq/m3

Table 29 Energy use and emissions for road transport normalised to total harvested volume

	Transport	Unit	Value
$A= F_1+F_2+F_3+F_0$	Sum energy use per harvested m3	kWh	22.3
$B= G_1+G_2+G_3+G_0$	Sum emissions per harvested m3	kg CO_2-eq	5.5

Table 30 Energy use and emissions for extra transport because of inaccessible municipal road network ("kipping")

	Sum per harvested m3	Unit	Value
A	Energy use	kWh	6.4
B	Emissions	kg CO2-eq	1.6

The emissions from transport per harvested m3 is lower in Western Norway than in Norway general as reported by Timmermann & Dibdiakova. That is mainly due to lower transport distances. The average distance to timber quay in Western Norway is 38 km. The average distance to production gate for sawn timber in Norway is 58 km, while the distance to production gate or railway terminal for pulp is 69 km according to Timmermann & Dibdiakova [62].

Planting

Table 31 shows plants used in Western Norway 2018 [63]. These data are used to normalise energy use and emission of CO_2-equivalents for planting in Western Norway 2015.

Table 31 Plants in Western Norway 2018.

Norway **2018**	Plants (1000')
Rogaland	1019

[62] Timmermann & Dibdiakova, page 9

[63] Statistics Norway, https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/skogkultur

Hordaland	643
Sogn og Fjordane	327
Sum	1989

Table 13 shows the estimate for energy use for planting normalised to total harvested volume in Norway 2010.

Table 32 Energy use for planting normalised to total harvested volume Norway 2010

Planting	Value	Unit	kWh	kg CO_2-eq.
Sum	1000	Pieces	286.6	71.7
Plants (1000)	1989	Plants	570053.1	142607.1
Total harvested volume Western Norway 2015	450 874	m3	1.264329	0.316

Seed and seeds production

According to Timmermann & Dibdiakova, 300 kg of seeds and 20 million plants were produced in Norway 2010 [64]. The total harvested volume in Norway that year was 8 396 000 m^3. The corresponding number for Western Norway in 2015 was 450 874 m^3. Assuming the same number seeds and plants per m^3 gives 16.1 kg of seeds and 1 074 021 plants in Western Norway 2015.

Table 14 shows the estimate for energy use for seed and seed production normalised to total harvested volume in Norway 2010.

Table 33 Energy use for seed and seed production normalised to total harvested volume Norway 2010

Seed and seed production	Value	Unit	kWh	kg CO_2-eq.
Sum for kg	1	kg	1111.5	79.4
Total kg seed Western Norway	16.1	kg	17906.0	1278.8
Total harvested volume	450 874	m3	0.04	0.0028

[64] Timmermann & Dibdiakova, page 3

Crane harvesting

According to ATSkog, 7% of the total volume in Western Norway is harvested by crane or cableway. This gives 31561 m3 harvested by crane or cableway of a total of 450 874 m3 in Western Norway 2015.

Table 34 shows the estimate for energy use for crane harvesting normalised to total harvested volume in Western Norway 2015.

Table 34 Energy use for crane harvesting normalised to total harvested volume Western Norway 2015

Crane harvesting	Value	Unit	kWh	kg CO_2-eq.
Sum per 1 m3	1	m^3	89.9	22.4
Total harvested volume crane/cableway Western Norway 2015	31 561	m3	2838431	707889.7
Total harvested volume Western Norway 2015	450 874	m3	6.29	1.57
Fraction harvested by crane Western Norway	7.0	Percent		

2.6 Forestry management practices

Clear-felling

In Norway 2010, 13% of the total harvested volume was thinning [65]. Since there is no thinning in Western Norway, it is assumed that clearfelled volume make up 93% of total harvested volume. Harvesting with cable crane make up the last 7%. This gives a total clearfelled volume of 419 313 m3 in Western Norway in 2015.

Table 35 shows the estimate for energy use for clearfelling normalised to total harvested volume in Norway 2010.

Table 35 Energy use for clearfelling normalised to total harvested volume Western Norway 2010

Clearfell	Value	Unit	kWh	kg CO_2-eq.
Sum per 1 m3			13.5	3.4

[65] Timmermann & Dibdiakova, page 3.

Total volume clearfell Western Norway 2015	419 313	m3	5651910.8	1409075.3
Total volume harvested Western Norway 2015	450 874	m3	12.5	3.13

Table 17 shows the estimate for energy use for terrain transport while clearfelling normalised to total harvested volume in Norway 2010.

Table 36 Energy use for terrain transport while clearfelling normalised to total harvested volume Western Norway 2010

Terrain transport while clearfelling	Value	Unit	kWh	kg CO_2-eq.
Sum per 1 m3			12.02	3.0
Total volume clearfell Western Norway 2015	419313	m3	5040079	1257594.7
Total volume harvested Western Norway 2015	450874	m3	11.18	2.79

Forest road

In Norway 2010, 83 km forest road was constructed for 8 396 000 m3. The figure for forest road reconstruction was 298 km. It is assumed that the distance of forest road construction and reconstruction in km in Western Norway is the same in proportion to total harvested volume. This gives 4.6 km for forest construction and 16 km for forest road reconstruction.

Table 37 shows the estimate for energy use for forest road construction and reconstruction in Western Norway 2015.

Table 37 Energy use for forest road construction and reconstruction normalised to total harvested volume Western Norway 2010

Forest road	Value	Unit	kWh	kg CO_2-eq.
Sum per km construction			166750.5	41494.0
Sum per km reconstruction			53486.3	13308.9
Total length new forest roads Western Norway 2015	4.45	km	743238.2	184946.6

Total length forest road reconstruction Western Norway 2015	16	km	855935.9	212980.76
Forest road building per m3 Western Norway 2015	450 874	m3	1.65	0.41
Forest road reconstruction per m3 Western Norway 2015	450 874	m3	1.9	0.47

Timber quay

The estimate is for a timber quay dimensioned for shipping 1 m3 of timber. The quay used as reference for the estimate is Ørsta timber quay opened on June 4th, 2018 [66]. It has a dimension of 45000 m3 shipped each year [67]. In the following estimate, an expected lifetime of 50 years is assumed. This means a total of 2.25 million m3 timber will be shipped over the Ørsta timber quay during its lifetime.

The estimate is designed as follows:

- Find input in materials and machine time required for shipping 1 m3 of timber.
- This input is calculated as total amount of materials and machine time for the reference quay distributed on the total shipped volume for that quay during its lifetime.
- Apply energy use factors and emissions factors for materials and machine use to calculate energy and emissions of CO_2-equivalents required for shipping 1 m3 of timber.
- Use shipped volume per year from Western Norway and find total energy use and emissions of CO_2-equivalents required for that volume.
- Divide calculated total energy and emissions of CO_2-equivalents on total harvested volume in Western Norway for the same year.

Materials

The amount of concrete is given as 1500 m3 according to the construction company for Ørsta timber quay [68]. To convert this into tonnes, a factor of 2385 kg per m3 is used [69]. The energy use and emission factors for CO2-equivalents

[66] Virkesterminaler ved sjø
[67] ibid.
[68] E-mail from company Nordang, March 20th 2020, https://nordang.no/entreprenor/avsluttede-prosjekter/tommerkai-orsta/
[69] This is the average of https://www.traditionaloven.com/conversions_of_measures/concrete-weight.html and https://www.spikevm.com/calculators/concrete/concrete-weight-kg-cubic-m.php

are obtained from the German online LCA database ProBas [70]. All energy use and emission factors include upstream energy use and emissions required to produce and extract raw materials, including energy, and transporting them to manufacture plant.

Table 38 Material composition of Ørsta timber quay

	Tonne	Percent
Concrete	3577	93.2
Armoured iron	200	5.2
Steel	60	1.6
Sum	3837	100.0

Table 39 Energy use and emission factors per kg material

Per kg material	MJ	kg CO2-eq
Concrete [71]	0.96	0.17
Iron [72]	12.57	0.88
Steel [73]	22.02	1.71

Machines

The number of hours different machines are in use are obtained from the construction company [74]. Energy use and emissions are distributed on the whole lifetime of the quay, not just on shipment for one year.

Engine output in kW is taken from different sources. For the crane truck, a Volvo FH with 540 horsepower is used [75]. For the mobile crane, specifications for LTM

[70] https://www.probas.umweltbundesamt.de/php/index.php
[71] Prozessdetails: Steine-ErdenBeton-DE-2010
[72] Prozessdetails: MetallFe-Guss-DE-2005
[73] MetallStahl-Oxygen-DE-2010
[74] E-mail from company Nordang, March 20th 2020
[75] https://www.olavhansen.no/kranbil/

1060-3.1 is used [76]. The truck is taken from Kraler et al [77]. All energy use and emission factors include all upstream energy use and emissions required to produce e.g. 1 litre of diesel. See Appendix for documentation of energy use and emission factors applied in the calculations.

Table 40 Machine use for Ørsta timber quay

	Hours (A)	Minutes per m³ per lifetime (B)	kW (C)	MJ (D=A*C)	Litre diesel [78,79] (E=D/3.6/13.9)	kg CO2-eq per hour [80] (F=E*3.46/A)
Crane truck	200	0.005	403	289928.2	5784.3	100.2
Mobile crane	300	0.008	270	291600	5817.7	67.2
Truck	200	0.005	200	169200	3375.7	58.5

Shipped volume from Western Norway

The total harvested volume in Western Norway in 2015 was 450 874 m³. Of this, 90% [81], or 405 787 m³, was transported by timber quay.

LCA timber quay

Table 41 shows input for calculating energy use and emissions of CO_2-equivalents for shipping 1 m³ of timber over a timber quay.

[76] http://www.roarwilhelmsen.no/sites/default/files/content/attachments/bildprospekt_ltm_1060-3.1.pdf

[77] Kraler, A., Krismer, V., Wieland, G.: Grbirgsholz - Wald ohne Grenzen, page 31.

[78] Using 13.9 kWh per litre diesel, including upstream energy use. Energy content from The Physics Factbook, indirect energy use from ProBas, Prozessdetails: RaffinerieDiesel-generisch

[79] 1 kWh=3.6 MJ

[80] Using an emission factor of 3.46 kg CO2-equivalents per liter diesel, including upstream emissions. Estimate from ProBas Prozessdetails: RaffinerieDiesel-generisch

[81] E-mail from ATSkog, October 16th, 2019

Table 41 Input for LCA timber quay

					Energy use (kWh)		Emissions CO_2-eq (kg)	
Category	Process	Lifetime use (A)	Value per m3[82] (B=A/ 2.25*1e6)	Unit	Per unit (C)	Per m3 (D=B*C)	Per unit (E)	Per m3 (F=B*E)
Product	Timber quay for shipping		1	m3				
Input	Concrete	3576923	1.6	kg	0.27	0.42	0.17	0.27
Input	Iron	200	0.1	kg	3.49	0.31	0.88	0.08
Input	Steel	60	0.0	kg	6.12	0.16	1.71	0.05
Input	Truck	200	0.005	minutes	3.92	0.02	0.97	0.01
Input	Mobile crane	300	0.008	minutes	4.50	0.04	1.12	0.01
Input	Crane truck	200	0.005	minutes	6.71	0.04	1.67	0.01
Sum						0.99		0.42

According to the estimates, a total energy use of 0.99 kWh is required for shipping 1 m³ of timber over the timber quay. Emissions are estimated to 0.42 kg CO_2-equivalents for the same volume. This volume is 1 m³ of timber under bark at quay. The next and final step is to distribute energy use and emissions on total harvested volume shipped from Western Norway in one year. Table 42 shows the final calculations for energy use and emissions per m³ harvested volume.

[82] The total shipped volume per year is 45 000 m³ for Ørsta timber quay (Virkesterminaler ved sjø, page 18). This gives 2.25 million m3 over the assumed lifetime of 50 years.

Table 42 Energy use and emissions estimated per harvested m3

	Per m3 shipped (A)	Total m3 shipped (B)	Total m3 harvested (C)	Per m3 harvested (D=A*B/C)
kWh	0.99	405 787	450 874	0.89
CO2-eq	0.42	405 787	450 874	0.38

Table 42 shows that the energy use for shipping 1 m3 timber is 0.89 kWh per m3 of harvested volume. The emissions are 0.38 kg CO2-equivalents per m3 of harvested volume.

Energy use and emissions Western Norway 2015

With the assumptions outlined above, Table 43 shows energy use and emissions for 1 m^3 of wood harvests in Western Norway. The figures are representative for all type of trees.

Table 43 Energy use and emissions for 1 m3 of timber under bark harvested in Western Norway delivered at timber quay

	kWh per m^3	MJ per m^3	kg CO_2-eq. per m^3 Western Norway	kg CO_2-eq per m^3 Norway [83]	kg CO_2-eq per hectare Western Norway
Planting	1.26	4.55	0.32	0.22[84]	72.7
Seed and seeding production	0.04	0.14	0.003		0.65
Site preparation	0.00	0.00	0.00	0.093	0.00
Reforestation	0.04	0.16	0.01		2.63
Tending	0.02	0.07	0.005	0.14	1.18

[83] From Timmermann & Dibdiakova, Tabell 16.

[84] Includes seed and seeding production

Spraying	0.00	0.00	0.00	0.0032	0.00
Fertilization	0.00	0.00	0.00	0.089	0.00
Pruning	0.0055	0.02	0.002	0.001[85]	0.34
Forest road construction	1.65	5.93	0.41	0.19	94.3
Forest road reconstruction	1.90	6.83	0.47	0.22	108.6
Thinning	0.00	0.00	0.00	1.08	0.0
Terrain transport while thinning	0.00	0.00	0.00	0.56	0.0
Clearfell	12.54	45.13	3.13	2.87	718.8
Terrain transport while clearfelling	11.18	40.24	2.79	2.79	641.5
Harvesting with cable crane/ cableway	6.30	22.66	1.57	0.29[86]	361.1
Timber transport, road	22.30	80.27	5.55	8.49	1275.8
Timber transport, rail	0.00	0.00	0.00	0.81	0.0
Timber transport, "kipping"	6.42	8.08	1.6		367.5
Timber quay	0.89	3.21	0.38		86.7
Sum	64.54	232.34	16.23	17.85	3732

As the table shows, harvesting 1 m3 of wood in Western Norway emits 1.6 kg CO_2-equivalents less than harvesting in Norway general according to figures from Timmermann & Dibdiakova (see Table 1). This is mainly due to shorter transport distances from harvest sites to nearest timber quay.

Emissions of CO_2-equivalents per hectare in Table 43 are calculated using 230 clearfelled m3 per hectare. Consequently, all activities are normalised to the clearfelled volume per hectare, not volume per hectare for the individual activity. Equation 17 shows the calculation.

[85] Norwegian "stammekvisting"
[86] Including "heltreavvirkning"

Equation 17 Emissions per hectare

$$\frac{CO_{2-eq-kg}}{hectare} = \left(\frac{CO_{2-eq-kg}}{hectare_{activity}} * \frac{hectare_{activity}}{m3_{clearfelled}}\right) * \frac{m3_{clearfelled}}{hectare}$$

As an example, consider the emissions for the activity tending in Western Norway. This is calculated to 16.9 kg CO_2-eq per hectare tended (see Table 22). This is the first term in the parenthesis in the equation above. A total of 137 hectare was tended in Western Norway in 2018 and the total clearfelled volume in Western Norway was 450 874 m^3. The second term inside the parenthesis is then 137/450874. The calculation inside parenthesis is 0.0051 which is showed in Table 43. The average volume clearfelled per hectare is 230 according to Timmemann & Dibdiakova [87]. The emissions of kg CO_2 per hectare is 0.0051*230=1.18 which is the number in the table above (with some more decimals used in the calculation). All emissions per hectare per activity in Table 43 are calculated by first normalising emissions for each activity to total clearfelled volume and then considering the volume per hectare for clearfelling. This makes all activities comparable since they are normalised to the same unit.

Including export transport

The estimate above does not include energy use and emissions related to transport for export of timber from Western Norway. According to ATSkog [88], 75% of the harvested volume in Western Norway is exported. The most important export destination is Rostock [89].

A report from SINTEF [90] lists the most relevant ship capacities for timber export from Norway. For these calculations, a ship with carrying capacity of 5000 m^3 is chosen. According to the report, the ship uses 450 litres per hour and travels with a speed of 11 knot per hour [91]. It uses 60 litres fuel per hour in port for

[87] Timmermann & Dibdiakova, page 8.

[88] Personal communication, July 26th, 2017

[89] E-mail from AtSkog October 16th, 2019

[90] Nørstebø V.S., Johansen U., Gabriel H.M., Talbot B., Nilsen J.E., Transport av skogsvirke i kyststrøk, SINTEF A20874, Tabell 4.

[91] The report uses 10 knots as lower range and 12 knots as upper range

loading and unloading and the loading speed is 250 m^3 per hour. The fuel is assumed to be heavy fuel oil.

The density for harvested wood under bark is 765 kg [92] per m^3. For one trip, the ship can carry 3825 tonnes. If we use Vadheim as the export quay in Western Norway, the distance to Rostock is 639 nautical miles or 1183 km [93]. The ship uses 64 hours for that trip [94], and it needs 20 hours for loading, 40 hours for both loading and unloading. The ship produces 4526612 tonne-km per trip from Vadheim to Rostock. This gives a total consumption of 31200 litres of heavy fuel oil, including loading and unloading the ship in port. Normalizing to ship's carrying capacity of 5000 m^3 gives 905 tonne-km per m^3.

For heavy fuel oil, the assumed energy content 38.2 MJ per litre [95] or 10.6 kWh per litre. According to the German online database ProBas, it requires 1.191 MJ [96] to produce 1 MJ of heavy fuel oil. Allowing for the inclusion of this upstream energy gives 45.6 MJ or 12.7 kWh per litre heavy fuel oil, or 0.0873 kWh per tonne-km.

The emission factor for heavy fuel oil, 3.114 gram CO_2 per gram fuel for propulsion, is taken from IMO [97]. Using a density of 0.9 kg per litre [98] this gives 2.8026 kg per litre of heavy fuel oil. Additionally, it takes 0.4524 kg CO_2-equivalents to produce heavy fuel oil, including all upstream emissions from extraction of oil, transport to refinery and production at refinery [99]. This gives a total of 3.25 kg CO_2-equivalents per litre fuel of heavy fuel oil or 22.4 kg CO_2-equivalents per tonne-km.

In these calculations, the return trip is not considered. According to the SINTEF-report, the return trip has an assumed load of 25%. They apply a factor of 1.75 [100]

[92] Ecoinvent, 2007, taken from Timmermann & Dibdiakova.
[93] https://sea-distances.org/
[94] ibid.
[95] https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html
[96] RaffinerieÖl-schwer-OPEC-2010
[97] Third IMO Greenhouse Gas Study 2014, Table 32, Annex 6, page 253
[98] https://www.oiltanking.com/en/news-info/glossary/details/term/heavy-fuel-oil-hfo.html
[99] ProBas, RaffinerieÖl-schwer-OPEC-2010
[100] Nørstebø et al., page 25.

to allow for this return trip. Using this factor, we get 0.153 kWh and 39.26 kg CO2-equivalents per tonne-km.

Table 44 Boat transport Vadheim-Rostock for 1 m3 of timber

	Process	value	unit	kWh	CO2 (kg)
Product	Timber transport, boat	1	m3		
Input	Timber transport Vadheim-Rostock	905.3	tonne-km/m3	138.4	35.5

Table 44 shows calculation of energy use and emissions for transport of 1 m^3 of exported timber. These figures are used to calculate total energy use and emissions by multiplying with total exported volume and then normalized to total harvested volume for Western Norway in Table 45.

Table 45 Energy use for boat transport normalised to total harvested volume Western Norway 2010

Boat transport	m^3	kWh	kg CO_2-eq.
Export volume (75%)	338 156	46 792 017	12 019 601
Per total harvested volume Western Norway	450 874	103.8	26.7

Table 46 shows energy use and emissions for 1 m^3 of harvested wood from Western Norway including boat transport for export to Germany.

Table 46 Energy use and emissions for harvesting 1 m^3 in Western Norway including boat transport

All figures normalized to harvested m^3	kWh per m^3	MJ per m^3	kg CO_2-eq. per m^3
Sum without boat transport	64.54	232.34	16.23
Timber transport, boat	103.78	373.61	26.66
Sum with transport boat	168.32	605.95	42.88

The table shows that energy use and emissions are more than doubled when export to Germany is included. Energy use and emissions for export with boat per harvested m3 is a factor of 1.6 higher than corresponding figures for harvesting.

3 LCA wood products

This section will look at LCA for different wood products. The discussion above provides us with an estimate of energy use and emissions related to harvesting 1 m^3 of wood, distributed on the volume of standing trees in the "green state".

In the following, these questions will be addressed:

- What is the energy use and emissions of CO_2-equivalents from exporting wood for further processing in Germany?
- How much energy may be saved, and emissions of CO_2-equivalents mitigated, by producing that same product in Norway instead of exporting?
- What is the effect (on energy use and emissions of CO_2-equivalents) of substituting non-wood products with wood products based on imported wood from Norway?

EPDs for different products will be used as basis for these evaluations. An estimate for energy use and emissions of CO2-equivalents related to the export of wood from Norway to Germany is shown above. For the production and consumption in Norway, transport from production facility to place of consumption will be estimated. Sogndal in Western Norway will be used as location for the consumption of the wood product in Norway.

EPDs are based on ISO standards. There are two general ISO's for LCA analysis (ISO 14404 and ISO 14044 from 2006) and one ISO specific for building products (ISO 15804 from 2012) [101]. All EPDs using this last standard may be compared directly.

EPDs consist of a set of standard activities distributed on modules. For each activity, energy use and emissions are calculated. The activities A1-A3 cover extraction and production of raw materials (A1), transporting them to production gate entrance (A2) and the production itself (A3). Activity A4 covers

[101] Rüter, S., Diederichs, S.:Ökobilanz-Basisdaten für Bauprodukte aus Holz, Arbeitsbericht, Institut für Holztechnologie und Holzbiologie, Hamburg, Nr 2012/1, https://literatur.thuenen.de/digbib_extern/dn050490.pdf, page 33

transport from production facility to end user while activity A5 defines installation at building site. The activities B1-B7 cover repair, maintenance and potential exchange of the product during its lifetime use. The activities C1-C4 cover removal of the product after use and transporting it to waste treatment facilities or recycling facilities. The activity D covers potential recycling or re-use of the product. The following analysis will concentrate on the activities A1-A3 with the addition of activity A4 for assumed consumption in Sogndal, Norway. The analysis will cover energy use and emissions of CO_2-equivalents.

Different EPDs for wood products are only comparable if they both use ISO 15804 and have the same product definition and the same functional unit (e.g. meter, m^2 or m^3). The standards for EPDs also contain instruction on how to distribute energy use and emissions on potential co-products, either through allocation or system expansion. The analysis presented here assumes that any allocation or system expansion is properly done by the different EPDs. This means that no further allocation or system expansion will be used in this analysis.

The advantage of using EPDs is that collection, evaluation and analysis of data conform to the same standards. If two product definitions are compatible, their EPS's should be directly comparable given that they follow the standards outlines above. In addition, manufacturing companies are providing input data for the analysis. This saves considerable time used for data collection.

Most EPDs do not split activities A1-A3 but report energy use and emissions aggregated together for these activities. The estimates for energy use and emissions of CO_2-equivalents presented above are for the activities A1 and A2, harvesting wood delivered to factory gate, where the factory may be a saw mill or a factory for producing e.g. particle boards. Table 20 presents different estimates for wood harvesting and production in Norway and Germany. These estimates, together with the estimates for wood harvesting in Western Norway, will be used for assessing the magnitude of the activities A1 and A2 when this is reported together with A3. Equation 18 shows the general idea.

Equation 18 Substituting activities A1 and A2 for EPD estimates

$$EPD'_{p-Norway-A1-A3} = EPD_{p-Germany-A1-A3} - E_{A1-A2,Germany} + E_{A1-A2,Norway}$$

In the equation above, p is any product produced in Germany and Norway, E is energy use or emissions and EPD' is the revised estimate for energy use and emissions for an EPD when estimates for activities A1-A2 in Germany is substituted with estimates for the same activities in Norway or Western Norway. The same approach can be used if the analysis concerns the impact of producing in Germany instead of Norway by substituting the countries throughout the equation.

For some products, the activity A1 comprise more raw materials than just wood. For e.g. particleboard, raw materials such as glue, wax and ammonium nitrate are produced in addition to wood. In that case, the equation above is still used since the activities subtracted and substituted for activity A1 only concern those relevant for wood harvesting.

The above approach assumes that no allocation or system expansion is performed for wood harvesting in phase A1 for the different EPDs. Any allocation or system expansion is presumably performed for the activity A3, manufacturing of the product. Since this activity is not corrected, the allocation or system expansion is still valid.

It is customary to split energy use on primary energy carriers and primary energy used as materials in EPDs. The first one is referred to as embodied energy while the last one is referred to as embedded or inherent energy [102]. In the following, the term energy use calculated from the EPDs will comprise energy used both as energy carriers and as material input. This is because the split between them is not consistent in the EPDs reviewed, and discarding energy used as materials may underestimate the total energy use for manufacturing a product.

[102] Hill, C., Zimmer, K.: The environmental impacts of wood compared to other building materials, NIBIO Report, Nr 56, 2018, page 29.

Since embedded and embodied energy is aggregated, the total energy use may be overestimated. This is because the embedded energy is a physical property and does not represent any use of energy carriers. However, since this approach is used consistently for all EPDs, the potential source of error is equal for all products analysed.

Substitution

For some products, we present a substitutional effect. This is the effect on emissions of CO2-equivalents from using a wood based product rather than a product based on non-wood materials. Since the wood based product store CO2 from biogenic carbon, we expect a mitigation effect from using it instead of the non-wood based alternative. This mitigation effect is a combination of two separate effects:

1. The avoided emissions of CO2-equivalents by using the wood based product.
2. The effect of storing CO2 rather than releasing it to the atmosphere

Equation 19 shows how the mitigation effect is calculated when a non wood-based product is substituted with a wood-based one.

Equation 19 Calculating mitigation effect when a non wood-based product is substituted with a wood-based one

$$CO_{2-eq-substitution-effect-wood-product} = CO_{2-stored-wood-product} + CO_{2-eq.-avoided-non-wood-product}$$

Emissions for non-wood products are usually given per kg or per m^2. All emissions in the equation above are calculated per kg to give compared products a normalized unit. The amount of stored CO_2 in wood products is taken from the product's EPD in m^3 and then recalculated in kg using the wood product's total weight pr m^3 product. The substitution effect and avoided emissions are then recalculated in m^3 using wood products total weight per m^3 product. This approach assumes that non-wood and wood products may be substituted for one another kg for kg.

The substitution calculations are based on these assumptions:

- The two products may be substituted, that is they have identical applications.
- The biogenic carbon in the wood-based product would have been oxidised and released into the atmosphere if it had not been harvested, e.g. through incineration.

An obvious alternative to the second assumption would be to leave the wood in the forest, in other words not harvesting it. The substitution calculations presented here do not consider this alternative.

Substitution effects are presented as negative numbers since this amount of CO_2 is saved from entering the atmosphere and thereby contributing to the global warming potential.

3.1 Extra particle board

Particle boards are basic wood products. This product is built from the same standards in Norway and Germany. We will concentrate on a particleboard P5 which is described as an extra board in the Norwegian EPD from Forestia AS in Braskereidfoss, Norway [103]. According to the EPD, the particleboard P5 is used as load bearing board in humid conditions. The same estimate is also valid for particleboard P3 which is used as non-load bearing board in humid conditions. The German EPD is taken from Ökobau online database [104]. They both conform to the ISO 15804 standard and the functional unit in both is 1 m^3 of produced particle board P5.

Table 47 Comparison of production of 1 m^3 of particleboard P5 in Norway and Germany

Activities A1-A3	P5 - Norway	P5-Germany
Use of renewable primary energy	2150	18710
Primary energy resources used as raw materials	11000	0
Use of non-renewable primary energy	3130	4703

[103] https://www.epd-norge.no/getfile.php/135684-1468919874/EPDer/Byggevarer/Bygningsplater/274N_Forestia-sponplater.pdf
[104] Prozess-Datensatz: Spanplatte

Non-renewable primary energy resources used as raw materials	2080	0
Total energy use per m^3	18360	23413
GWP [105] (gross) per m^3	346	429

The gross GWP emissions are calculated by taking the negative impact estimated for GWP in CO_2-equivalents for activities A1-A3 and adding potential CO_2 stored in the wood. The potential CO_2 storage is found by taking the carbon fraction and multiplying with atomic mass of CO_2-molecule (44) relative to atomic mass of a carbon atom (12) [106]. Since only carbon is stored in wood, we will use the term potential storage for CO_2. The gas is emitted when the wood product is incinerated.

The potential storage for CO_2 is given in the Norwegian EPD as 1057 kg per m^3 of particle board. The actual emissions of GWP for activities A1-A3 due are given as -711 kg CO_2-equivalents. A negative number indicates storage of CO_2 since emissions are avoided. This gives emissions of -711+1057=346 kg CO_2-equivalents for 1 m^3 of particle board. These emissions for activities A1-A3 are related to wood harvesting, production of other raw materials, transport to production site and emissions during production.

For the German estimate, this amount is calculated by using the density for particleboard. This is given as 700 kg per m^3. The humidity is given as 8.5% which is considered as totally dried wood. We use a carbon fraction of 0.515 based on Hohle [107] and Finsa [108]. This gives an estimated potential storage of 1322 kg CO_2. GWP emissions for activities A1-A3 are given as -893 kg CO_2-equivalents, a negative number indicates storage of CO_2. Adding the potential

[105] GWP is the term used in the EPD. This is understood to mean the same as emissions of CO_2-equivalents in a 100 years time period.

[106] University of Calgary, https://energyeducation.ca/encyclopedia/C_vs_CO2

[107] Hohle. E.E.: Bioenergi - Miljø, teknikk og marked. Energigården Brandbu, 2001, taken from Schlaupitz, H.: CO_2-utslipp fra skogbasert bioenergi

[108] For calculation of biogenic content of wood and conversion to CO_2, see Section 8 in Finsa EPD for particleboards and melamine faced particleboards.

CO_2-storage (-893+1322) we get emissions of 492 kg CO_2-equivalents for activities A1-A3 for the German product.

The energy use for activities A1-A3 in Table 47 differs considerably between the two EPDs. In the Norwegian one, use of renewable primary energy resources as material is estimated to 11 000 MJ. In the German estimate, this amount is 0. These resources are presumably wood residuals from the production (chips, sawdust) used for heat production applied in production or for heating production facilities. We assume that in the German EPD, this amount is registered under primary energy use. The sum of both renewable and renewable primary energy resources, used both as energy and materials, is presumably the correct basis for comparison of energy use. This is estimated as "Total energy use per m^3" in the table.

The German EPD estimates 23414 MJ for activities A1-A3 while the corresponding number from the Norwegian EPD is 18360 MJ. This suggests that the German production consumes about 27% more energy per functional unit. The gross emissions of CO_2-equivalents are about 24% higher for the German product.

The focus here is on the effect of producing the particleboard in Norway based on wood from Western Norway instead of exporting that wood to Germany, produce the particleboard there and import it back to Norway. This means energy use and emissions of CO_2-equivalents related to transport from Western Norway to Germany must be considered. It is assumed that the wood used in the EPD estimate for particleboard in Germany is based on wood harvested in Germany. There is no mentioning in the EPD of any import of raw materials.

In addition, the effect of importing the particleboard back to Norway will be considered. This may be due to higher production costs in Norway and low transportation costs. The imported particleboard is based on imported wood from Western Norway. This imported particleboard is then a product in direct competition to the particleboard produced in Norway.

For transport of 1 m³ particle board, we present three scenarios. The production facility Gschwend, Baden-Württemberg, Germany is listed as data source for the German EPD. This facility was closed in 2010. The selected production facility is for the company Pfleiderer Industrie GmbH in Gütersloh, Nordrhein-Westphalen. It had a production capacity of 605 000 m3 in 2010 [109]. The production facility in Norway is in Braskereidfoss.

- The first scenario is boat from Western Norway to Rostock and truck from Rostock to Gütersloh. This is export of wood from from Western Norway for production in Germany.
- The second is transport inside Norway from Braskereidfoss to Sogndal. Truck is the only possible transport mean for this distance.
- The third scenario is by truck from Gütersloh to Sogndal.

All energy use and emissions from transport are allocated 1 m³ particleboard. The tonne-km for the transport is calculated using 765 kg per m³ for raw timber [110] and 665 kg per m³ for particleboard [111].

For road transport, a truck with loading capacity larger than 18 tonnes is assumed. Estimates for energy use and emissions are taken from the Austrian Environment Agency [112]. The energy use factor is 0.623 kWh per tonne-km which includes indirect, upstream energy required to transform oil to diesel. The emission factor, 0.1533 kg CO_2-equivalents per tonne-km, is also taken from the same source. For transport in Germany the energy use and emissions factors for an articulated lorry with a loading capacity of 40 tonnes are used [113], as it is assumed that roads in Germany allow for larger trucks. These factors are also used for the whole distance Gütersloh-Sogndal. The factors include both direct and indirect (upstream) energy use and emissions [114].

The boat used for transport of wood from Western Norway to Germany is assumed to have a carrying capacity of 5000 m³. It has a 25% load on return. The energy use, 0.153 kWh/tonne-km, is based on 31 200 litre per trip for the boat,

[109] Mantau, U.: Standorte der Holzwirtschaft, Universität Hamburg 2012, Tabelle 2-2.
[110] Ecoinvent 2007, From Timmermann & Dibdiakova
[111] EPD Forestia Sponplater , lower range 630 kg pr m³, upper range 700 kg per m³ for particleboard
[112] Austrian Environment Agency , updated May 2019.
[113] In German, this lorry is called Sattelzüg.
[114] Austrian Environment Agency , updated May 2019.

including loading and unloading. The figure is taken from SINTEF [115]. Total energy use is 12.7 kWh/litre including indirect (upstream) energy use required for transforming oil into heavy fuel oil, 2.03 kWh/litre which is taken from ProBas [116]. The emission factor, 3.255 kg CO_2-eq per litre, is taken from IMO and includes upstream emissions required to transform oil into heavy fuel oil which is 0.45 kg CO2-eq per litre taken from ProBas [117].

Table 48 Transport 1 m³ particleboard.

	Transport mode	Route	Weight ¤	km	Tonne-km	MJ per m³ particle-board	kg CO_2 per m³ particle-board	Note
A	Truck	Distance to timber quay [118]	0.765	38	29.1	65.2	4.5	To timber quay Western Norway
B	Boat	Vadheim-Rostock &	0.765	1183	905.3	498.1	35.5	Export to Germany
C	Truck	Rostock-Gütersloh	0.665	455	302.6	283	20	Production site in Germany
D=A+B+C		Sum		1676	1237	846.3	60	Sum export to Germany
E	Truck	Gütersloh - Sogndal	0.665	1354	900.4	841.8	59.5	Import to Norway
F=D+E		Sum		3030	2137.4	1688.1	119.5	Export-production-import
G	Truck	Distance to timber quay	0.765	38	29.1	65.2	4.5	To timber quay Western Norway
H	Truck	Skei-Braskereidfoss	0.765&	422	322.8	724.4	49.5	Wood Harvest Western Norway
I	Truck	Braskereidfoss-Sogndal	0.665	364	242.1	543.2	37.1	Internal Norway
J=G+H+I		Sum #		824	594	1332.8	91.1	Wood harvest Western Norway

¤ 1 m3 particle board in tonne & Raw timber with a density of 765 kg per m3 # Internal Norway with wood harvest from Western Norway

Table 48 shows that import from production facility in Germany to Sogndal (E) emits about 1.6 more CO_2-equivalents per m³ than transport from production

[115] Transport av skogsvirke i kyststrøk , page 25
[116] RaffinerieÖl-schwer-OPEC-2010
[117] RaffinerieÖl-schwer-OPEC-2010
[118] Average transport distance, E-mail from ATSkog, October 16th, 2019.

site in Braskereidfoss to end user in Sogndal (I). Export to Germany from Western Norway (D) emits 11% more CO_2-equivalents per m^3 than transport from Western Norway to Braskereidfoss (G+H) even though the amount of tonne-km is 3.5 higher. This is because the truck emits almost 4 times more CO_2-equivalents per tonne-km than the boat.

If harvested wood from Western Norway is exported to Germany and produced particle boards are imported back to Sogndal (F), the emission per m^3 is 1.3 times higher than production in Norway with wood from Western Norway (J) and more than 3 times higher if production in Norway is based on local harvest (I).

Table 49 Scenarios for production and consumption of 1 m3 particleboard

Particleboard	MJ per m^3	CO2-eq per m^3	
A:A1-A3, harvested wood from Germany	23413	429	Production and consumption in Germany, from EPD
- A1-A2 MJ per m3	379	7.4	ProBas estimate.
+ Substituting import from Western Norway	323	16.2	Estimate for production of wood in Western Norway
+ Vadheim-Rostock	374	26.7	Boat
+ Rostock-Gütersloh	283	20.0	Truck
B : Based on imported wood	23923	484.8	Production in Germany, wood from Western Norway
C: Production Norway	18360	346	Production in Norway, from EPD
D: Production Norway	19628	433	Production in Norway from EPD, end user Western Norway
E: Imported back to Norway	842	59.5	Truck Gütersloh-Sogndal
F: B + E	24765	544.3	Production Germany, import product back to Western Norway
G: Production in Western Norway §	18358	344.4	Substituting harvesting Western Norway, estimate A1-A3

§ Substituting estimate A1-A2 from Norway with A1-A2 from Western Norway

Table 49 shows different scenarios for production and consumption of 1 m^3 of particleboard. The estimates from EPDs (estimate A and C) do not include the activity A4, transport to end user. The estimates are comparable to each other. In addition, we have an estimate for production in Germany based on imported wood from Western Norway. This is estimated in B in Table 49.

Production in Germany based on imported wood from Western Norway (B) is only slightly more energy consuming than the EPD estimate based on German wood (A), while the emissions of CO_2-equivalents are about 13% higher. The energy requirements for harvesting wood in Western Norway is lower than in Germany while transport contributes to higher emissions of CO_2-equivalents per m^3. Harvesting in Germany may include more use of heavy machinery (forwarder, harvester). The report from University of Innsbrück on harvesting wood in Tyrol compares their own estimates with values used in the Ecoinvent database [119]. They find that: "The ecoinvent process shows impact numbers that are about twice as high. This is mainly due to higher diesel consumption and power sawing input." The energy estimate for Germany is taken from ProBas which uses the database Gemis. It may be that generic system borders and energy use factors taken from online databases give higher energy use than estimates based on specific use of machinery tailored for different activities such as the ones made by Timmermann & Dibdiakova and adjusted to wood harvesting in Western Norway.

The production of 1 m^3 particleboard in Norway (C) requires 78% of energy use and 81% of emissions of CO_2-equivalents compared to production in Germany (A), based on German harvest. Both estimates are based on the EPDs. If production in Germany is based on imported wood from Western Norway (B), emissions of CO_2-equivalents in the Norwegian production drop to 71% of the emissions in Germany (A). This is the effect of increased emissions from transport of wood from Western Norway to Germany.

[119] Kraler, A., Krismer, V., Wieland, G.: "Mountain Wood vs. Lowland Wood", an ecological process assessment - a case study. University if Innsbrück, 2011, Section 5: Comparison with the Ecoinvent database

The other two estimates, D and F, include transport to end user. If harvested wood for the particleboard in Germany is imported from Western Norway, produced in Germany and imported back to Western Norway (F) energy use is 35% higher than production in Norway with wood harvest and end user from Western Norway (G). The corresponding figure for emissions of CO2-equivalents is 58% higher. This is the impact of increased transport to and from Western Norway.

If production was possible in Western Norway, the transport to production facility in Braskereidfoss and back to end user in Western Norway can be discarded. Table 1 shows that energy use for 1 m^3 of harvested wood in Norway is 235 MJ and emissions of CO_2-equivalents are 17.8 kg. These estimates can be substituted for estimates for harvesting wood in Western Norway from Table 43, which shows 232 MJ and 16.2 kg CO2-equivalents per m^3. These estimates are for activities A1 and A2. If energy use and emissions from production (A3) are the same, this is estimate G in Table 49. The difference in energy use and emissions compared to the Norwegian EPD (C) is negligible. This is because the energy and emissions for harvesting the wood and transporting it to factory gate (A1-A2) is small compare to the production phase (A3). For emissions of CO_2-equivalents, the estimate for harvesting wood in Norway from Timmermann & Dibdiakova accounts for only 5% of total gross emissions during the A1-A3 phase estimated by the EPD.

Substitution

In this section, we will present an estimate for a product that may be substituted with extra particle board presented in the previous section. The product is a polyurethane(PU) foam insulation board. The EPD [120] for the product is made by PU Europe [121], an advocacy group for the European polyurethane insulation industry. According to the EPD, the board is applied for "thermal insulation of residential and commercial buildings, e.g. as interior and exterior insulation for roofs, floors, ceilings and walls".

[120] https://www.poliuretano.it/pdf_EPD/PU_thermal_insulation_board_with_mineral_fleece_facing.docx-1.pdf
[121] https://www.pu-europe.eu/

In the following, it is assumed that this PU may be substituted by an extra particleboard of type P3 or P5. We do not include any transport of the final products and consequently assume that they both are produced in Western Norway.

Table 50 Material composition of PU foam insulation board

	kg	%
Methylene diphenyl diisocyanate (MDI)	2.80	60.5
Polyols	1.34	29
Pentane	0.23	5
Additives	0.25	5.5
Sum	4.63	100

The declared unit is 1 m² of PU thermal insulation board with a mineral fleece facing and thickness of 13 mm. Table 51 shows energy use and emission of CO_2-equivalents for activities A1-A3 for producing the declared unit. These activities comprise the production of the final product as well as production of all raw materials and energy required for this production. The activities also include transport of raw materials to production site.

Table 51 Energy use and GWP for production of 1 m² of PU thermal insulation board, activities A1-A3.

	Parameter	Unit	A1-A3
A	Use of renewable primary energy	MJ	9.89
B	Primary energy resources used as raw materials	MJ	0
C=A+B	Total use of renewable primary energy resources	MJ	9.89
D	Use of non-renewable primary energy	MJ	195
E	Non-renewable primary energy resources used as raw materials	MJ	101
F=D+E	Total use of non-renewable primary energy resources	MJ	296
G=C+F	Total energy use (including materials)	MJ	306

	GWP	kg CO2-eq.	12.9

To compare production of extra particle board (P3, P5) with the PU insulation board, they must be normalized to the same unit. Table 52 shows the estimates for energy use and emission of CO_2-equivalents for the two products normalized to 1 kg. The GWP net estimate for the particle board includes the amount of CO_2 stored in the wood. The net estimate is the potential CO2 storage for the unit plus emissions related to activities A1-A3 (see Equation 10).

Table 52 Energy use and emission of CO^2-equivalents for producing 1 kg of PU insulation board and extra particle board. Activities A1-A3.

			PU insulation board	Particle board extra (P3-P5)
	Parameter	Unit	A1-A3	A1-A3
A	Use of renewable primary energy	MJ	2.14	3.06
B	Primary energy resources used as raw materials	MJ	0.00	15.66
C=A+B	Total use of renewable primary energy resources	MJ	2.14	18.72
D	Use of non-renewable primary energy	MJ	42.12	4.46
E	Non-renewable primary energy resources used as raw materials	MJ	21.82	2.96
F=D+E	Total use of non-renewable primary energy resources	MJ	63.94	7.42
G	Use of renewable secondary fuels	MJ	0.00	1.48
H=C+F+G	Primary energy with materials	MJ	66.07	26.14
H_{WN}	- Using wood from Western Norway	MJ		26.13
I	GWP	kg CO2-eq.	2.79	0.49
I_{WN}	- using wood from Western Norway	kg CO2-eq.		0.49
Substitution				
J	Stored CO2 per kg wood product	kg CO2		-1.50

K	Substitution effect per kg #	kg CO2-eq.		-4.29
L	Substitution effect per m3 of particle board §			-3014.25
M	-of this, stored CO2 per m3 of particle board			-1057
N	-of this, avoided emissions per m3 of particle board §			-1957.25

Row I for PU board*-1+row J particleboard § Using wood product's total weight in kg pr m3 for recalculating to m3

According to the table above, the GWP effect of substituting PU insulation board with P5 particle board is -4.29 kg CO_2-equivalents per kg particle board. This figure is calculated as the number of CO_2-equivalents avoided by not using the PU board plus CO_2 stored in the particle board according to Equation 19 (see explanation below the table). This corresponds to 3014 kg CO_2-equivalents for each m3 of P5 particle board. Of this, 1057 kg CO2 is stored in 1 m3 of particle board and emissions of 1957 kg CO_2-equivalents are saved pr m3 of particle board by not using the PU insulation board.

3.2 Steel and glue laminated bar

This section will address the question of substitution of a structural steel building product with a corresponding product based on laminated wood. We will use a structural bar as an example. A structural building component has been defined as "the primary load bearing components of a building". [122] The specific purpose of a structural bar is to transfer the load form the floor above to the columns [123].

Both the structural bar and the glue laminated bar is produced in Norway. We will use their EPDs to analyse the effect of substituting the steel bar with the glue laminated bar. It is assumed that a substitution between the two products is feasible without compromising structural requirements.

[122] https://gharpedia.com/structural-components-of-buildings/

[123] Basic components of a building structure, section 4. https://theconstructor.org/building/12-basic-components-building-structure/34024/

The steel bar is produced in Roverud, Norway and manufactured by Contiga AS [124]. The product is a welded plated beam and the functional unit is 1 kg of building steel structure with an expected service life of 100 years. The glue laminated beam is produced by Moelven, Norway at two production facilities, one in Moelven and one in Vatnestraum. The functional unit is 1 m^3 of glue laminated timber from spruce with an expected reference lifetime of 60 years [125]. The average density for glue laminated timber from spruce is 425 kg per m^3 [126]. The amount of biogenic carbon stored as CO_2 is given as 687.5 kg per m^3 timber based on a density of 375 kg per m^3 for totally dried biomass.

We will concentrate on the activities A1-A3 in this section. These activities comprise extraction and manufacturing of raw materials (A1), transporting them to production site (A2) and manufacturing of the product itself (A3). In both EPDs the activities are grouped together. This means that it is not possible to separate e.g. A1 from the other activities. For glue laminated timber, A1 includes manufacturing of glue in addition to harvesting wood. To produce 1 kg of glue laminated timber, 375 kg of spruce in dry condition and 4.85 kg of glue is required [127].

Table 53 shows energy use in MJ and contribution to GWP in kg CO_2-equivalents for 1 kg of structural bar from different products. The energy consumption for the glue laminated timber bar is recalculated from m^3 to kg by using Equation 20 where the last term is the inverse of the density with spruce as raw material. The equation is also used for calculating GWP potential for 1 kg glue laminated bar.

Equation 20 Recalculating energy use from m³ to kg for glue laminated timber bar

$$\frac{MJ}{kg} = \frac{MJ}{m^3} * \frac{m^3}{kg}$$

[124] https://www.epd-norge.no/getfile.php/135955-1469040552/EPDer/Byggevarer/St%C3%A5lkonstruksjoner/76_Type-12--Welded-plated-beams--like-hat-profile--HSQ-beam.pdf

[125] https://www.epd-norge.no/getfile.php/139068-1530528866/EPDer/Byggevarer/Heltreprodukter/NEPD-1576-605_Standard-limtrebjelke.pdf

[126] Tekniske data, EPD Cross laminated timber

[127] ibid.

Table 53 Energy use and contribution to GWP for production of 1 kg of structural bar from different materials

		Unit	Steel bar	Glue laminated bar
A	Renewable primary energy resources used as energy carrier	MJ	9.7	7.9
B	Renewable primary energy resources used as raw materials	MJ	0.00005	16.7
C=A+B	Total use of renewable primary energy resources	MJ	9.7	24.6
D	Non-renewable primary energy resources used as energy carrier	MJ		2.8
E	Non-renewable primary energy resources used as materials	MJ		0.3
F=D+E	Total use of non-renewable primary energy resources	MJ	30.4	3.2
G=C+F	Total energy use including materials	MJ	40.1	27.8
H=C/G*100	Percent renewable energy	%	24	88.6
I	GWP (Global Warming Potential), gross	kg CO2-eq.	2.9	0.19
J	GWP with biogenic CO_2 storage	kg CO2-eq.		-1.4
K	Transport 1 kg to Sogndal	kg CO2-eq.	0.044	0.061
L=I+K	GWP (Global Warming Potential), gross inclusive transport		2.93	0.23

Table 54 Transport inside Norway for steel bar and glue laminated bar

	1 kg in tonne	km	Tonne-km	Type	g CO_2-eq per tkm	kg CO_2-eq.
Moelven-Sogndal (glue-laminated timber)	0.001	288	0.288	Truck,>18 t	153.3	0.044
Roverud-Sogndal (steel bar)	0.001	416	0.416	Truck,>18 t	153.3	0.061

It should be noted that the expected lifetimes for the two products are not identical. The steel bar has an expected lifetime of 100 years while the expected lifetime for the glue laminated bar is 60 years. This will give the steel bar an advantage since the lifetime is over 65% longer. If energy use and contribution to GWP for the steel bar had been calculated for a shorter lifetime, their values would have been higher per kg.

The contribution to GWP is 15.3 times higher for 1 kg of steel bar compared to 1 kg of glue laminated timber (I) . The total energy use for the steel bar is only 1.4 times higher than the glue laminated timber bar (G). This includes using energy as materials, e.g. using wood residuals at sawmill as process energy or for heating buildings. The percentage of renewable energy for the glue laminated bar is 87 percent compared to 24 percent for the steel bar (H). This difference in energy composition is reflected in the different contributions to the GWP.

If we take biogenic carbon storage into consideration, the glue laminated timber bar has a totally different performance than the steel bar since it acts as a sink rather than an emission source. This again assumes that the timber is incinerated at the end of its lifetime so that the stored carbon re-enters the carbon cycle while the energy produced substitutes energy from non-renewable sources. If the timber bar is transported to landfill, the sink functions potential is not realized [128]. This means that the activities C1-C4 and activity D must be included in the EPD, which is the case for the EPD used in this section. It is assumed that the wood is incinerated in an appropriate facility and that through combustion of the wood the inherent energy is recovered. Further it is assumed that this energy substitutes energy from the national electricity mix and electricity from district heating. With these assumptions, the biogenic carbon may be allocated to activities A1-A3.

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[128] Bruksanvisning for hvordan tolke EPD'er: Bygningsplater. https://www.epd-norge.no/getfile.php/136573-1470750755/Dokumenter/Bruksanvisninger%20tolke%20EPDer/Bruksanvisning%20for%20EPD%20-%20bygningsplate.pdf

One objection to this analysis is that the correct unit for comparison of environmental impact from the two products is the whole building into which they are placed, not just 1 kg of product. And when the whole building is the unit, the use phase of the building must be considered. In the glue laminated timber EPD the use phase activities (B1-B5) are not included and it is claimed that there are no LCA relevant impacts. These activities cover the use of the product during its lifetime (B1), energy and emissions related to maintenance (B2), repair (B3), exchange (B4) and refurbishing (B5).

Cole and Kernan (1996) found that operational energy contributed most to the life cycle energy of a building [129]. Marceau and VanGeem (2006) [130] claimed that the most important factor for life cycle energy use was the energy used for heating and cooling the building. This was more important than the materials used for the building. They claimed that buildings made from timber required more energy for heating and cooling than building made from concrete. It should be noted that their research was supported by the cement industry. In any case, this discussion shows that the use phase may be a determining factor when calculating the total effect of building materials over the whole lifetime of a building.

3.3 Steel and glue laminated bar in Germany based on imported wood from Western Norway

This section will compare energy use and emissions of CO_2-equivalents from producing a glue laminated bar and structural steel in Germany. The research question is what substitutional effects can be realized by using a wood product instead of a steel product. This effect will also be analysed using imported wood from Western Norway.

[129] Hill, C., Zimmer, K., The environmental impact of wood compared to other building materials, NIBIO Report nr 56/2018, page 100. https://nibio.brage.unit.no/nibio-xmlui/bitstream/handle/11250/2496052/NIBIO_RAPPORT_2018_4_56.pdf?sequence=1

[130] ibid., page 102.

The EPD for the glue laminated bar is taken from the German online database Ökobau [131]. The weight of the bar is 443 kg which is 18 kg more than the Norwegian corresponding product. According to the EPD it takes 2.1 MJ more to produce one kg of a glue laminated bar in Germany than in Norway (see previous section). The contribution to GWP is however smaller in Germany than in Norway per kg. The German bar emits 0.05 kg CO_2-equivalents per kg bar.

The EPD for structural steel produced in Germany is for galvanized hot rolled steel used as structural sections, merchant bars and heavy plates [132]. The rolled steel is intended for use is bolted, welded or otherwise connected constructions in buildings, bridges and similar structures [133].

Table 55 Energy use and emissions of CO_2-equivalents for 1 kg of hot rolled steel and glue laminated bar

	Activities A1-A3 for 1 kg product		Galvanized hot rolled steel (1)	Glue laminated bar (2)
A	Renewable primary energy as energy carrier	MJ	2.43	5.2
B	Renewable primary energy resources as material utilization	MJ	0	19.3
C=A+B	Total use of renewable primary energy resources	MJ	2.43	24.5
D	Non-renewable primary energy as energy carrier	MJ	14.8	5.1
E	Non-renewable primary energy as material utilization	MJ	0	0.3
F=D+E	Total use of non-renewable primary energy resources	MJ	14.8	5.4
G	GWP	kg CO_2-eq.	1.32	0.38¤

¤ Gross emissions, not including carbon storage in product

[131] https://oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=07fe8f43-6a63-4d93-aec0-811d46447953&stock=OBD_2019_III&lang=en

[132] bauforumstahl e.V & Industrieverband Feuerverzinken e.V.

[133] ibid., see Scope.

Table 55 shows energy use and emissions for production of 1 kg of galvanized hot rolled steel and 1 kg of glue laminated timber. Both products can be used for structural purposes in a building. The emissions of CO_2-equivalents for the glue laminated timber are not corrected for carbon storage in the product. According to the EPD [134], the carbon content of 1 m^3 of glue laminated timber is 221.3 kg. This is converted into stored CO_2 by multiplying with the atomic weight of CO_2-molecules relative to carbon (44/12). This gives 811.4 kg CO^2 stored in 1 m^3 of glue laminated timber. The net emissions of CO2-equivalents for 1 m^3 is given as -750.6 kg in activity A1 and -643.2 kg CO_2-equivalents for activity A1-A3. Adding storage of CO_2 gives the gross emissions. This means that if there were no emissions for e.g. activity A1 the gross emissions would be zero. Equation 21 shows the equation for the calculation. The storage number is assumed to be a positive number [135].

Equation 21 Calculation of gross emissions of CO_2-equivalents per m3 of cross laminated timber

$$\frac{Emissions_{CO_2eq-gross}}{m^3} = \frac{Emissions_{CO_2eq-net}}{m^3} + \frac{Storage\ _{CO_2}}{m^3}$$

According to Table 55, the emissions of CO_2-equivalents for 1 kg of hot rolled steel is about 3.5 times higher than for 1 kg of cross-laminated timber. For each substitution of 1 kg of hot rolled steel with 1 kg of cross laminated timber, emission of 0.94 kg of CO_2-equivalents is avoided (G1-G2). In addition, glue laminated timber stores 811 kg of CO_2 which also could be considered as avoided emissions of CO_2.

What is the impact on levels of emissions of importing wood from Western Norway for the cross laminated timber? Presumably, the German EPD is based on wood from Germany. If we assume that the ProBas estimate I in Table 19 gives the energy use and emissions of CO_2-equivalents for producing 1 m^3 of timber under bark in Germany, this can be substituted with the corresponding energy use and emissions for 1 m^3 of timber from Western Norway from Table 43.

[134] See Excel datasheet for download

[135] As opposed to Equation 10, where the storage is assumed to be a negative number.

Table 56 Environmental impact of using imported wood from Western Norway for production of 1 m3 of cross-laminated timber in Germany

	Cross laminated timber (CLT) Germany (A)	ProBas I (B)	Western Norway (C)	Western Norway incl. transport ¤ (D)	Corrected CLT (E=A-B+D)
Energy MJ per m3	10334	379	232.3	608.6	10563.2
GWP kg CO2-eq. per m3	60.8	7.4	16.2	43.5	97.0

¤ Boat transport from Vadheim to Wismar and transport from Wismar to Bornhöved

Table 56 shows the impact of substituting timber from Germany with timber from Western Norway. The production site for glue laminated timer in Germany is assumed to be Bornhöved [136]. Emissions of CO_2-equivalents for 1 m3 of wood are higher in Western Norway than in Germany when boat and truck transport from Vadheim to Bornhöved is included. We have used a ProBas estimate for wood harvesting which shows higher energy use per m3 than estimates from Timmermann & Dibdiakova but lower emissions of CO_2-equivalents per m3 [137]. This may be due to system border applied and differences in definition of upstream emissions. Transport to production site is not included in the ProBas estimate, which means only activities related to EPD-definition A1 is included, not activity A2. These differences explain why estimates for Western Norway show lower energy use but higher emissions per harvested m3 than the German estimate from Probas.

Substitution

Assuming both products are manufactured in Norway, what amount of emissions of CO_2-equivalents can be saved by substituting a steel bar with a cross laminated timber bar? Equation 19 and Table 53 can be used to answer

[136] https://www.holzruser.de/de/brettschichtholz.html

[137] Prozessdetails: Forst-D&EStamm-Fichte-atro-DE

this question. We assume that production of both products take place in Western Norway so that no transport is included in the estimate.

Table 57 Substitution of 1 kg steel beam with 1 kg cross laminated timber (CLT) Norway.

		Unit	Steel bar	Glue laminated bar (CLT)
A	From Table 53, A1-A3 GWP, gross per kg	kg CO2-eq.	2.9	
B	Biogenic CO_2 storage per kg §	kg CO2-eq.		-1.6
C=(A*-1)-B	Substitution effect per kg	kg CO2-eq.		-4.5
D	Substitution effect per m^3 §	kg CO2-eq.		-1907
E	- of this, stored CO2 per m3			-687.5
F	- of this, avoided emissions per m3 of CLT			-1219

§Using CLT's total weight (Table 53 uses dry wood fraction)

Table 57 shows that for each kg of CLT used instead of a steel beam, emissions of 4.5 kg CO_2-equivalents are saved. This corresponds to -1907 kg saved CO_2-equivalents for each m^3 with CLT, using CLT's total weight of 425 kg per m^3 for recalculating from kg to m^3. Of this, stored CO_2 amounts to 687.5 kg pr m3 CLT and avoided emissions amount to 1219 kg CO2-equivalents per m^3 of CLT.

3.4 Wood harvesting for energy production

Wood is used for heating in private homes. In 2016, a total of 5.7 TWh was produced by burning harvested wood in Norway, corresponding to 2.3 million m3 of wood [138] . This gives 2478 kWh per m^3.

Birch is the most used tree sort for energy production. In the following, it is assumed that estimates for energy use and emissions of CO_2-equivalents required for harvesting one m^3 wood in Western Norway is the same for all tree sorts.

[138] NIBIO: Virke til bioenergi

Table 58 Energy use and CO_2-emissions for 1 ha of harvested wood for energy production

Category	Process	value	unit	kWh	kg CO_2 -eq.
Product	Energy wood	1	ha		
Input	workers, time used	92	hours	238.9	64.4

Table 58 shows energy use and emissions of CO_2-equivalents for harvesting 1 hectare of wood with chain saw. The basic figure, 0.4 hours of chain saw use per m^3, is taken from Kraler (2011 [139]) and recalculated per hectare using 230 m^3 per hectare [140]. Energy use factor for chain saw is presented in Appendix A, including upstream energy use required for producing the fuel. Table 59 shows energy use and emissions of CO_2-equivalents per harvested m^3 and per produced kWh from burning 1 m^3 of birch wood.

Table 59 Energy use and CO_2-emissions per m^3 of harvested wood for energy production

	kWh	kg CO_2-eq.
Energy use/emissions per ha	238.9	64.4
Energy use/emissions per m^3	1.04	0.28
Produced kWh per m^3	2478	
Per produced kWh	0.0004	0.0001

3.5 Substitution

The assumption for calculating this substitution effect is that energy from birch wood replaces Norwegian electricity consumption. The emission factor for Norwegian electricity production is 0.0312 kg CO_2-equivalents pr kWh. This includes:

- production of electricity,
- import,

[139] Kraler, A., Krismar, V.,Wieland, G.:Gebirgsholz-Wald ohne Grenzen, Universität Innsbruck, 2011, page 33 and 76

[140] Timmermann & Dibdiakova, page 8.

- production and maintenance of electricity grid,
- loss from electricity transfer over the grid

The figure is from Ecoinvent, v 3.4, October 2017 [141]. There is no biogenic storage of CO_2 to consider since the birch wood is incinerated. In the calculations above, an energy production of 2478 kWh per m3 is assumed. Using the emission factor from Ecoinvent, a total emission of 77.3 kg CO2-equivalents is saved by using 1 m3 of birch wood for production production. According to Statistics Norway, a typical Norwegian household used 16044 kWh in 2012 [142]. If this electricity were to be replaced by energy from birch wood, a total emission of 500.5 kg CO_2-equivalents would be saved by this household. For comparison, a diesel car using 0.5 litre per 10 km will generate the same amount of emission by using 187.6 litre or travelling 3753 km.

3.6 Plywood from birch

The following estimate is for 1 m3 of plywood from birch [143]. The plywood is coated with phenol formaldehyde impregnated papers. The production site is in Järvelä, Finland. The product can be used in vehicles, heavy trailers, light delivery vans as well as in construction of buildings. It has a density of 680 kg/m^3. Table 60 shows the material composition of the product. The functional unit for the estimate is 1 m^3 of birch plywood.

Table 60 Material composition for birch plywood

Materials	%	kg
Wood	89.30%	607.24
Phenolic resin	5.30%	36.04
Paper (lamination)	1.60%	10.88
Phenolic resin (lamination)	2.90%	19.72

[141] Moelven EPD: Standard cross laminated beam

[142] https://www.ssb.no/energi-og-industri/statistikker/husenergi

[143] https://www.koskisen.com/file/epd-the-environmental-product-declaration-phenol-coated-birch-plywood/?download

Limestone aggregate	0.50%	3.4
Hardeners	0.30%	2.04
Polypropylene	0.00%	0
Total	100.00%	679.32

Table 61 Energy use and emissions for 1 m^3 of birch plywood, activities A1-A3

	Category	Unit	Value
A	Renewable primary energy resources used as energy carrier	MJ	17000.0
B	Renewable primary energy resources used as raw materials	MJ	8520.0
C=A+B	Total use of renewable primary energy resources #	MJ	25500.0
D	Non-renewable primary energy resources used as energy carrier	MJ	10800.0
E	Non-renewable primary energy resources used as materials	MJ	32.9
F=D+E	Total use of non-renewable primary energy resources #	MJ	10800.0
G	Use of renewable secondary fuels	MJ	0.0
H	Use of non-renewable secondary fuels	MJ	3.4
I	Global Warning Potential (GWP)	kg CO_2-eq.	438

Any discrepancies in sums due to rounding in the EPD

Table 61 shows energy use and emission for production of 1 m^3 of birch plywood. Including embedded or inherent energy, a total of 36 353 MJ (C+F) is required for the production. If we use figures for activities harvesting (A1) and transport (A2) from Norway [144], and assuming energy use and emissions of CO_2-equivalents are the same for wood harvesting in Finland and Norway, 234.4 MJ and 17.8 kg CO_2-equivalents will be used on these activities.

[144] LCA from Timmermann & Dibdiakova, Tabell 16 for emissions of CO_2-equivalents.

Assuming that the carbon content is equal to 50% of dry wood, a total of 303.6 kg of carbon is stored in the birch wood from the product. This is identical to a storage of -1113.3 kg of CO_2 per m^3. The total emissions for producing 1 m^3 of birch plywood is estimated to 438 kg CO_2-eq pr m^3 without considering any carbon storage. The net storage of CO_2 during the product's lifetime is therefore -675.3 kg per m^3 (see Equation 10).

Table 62 Energy use and emissions using wood from Western Norway

	All figures per 1 m^3 of birch plywood	MJ	kg CO_2-eq
A	Total	36352.9	438.0
B	-minus harvest/transport (A1-A2) from wood #	234.4	17.8
C=A-B	A3 plus non-wood elements A1-A2	36118.5	420.2
D	-A1-A2 from wood harvest Western Norway	234.3	16.2
E=C+D	Total with wood from Western Norway	36350.9	436.4
F=E-A	Impact of production in Norway	-2	-1.6

Using general Norwegian figures from Timmermann & Dibdiakova

Table 62 shows the impact on energy use and emissions from using wood from Western Norway to produce 1 m^3 of birch plywood. The production is assumed to take place in Western Norway; therefore no additional transport is estimated. In (B), it is assumed that the energy use and emissions for wood harvest in Finland is identical to general figures for Norway, taken from Timmermann & Dibdiakova. The average transport distance is also assumed to be identical in the two countries. The table shows that energy use and emissions are practically identical regardless of whether activities wood harvesting and transport takes place in general Norway (serving as proxy for Finland) or Western Norway. The table also indicates that the production phase (A3) is dominating the environmental impact of production of 1 m^3 of birch plywood.

3.7 Substitution

According to the US online web shop Displays2Go [145], plywood from hardwood can be used for wall structures. This makes plywood from birch an alternative to plasterboard. In this section, energy use and emissions of CO_2-equivalents from production of plywood will be contrasted with the same indicators for production of plasterboard. The plasterboard is taken from the Norwegian EPD for standard plasterboard made in Fredrikstad, Norway [146]. The functional unit for that EPD is 1 m^2 of plaster board. To compare energy use and emissions from plasterboard and plywood, both estimates are normalized to 1 kg. The plasterboard weighs 9 kg per m2 while the density for plywood is of 680 kg/m^3 as given above. It will be assumed that both products are made in Western Norway to make them comparable without any additional transport.

Table 63 shows the material composition of 1 m^2 of standard plasterboard.

Table 63 Material composition of standard plasterboard

Material	kg	%
Stucco	7.326	81.4%
Paper liner	0.335	3.7%
Other additives	0.112	1.2%
Water	1.227	13.6%
Total	9	100.0%

Table 64 Energy use and emissions for 1 m^2 of standard plasterboard, activities A1-A3

		Unit	Value
A	Renewable primary energy resources used as energy carrier	MJ	3.90

[145] https://www.displays2go.com/Guide/Comparing-Building-Materials-Particle-Board-MDF-Plywood-17

[146] https://www.gyproc.no/sites/gypsum.nordic.master/files/gyproc-site/document-files/Environmental-NO/NEPD-1260-406-Gyproc-Normal.pdf

B	Renewable primary energy resources used as raw materials	MJ	6.40
C=A+B	Total use of renewable primary energy resources	MJ	10.30
D	Non-renewable primary energy resources used as energy carrier	MJ	28.50
E	Non-renewable primary energy resources used as materials	MJ	4.50
F=D+E	Total use of non-renewable primary energy resources #	MJ	33.40
G	Use of renewable secondary fuels	MJ	
H	Use of non-renewable secondary fuels	MJ	
I	Global Warning Potential (GWP)	kg CO2-eq	1.70

Any discrepancies in sums due to rounding in the EPD

Table 64 shows energy use and emissions of CO2-equivalents for producing 1 m^2 of standard plasterboard.

Table 65 Energy use and emissions for 1 kg of plywood and standard plasterboard, activities A1-A3

			Plywood	Plaster board
A	Renewable primary energy resources used as energy carrier	MJ	25.00	0.43
B	Renewable primary energy resources used as raw materials	MJ	12.53	0.71
C=A+B	Total use of renewable primary energy resources	MJ	37.50	1.14
D	Non-renewable primary energy resources used as energy carrier	MJ	15.88	3.17
E	Non-renewable primary energy resources used as materials	MJ	0.05	0.50
F=D+E	Total use of non-renewable primary energy resources	MJ	15.88	3.71
G=C+F	Energy+materials, C+F	MJ	53.46	4.81

H	Energy+materials, assuming wood from Western Norway	MJ	53.56	
Substitution				
I	GWP per kg	kg CO2-eq.	0.64	0.19
J	GWP per kg, assuming wood from Western Norway	kg CO2-eq.	0.64	
K	Stored CO_2 per kg plywood §	kg CO2-eq.	-1.64	
L=K-I¤	Substitution effect per kg plywood	kg CO2-eq.	-1.83	
M	Substitution effect per m^3 plywood &	kg CO2-eq.	-1241.6	
N	- of this, stored CO2 per m^3 plywood &	kg CO2-eq.	-1113.3	
O	- of this, avoided emissions per m^3 plywood *	kg CO2-eq.	-128.3	

§Using the wood product's total weight per m^3 ¤Only third column for row I & Using plywood weight of 680 kg per m^3 * Using column 3 for I and plywood weight of 680 kg per m^3

Based on Table 64 and Table 61, we can construct Table 65 where both estimates for energy use and emissions of CO_2-equivalents are normalized to 1 kg. Estimates for energy use and emission for plywood based on wood from Western Norway are included in the table. The table shows that 1.83 kg CO_2-equivalents can be saved by using 1 kg plasterboard instead of one kg plywood. This figure is calculated as the saved emissions from production of 1 kg of plasterboard (0.19 kg CO_2-eq) plus kg CO_2 stored in the plywood (1.64 kg). This corresponds to 1241.6 kg CO_2-equivalents for 1 m^3 of plywood. Of this, 1113.3 kg comes from CO_2 stored in the plywood.

4 Substitution overview

Table 66 shows the substitution effects presented previously for different wood products. The effects are calculated as emissions of kg CO_2-equivalents per m^3 of wood product.

Table 66 Overview of substitution effects calculated as emissions of kg CO_2-equivalents per m^3 of wood product

Life cycle phase		Spruce		Birch	
		Technology		Technology	
		Low	High	Low	High
		Particle-board	Cross laminated timber	Energy production	Plywood
	Gross emissions				
A	- Wood management (A1§)	1.22	1.22	0.00	1.22
B	- Wood harvesting (A1)	9.46	9.46	0.28	9.46
C	- Transport to processing (A2)	5.55	5.55	0.00	5.55
D	- Processing (A3)	328.2	61.7	0	420.2
E=A+B+C+D	Gross emissions A1-A3	344.4	77.9	0.28	436.4
	Substitution				
F	- Avoided emissions	-1957.25	-1219.32	-77.32	-128.32
G	- Carbon storage	-1057.00	-687.50	0.00	-1113.27
H=F+E	Net avoided emissions	-1612.9	-1141.4	-77.0	308.1
I=G+E	Net carbon storage	-712.6	-609.6	0.28	-676.9
J=(F+G)+E	Net substitution effect	-2669.9	-1828.9	-77.0	-805.2

§ Refers to the definition of the activity according to EN 15804 [147]

[147] Environmental Product Declarations

Assumptions for calculations of the substitution effects are:

- All EPDs report activities A1-A3 together.
- Estimate for emissions in activity A3 (processing) is calculated by subtracting an estimate for emissions for activities A1-A2 based on general Norway figures from Timmermann & Dibdiakova (Table 1). This estimate for A1-A2 is considered generic, it is supposed to be universally valid for harvesting and transport to production gate for all countries supplying an EPD.
- This means the estimate for activity A3 from the previous calculation is considered given. This estimate is row D in Table 66.
- Then estimates for activity A1-A2 from Western Norway are added to the given estimate for activity A3. These estimates are in row A, B and C in Table 66. This gives a new estimate for the aggregated emissions for activities A1-A3 based on wood harvesting from Western Norway. This estimate is called "Gross emissions A1-A3" (row E) in Table 66.
- Wood management comprise activities
    - planting,
    - seed production,
    - thinning,
    - terrain transport for thinning,
    - pruning,
    - fertilizing,
    - spraying,
    - tending,
    - site preparation,
    - construction and maintenance of forests roads.
- Wood harvesting comprise activities
    - clearfell,
    - terrain transport for clearfelling,
    - harvesting by cable car,
    - timber quay,
    - extra transport because of municipal road network ("kipping" in Norwegian).
- All production is assumed to take place in Western Norway. So no transport from production gate (activity A4) is assumed. Transport to production gate (A2) is the estimate for timber transport by road and rail from Table 1.
- The average transport distance from harvest site to timber quay is used as proxy for hypothetical distance to processing plant.
- The CLT bar weighs 425 kg per m^3, the particleboard weighs 702 kg and the plywood weighs 679 kg. The difference in weight probably explains why GWP gross emissions is lower for the CLT bar pr m^3.

- For energy production from birch wood, it is assumed that the emissions are equal to carbon uptake by tree growth on harvest site.
- Net avoided emissions for a product A are the emissions saved by substituting another product B plus the emissions required for activities A1-A3 for product A. This is row H in Table 66.
- Net carbon storage for Product A is carbon storage calculated as CO_2 plus emissions required for activities A1-A3 for product A. This is row I in Table 66.
- Net substitution effect for product A is calculated as carbon storage calculated as CO_2 in A plus avoided emissions by substituting A for product B plus emissions required for activities A1-A3 for product A. This is row J in Table 66.
- Calculation of carbon storage as CO_2 is presented in the analysis section for each product above.

Table 66 shows that substitution of plaster board with birch plywood increase net avoided emissions since emissions for activities A1-A3 are larger for birch plywood pr kg, according to the EPDs used. This result does not consider carbon storage in plywood.

5 LCA for BalanC sites

The model for LCA analysis of wood harvesting is applied on experimental sites developed in the BalanC project. These are Jølster I and II, Ørsta and Stranda. Only spruce harvesting is included in the analysis. The analysis is a cradle-to-gate analysis for activities A1 and A2, extraction and production of raw materials and transport of them to closest timber quay which is a proxy for production gate.

The application of the LCA model on these sites allows for a more precise analysis since the input and transport distances are more specific for individual sites than for whole regions. Especially for transport this gives a more detailed picture of the energy use and emissions related to this activity.

5.1 Assumptions

The following assumptions are made:

- Spraying Jølster II and Stranda. Assumed same ha per m^3 as national figures [148].
- Planting. Number of plants given by NIBIO. Seeds in kg calculated by using same ratio of seed mass to number of plants as for Norway in general given by Timmermann & Dibdiakova [149].
- In the following, the initials Fv refers to the Norwegian term "Fylkesvei" which is a road managed by the Norwegian regional counties ("fylke").
- The maximum allowable load for timber trucks in Norway is 60 tonnes [150]. None of the roads from BalanC sites to the closest timber quay can accommodate the largest trucks. The maximum allowable load is 50 tonnes on these roads. For roads with a load of 50 tonnes, no extra transport for loading timber on the trailer ("kipping") is assumed.

[148] Skogkultur, Kjemisk rydding og ugrasskontroll 2018. Statistics Norway . Normalized to clearfelled volume from Timmermann & Dibdiakova 2010, see 2.2 Forutsetninger, page 3 (8 396 000 m^3).

[149] "Det ble produsert 300 kg frø (Skogfrøverket 2012) og 20 millioner planter i 2010", Timmermann & Dibdiakova, page 3

[150] Fjeld,D., Vennesland, B., Bjørkelo, K.:Flaskehalser i det kommunale vegnettet, NIBIO-rapport nr 97, 2019. Page 5

- Road Fv 451 has a maximum load of 50 tonnes [151]. The distance to Kvamen timber quay is 61.5 km for Jølster I and 67.5 km for Jølster II. The maximum load for the last distance for road Fv57 from Bygstad to timber quay is 50 tonnes [152].
- Site Ørsta. Maximum load allowed for road Fv 665 from Brautaset to Ørstaterminalen is 50 tonnes [153]. "Kipping" activity (extra transport for loading timber on the trailer) is assumed to be from harvest site to Vassenden bridge, a distance of 2 km. A "kipping" factor of 5 is assumed for this distance. From Vassenden bridge the maximum allowed load is 50 tonnes for road Fv 45 until it reaches road Fv 665 (0.5 km). The transport distance is defined from Vassenden bridge to Ørstaterminalen, a distance of is 9.7 km.
- "Kipping" Stranda. The "kipping" distance is from harvest site Svemorka to Engset mechanical workshop, a distance of 3.9 km. A "kipping" factor of 5 is assumed for this distance. The transport distance is defined from the workshop at Engset to Ørstaterminalen, a distance of 92.4 km following Fv60.
- Stranda. Maximum load for road Fv 60 is 50 tonnes for the distance Støverstein - junction E39 at Grodås. The maximum load for Stranda - Støverstein is 60 tonnes [154]. Since the load is 50 tonnes on part of the road, this load is assumed for the whole distance on Fv 60.
- The following algorithm will be used to find the extra amount of transport since 60 tonnes trucks cannot be used on roads from BalanC sites to the closest timber quay:
    - For each site, find the mass of the harvested volume M in tonnes (T). For each site, a density of 765 kg per m^3 is used.
    - Let A be the number of trips required to transport the estimated mass T by a 60 tonnes truck. This is an integer number, rounded down.
    - Let B be the number of trips required to transport the estimated mass T by a 50 tonnes truck. All roads (except the roads used for "kipping") are accessible by a 50 tonnes load.
    - Let C be the difference in trips, C=A-B.
    - Let D be the transport distance in km.
    - Let Q be the surplus transport km not accounted for by number of trips in B. Take site Jølster I as an example. There are 9 trips with a 50 tonnes truck which gives a total of 450 tonnes. The total mass to be transported from the site is 455.18 tonnes. Q is then 455.18-450=5.18 tonnes multiplied with the transport distance which is 61.5 km. This gives 318.3 extra tonne-km (using some extra decimals for the mass).

[151] Vegliste Sogn og Fjordane 2019, Statens Vegvesen.

[152] Vegliste Vestland 2020, Tømmertransport, Statens Vegvesen

[153] Vegliste Møre og Romsdal 2020, Tømmertransport. Statens Vegvesen.

[154] ibid.

- Let E=(C*D*50)+Q since there will have to be C more trips over a distance of D km with a 50 tonnes truck. This is the amount of extra tonne-km required by using a 50 tonnes truck instead of a 60 tonnes truck.
- Let F=E/M where M is the harvested volume.
- Let G=F*EUF where EUF is the energy consumption factor per tonne-km for a 50 tonnes truck. The energy use factor is 0.623 kWh per tonne-km which includes upstream energy use for producing the fuel [155]. G is the extra energy use in kWh per m^3.
- Let H=F*EF where EF is the emission factor of CO_2-equivalents per tonne-km for a 50 tonnes truck [156]. This is 0.25 kg CO2-equivalents pr tonne-km, including upstream emissions required to produce the fuel. H is the extra emissions in kg CO_2-equivalents per m^3.
- Finally let I=H/D, the extra emissions of CO_2-equivalents per km transported.
- The extra transport calculated in this manner is not considered in the sum estimate for emissions for harvesting and transport for a site. It will be reported as extra emissions arising because the road standard is not suitable for optimal truck transport. As such, this is not actual transport but an estimate of the effect of extra emissions due to lower road standard.

5.2 Input for LCA analysis

Table 67 shows input for LCA analysis of different BalanC sites.

Table 67 Input for LCA analysis of different BalanC sites

Site	Unit	Jølster I	Jølster II	Ørsta	Stranda
Total harvested volume	m3	595	478	558	373
Crane harvesting	%	0.0	100.0	0	0
Thinning	m3	0	0	0	0
Site preparation	ha	0	0	0	0
Tending	ha	0	0	1	0

[155] The direct energy use factor is for a 18 tonnes truck obtained from Austrian Environment Agency , the indirect (upstream) use factor is from ProBas.

[156] Taken from the same source as above.

Reforestation	ha	2.0	2.0	2	2
Pruning	ha	0	0	0	0
Fertilization	ha	0	0	0	0
Planting	1000's	3.17	2.73	4.24	3.44
Seed production	kg	0.05	0.04	0.06	0.05
Spraying	ha	0	0.15	0	0.12
Transport, road	km	61.5	67.5	9.7	92.5
Percentage sawn timer	%	60	55	59	55
Extra transport, "kipping"					
- Distance	km	0	0	2	3.9
-Maximum allowable truck				<40 tonnes	<40 tonnes
Density kg/m3		765	765	765	765
Forest road					
- construction	km	0.00	2.00	0	6.2
- reconstruction	km	1.00	0.00	2.7	0

Table 68 shows the calculations of extra tonne-km for each site because of not being able to use the maximum allowed timber truck size (60 tonnes). The letters in the first column correspond to the letters used in describing the algorithm above.

Table 68 Extra tonne-km related to maximum truck allowed

		Jølster I	Jølster II	Ørsta	Stranda
M	Volume, harvested	595	478	558	373
T	Weight, tonnes	455.175	365.67	426.87	285.345
A	Trips, using 50 tonnes truck	9	7	8	5

B	Trips, using 60 tonnes truck	7	6	7	4
C=A-B	Difference in trips	2	1	1	1
D	Transport distance in km	61.5	67.5	9.7	92.5
Q	Surplus tonne-km	318.26	1057.73	260.64	3269.41
E=C*D*50+Q	Extra tonne-km	6468.26	4432.73	745.64	7894.41
F=E/M	Extra tonne-km per m3	10.87	9.27	1.34	21.16
G	Extra energy consumption	6.78	5.78	0.83	13.19
H	Extra emissions per m3	1.69	1.44	0.21	3.28
I	Extra emissions per km	16.3	10.2	11.9	13.2

5.3 Results

Table 69 shows the results of LCA analysis for different BalanC sites. The analysis shows:

- For Jølster II, crane harvesting is 100%. This has a great impact on the estimate which is higher than other locations.
- For Stranda, the transport distance by road to the nearest timber quay is higher than for the other sites. This gives higher emissions per harvested m3.
- Ørsta has the opposite effect, it has a lower distance from the site to the timber quay than other sites.
- For all sites, transport is the most decisive factor for emissions of CO_2-equivalents per harvested m3. Emissions related to wood harvesting and wood management are far lower.
- Extra emissions due to lower road capacity increases emissions with almost 14% for site Stranda. These extra emissions are higher for Jølster I than for Jølster II even if the transport distance is larger for the last site. This is because harvested volume and corresponding mass is larger for Jølster I, thus the extra amount of tonne-km is larger for this site.
- Ørsta site has lower emissions per m3 than for general Norway estimate by Timmermann & Dibdiakova and for Western Norway in general. This is due to lower transport for the site since it is located near the timber quay.

- All other sites have higher emissions than general Norway and Western Norway. Jølster II is highest because all harvesting is done by cable crane. This estimate is more than double the estimate for Western Norway, not including extra transport because of lower road capacity. Emissions for Stranda are 48% higher than for Western Norway when this extra transport is not considered.
- Jølster I is the site with emissions closest to the estimate for Western Norway. The transport distance (61.5 km) is larger than average for Western Norway (38 km) but there is no extra transport because of larger trucks not allowed on municipal roads ("kipping"). In Western Norway, this activity amounts to 1.6 kg CO_2-equivalents per m^3.
- It should be noted that emissions for all sites are distributed on far lower harvesting volumes, this may lead to anomalies compared to estimates for larger geographical units rather than for individual sites.

Table 69 LCA analysis of BalanC sites. Emissions of CO2-equivalents per m3

kg CO2-eq/m3	Jølster 1	Jølster II	Ørsta	Stranda
Planting	0.76	0.82	1.09	1.32
Seed and seeding production	0.013	0.014	0.018	0.022
Site preparation	0	0	0	0
Reforestation	0.04	0.06	0.05	0.07
Tending	0	0	0.016	0
Spraying	0	0.0001	0	0.0001
Fertilization	0	0	0	0
Pruning	0	0	0	0
Forest road construction	0	0.41	0	0.41
Forest road reconstruction	0.47	0.00	0.47	0.00
Thinning	0	0	0	0
Terrain transport while thinning	0	0	0	0
Clearfell	3.36	0.00	3.36	3.36
Terrain transport while clearfelling	3.00	0.00	3.00	3.00

Harvesting with cable crane/ cableway	0.00	22.36	0.00	0.00
Timber transport, road	8.33	9.05	2.19	12.01
Timber transport, rail	0	0	0	0
Timber transport, "kipping"	1.04	1.04	2.23	3.35
Timber quay	0.42	0.42	0.42	0.42
Sum	**17.45**	**34.16**	**12.84**	**23.97**
- plus extra transport by road per m^3	1.69	1.44	0.21	3.28
Sum with extra transport	**19.13**	**35.60**	**13.04**	**27.25**

APPENDIX A

	Unit	Total	Direct	Indirect	Source	
Diesel	kWh/litre	13.923	10.722	3.201	hypertextbook.com	ProBas
Diesel	Weights	1.000	0.770	0.230	Proportions of direct and indirect energy	
Diesel	kg CO2-eq./litre	3.464	2.640	0.824	ecoscore.be	ProBas
Diesel	kg CO2-eq./kWh	0.249	0.246	0.257	Weighted sum	
Gasoline	kWh/litre	11.374	8.760	2.614		
Gasoline	Weights	1.000	0.770	0.230	Proportions of direct and indirect energy	
Gasoline	kg CO2-eq./litre	3.064	2.392	0.672	ecoscore.be	ProBas
Gasoline	kg CO2-eq./kWh	0.269	0.273	0.257	Weighted sum	
Gasoline	kWh/pkm	0.740	0.570	0.170	umweltbundesamt.at	
Gasoline	kWh/car-km	0.851	0.656	0.196		
Heating oil	kg CO2/litre	3.445	2.993	0.453	ssb.no	ProBas
Heating oil	kg CO2 per kWh	0.285	0.243	0.042		
Heating oil	kWh per litre	12.330	10.762	1.569		
Truck, <18t	kWh/tkm	1.519	1.170	0.349	umweltbundesamt.at	
van	kWh/tkm	3.337	2.570	0.767	umweltbundesamt.at	
Truck, >18t	kWh/tkm	0.623	0.480	0.143	umweltbundesamt.at	
Helicopter	litre/hour	105.000			gemis.de	
Passenger per km	pkm/km	1.500			umweltbundesamt.at	
Kerosene	MJ/Litre	35.060			hypertextbook.com	
Freight train, electric	kWh/tkm	0.050			umweltbundesamt.at	
Freight train, diesel	kWh/tkm	0.158			http://transport.vestforsk.no/	
Freight train, diesel	kg CO2-eq./kWh	0.047			http://transport.vestforsk.no/	
Freight train, diesel	kg CO2-eq./kWh	0.000			Hydroelectricity in Norway	

Heavy fuel oil	kWh per litre	12.672	10.639	2.033	researchgate.net	
Heavy fuel oil	CO2-eq kg. /litre	3.522	3.070	0.452	umweltbundesamt.de	
Heavy fuel oil	CO2-eq kg/kWh	0.511	0.289	0.223		
Cargo ship 10,000+ dwt	MJ per tkm	0.190	0.160	0.030	http://transport.vestforsk.no/	
Medium ship, 5000 m³	litre per hour	300			Sintef	Table 4
Medium ship, 5000 m³	litre per hour, port	60			Sintef	Table 4
Medium ship, 5000 m³	Average km/t	20.4			Sintef	Table 4
Chain saw	kW	2.6	2	0.6	Stiga	
Concrete	MJ per kg	0.96			ProBas	
Concrete	kg CO2-eq per kg	0.17			ProBas	
Iron	MJ per kg	12.57			ProBas	
Iron	kg CO2-eq per kg	0.88			ProBas	
Steel	MJ per kg	22.02			ProBas	
Steel	kg CO2-eq per kg	1.71			ProBas	

APPENDIX B

Percentage of municipal roads accessible by trucks of different capacity, Sogn og Fjordane 2019.

Average extra transport distance is 3 km [157].

Municipality	Yearly volume	Tonnes [158]	50 tonnes, 3 extra trips	40 tonnes, 4 extra trips	<40 tonnes, 5 extra trips	Tonne-km
Flora	1250	956	5.40%	0.00%	94.60%	14035
Gulen	207	158	14.60%	0.00%	85.40%	2236
Solund	18	14	22.20%	0.00%	77.80%	188
Hyllestad	1031	789	11.10%	0.00%	88.90%	11305
Høyanger	2602	1991	11.00%	0.00%	89.00%	28543
Vik	1655	1266	25.70%	0.00%	74.30%	17041
Balestrand	0	0	15.60%	0.00%	84.40%	0
Leikanger	0	0	5.90%	0.00%	94.10%	0
Sogndal	263	201	20.40%	0.00%	79.60%	2772
Aurland	0	0	3.60%	0.00%	96.40%	0
Lærdal	9	7	41.70%	0.00%	58.30%	86
Luster	43	33	7.40%	0.00%	92.60%	479
Askvoll	47	36	23.10%	0.00%	76.90%	490
Fjaler	501	383	16.40%	0.00%	83.60%	5371

[157] Fjeld, Vennesland & Bjørkelo, NIBIO Rapport 97, 2019, Page 7

[158] Using a density of 765 kg/m3, Ecoinvent 2007, from Timmermann & Dibdiakova, page 3.

Gaular	2698	2064	23.10%	0.00%	76.90%	28102
Jølster	844	646	23.00%	24.10%	52.90%	8327
Førde	2513	1922	7.10%	0.00%	92.90%	28013
Naustdal	1468	1123	27.60%	0.00%	72.40%	14987
Bremanger	2359	1805	14.10%	0.00%	85.90%	25541
Selje	0	0	6.60%	0.00%	93.40%	0
Eid	5059	3870	29.30%	0.00%	70.70%	51250
Hornindal	4	3	26.90%	0.00%	73.10%	41
Gloppen	1533	1173	7.80%	0.00%	92.20%	17040
Stryn	10190	7795	28.20%	0.00%	71.80%	103746
Total	**34294**	**26235**				**359592**