REPORT

LCA calculations on Swedish wood pellet production chains

- according to the Renewable Energy Directive

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Report Summary

Project title

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Title and subtitle of the report

LCA calculations on Swedish wood pellet production chains - according to the Renewable Energy Directive.

Summary

The study includes calculations of typical life cycle emissions of greenhouse gases for representative Swedish pellet production chains in accordance with the calculation rules in RED (Directive 2009/28/EC). The study also intends to analyse how the directive is applicable on solid biofuels in general and on wood pellet production in particular, and to identify such aspects of the methodology in RED that are associated with obscurities, problems or lead to misleading results compared to other life cycle analysis principles. The report includes a large number of alternative calculations to show how different facts, assumptions and methodological choices affect the results. This includes the effect of what fuels are used for drying, different transport distances, assumed fuel mix for purchased electricity, the variance in efficiency between the investigated plants as well as the effect of different interpretations of the RED methodology for greenhouse gas calculations.

Keyword

pellets, LCA, emissions, Renewable Energy Directive, greenhouse gases

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Foreword

The scope of the study and the fuel chains analysed are a result of discussions between Matti Parikka at the Swedish Energy Agency and the authors at IVL Swedish Environmental Research institute. Methodological choices and interpretations used in the study or opinions expressed throughout the report are exclusively the view of the authors.

The authors would like to thank the Swedish Energy Agency for the financial support and for valuable comments on the report. We would also like to thank Staffan Berg at the Forest Research Institute of Sweden for valuable data. Last but not the least we would like to thank all Swedish pellet producers for the valuable help and data from the different pellet plants we have received, that made this study possible.

Sammanfattning

I det nya EU -direktivet[1] om främjande av användningen av energi från förnybara energikällor (hädanefter kallat RED, Renewable Energy Directive) fastställs hållbarhetskriterier som anger utsläppsminskningar som måste uppnås för biodrivmedel och andra biovätskor liksom en metod som skall användas vid beräkningar av livscykelemissioner av växthusgaser för biodrivmedel (Bilaga V, Del C). EU-kommissionen har redan annonserat att hållbarhetskriterier också kan komma att fastställas för fasta biobränslen. I denna studie görs beräkningar av typiska livscykelemissioner av växthusgaser för svenska pelletsproduktionskedjor i enlighet med beräkningsreglerna i RED. Som underlag för den nationella implementeringen av direktivet syftar studien också till att analysera direktivets tillämpbarhet på biobränslen i allmänhet och på träpellets i synnerhet. I detta ingår att identifiera sådana aspekter i metodiken som är oklara, är förenade med problem eller leder till missvisande resultat jämfört med andra beräkningsprinciper. Analysen baseras på data från ett stort antal svenska pelletsanläggningar för att uppskatta standardvärden för representativa pelletsproduktionskedjor giltiga för svenska förhållanden och för att täcka in de olika produktionssystem som återfinns i Sverige.

Beräkningar har gjorts för pellets från tre olika typer av råmaterial som är av intresse i Sverige: vått råmaterial (sågspån), torrt råmaterial (kutterspån/torrt sågverksflis) och rundved. Huvuddelen av produktionen sker i fristående anläggningar med pellets som enda produkt och där torkenergin produceras från biobränslen, vilket antas som grundfall i beräkningarna. Det finns dock fall där även fjärrvärme produceras från återvunnen torkenergi och fall där pelletsanläggningen är mer eller mindre integrerad med ett kraftvärmeverk eller sågverk. Metoden i RED är otydlig i hur sådana anläggningar skall betraktas. Detta illustreras genom beräkningar för pelletsproduktion i energikombinatet i Hedensbyn i Skellefteå, där pelletsanläggningen är integrerad med ett kraftvärmeverk.

Rapporten inkluderar ett stort antal alternativa beräkningar för att visa hur olika produktionsförutsättningar, antaganden och metodval påverkar resultaten. Det inkluderar betydelsen av vilket bränsle som används vid torkningen, transportavstånd, antagen bränslemix för elanvändning, skillnader i effektivitet mellan individuella anläggningar liksom betydelsen av olika tolkningar av RED-metoden för beräkningar av växthusgasemissioner.

Totala växthusgasemissioner för de analyserade pelletskedjorna presenteras i Figur S1 (emissioner från pelletsförbränning är ej inkluderade).

Typiska emissioner för svensk pelletsproduktion i fristående anläggningar (Anläggning 1-3 i figuren) har beräknats till ca 3-4 g $CO_{2eq}/MJ_{pellets}$ för alla tre typerna av råmaterial. Vid användning av spillvärme som torkenergi eller om torkenergin återvinns för fjärrvärmeprodudduktion blir emissionerna något lägre. Om olja används för torkningen ökar dock emissionerna signifikant, till ca 19 g $CO_{2eq}/MJ_{pellets}$. Transportavståndet för pellets har också viss påverkan på resultatet eftersom transportavståndet kan variera kraftigt mellan olika pelletsproducenter och slutkunder.

I grundfallet har vi antagit att sågspån, kutterspån och andra biprodukter från sågverk delar emissionerna från sågverksprocessen och betraktas därmed inte som avfall eller restprodukter. Beräkningsreglerna i RED är dock otydliga på denna punkt och kan tolkas som att sådana material

[1] Direktiv 2009/28/EG

skall anses ha noll emissioner fram till insamling. Den senare tolkningen kan vara adekvat för restprodukter eller biprodukter som skulle ha genererats även om de inte använts som bränsle; exempelvis restprodukter från sågverk eller skogsbruk. Detta diskuteras ingående i rapporten. Alternativa beräkningar har därför gjorts där restprodukter från sågverk anses vara befriade från emissioner fram till insamling och transport. Denna tolkning har större effekt för pellets från torra material än från våta material som visas i Figur S1 (staplar markerade med Bi-prod=0). Detta förklaras av att torra biprodukter genereras senare i sågverksprocessen (efter torkning av sågade trävaror) och därmed bär mer av emissionerna i grundfallet.

En annan oklarhet med beräkningsreglerna i RED är om emissioner av CH_4 ochN_2O vid förbränning av biobränslen (inklusive pellets) ska medräknas. I grundfallet är emissioner från pelletsförbränning exkluderade eftersom det är den strikta tolkningen av reglerna i RED. Om emissioner från all förbränning av biomassa i tidigare steg i produktionscykeln också exkluderas som framgår av staplarna markerade med BC=0 i Figur S1 så minskar emissionerna något. Men förbränningsemissioner av pellets kan vara av betydelse i vissa fall, beroende på typ av panna och förbränningsförutsättningar, och bör ingå i en fullständig livscykelanalys. I rapporten presenteras därför också resultaten inklusive emissioner från storskalig pelletsförbränning. Det ger ett påslag på ca 0.2 g $CO_{2eq}/MJ_{pellets}$ för varje pelletskedja i Figur S1. CH_4- och N_2O-emissioner vid förbränning av biomassa i småskaliga pannor kan under vissa förutsättningar vara höga, men eftersom bra mätningar av särskilt N_2O saknas från modern pelletsförbränning har småskalig förbränning inte inkluderats i studien. Det är dock viktigt att sådana mätningar genomförs.

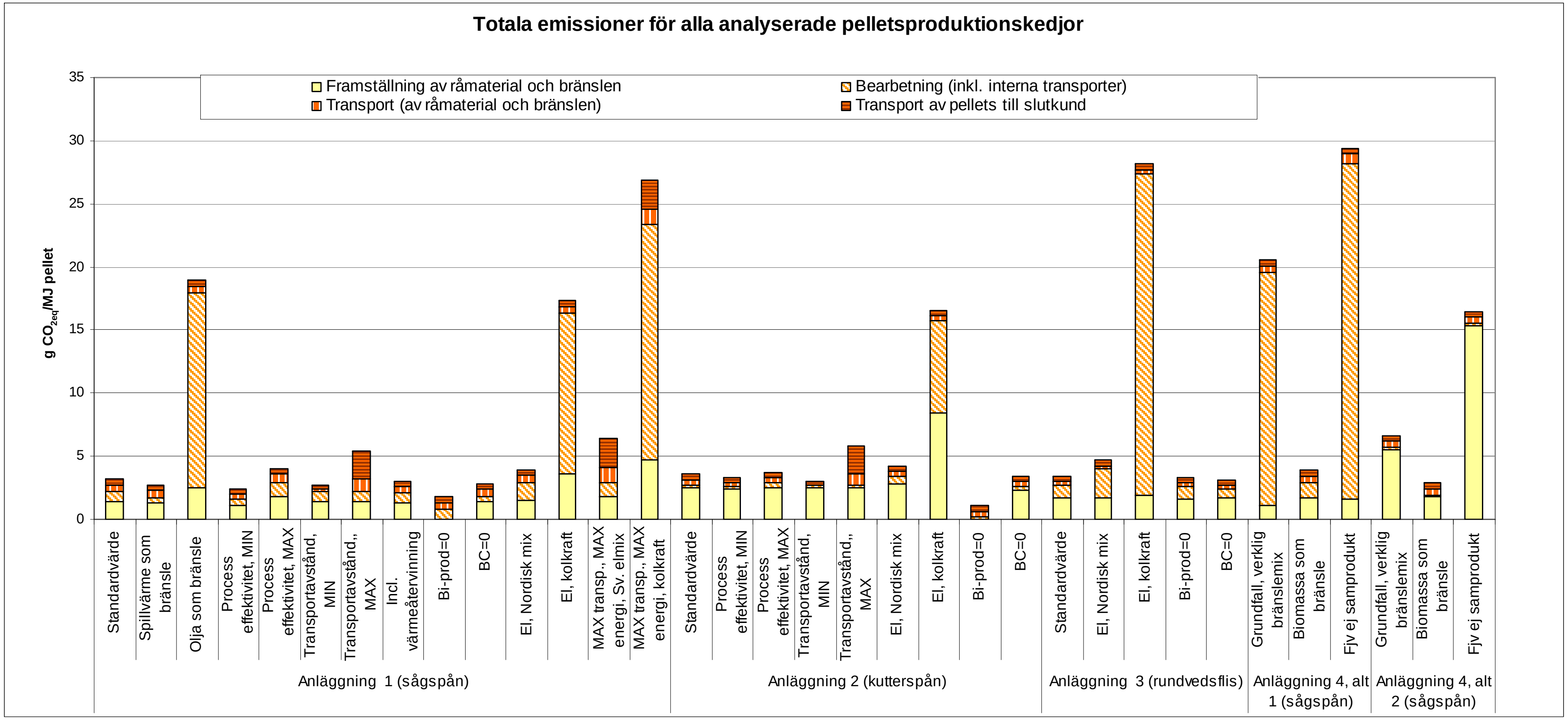
Miljövärdering av köpt el har stor betydelse för de totala emissionerna. RED anger bara att genomsnittliga emissioner från el producerad i en definierad region ska användas. I grundfallet har vi antagit svensk elmix, men om el med högre emissionsintensitet antas kan emissionerna bli upp till sex gånger högre, vilket visas i Figur S1 (pellets från rundvedsflis med el från kolkondens). Effekten av vald elmix är störst för pellets från rundvedsflis eftersom elförbrukningen vid förbehandlingen av råvaran där är större.

För pelletsproduktion i energikombinat har vald beräkningsmetod utifrån olika tolkningar av RED stor betydelse för resultatet (Anläggning 4 i Figur S1). Beräkningarna baseras på ett verkligt fall, anläggningen i Hedensbyn i Skellefteå, där bränslet i kraftvärmeverket som förser pelletsprocessen med torkenergi består av 26% torv och 74% biomassa, vilket ger högre emissioner än för de andra anläggningstyperna i studien. Eftersom den höga andelen torv är relativt ovanlig för svenska kraftvärmeverk och inte särskilt representativ för andra befintliga eller kommande energikombinat med pelletsproduktion så visas också alternativa beräkningar där enbart biomassa antas. Om ursprunglig bränslemix antas blir de totala emissionerna för pelletskedjan mer än tre gånger högre om hela anläggningen betraktas som ett energikombinat (Alternativ 1) jämfört med om pelletsanläggningen betraktas som en fristående anläggning som köper ånga från kraftvärmeverket. Detta beror huvudsakligen på att reglerna i RED ger olika värde på värme och el från kraftvärmeverket i de två tolkningarna. I det första fallet betraktas pellets, el och värme som samprodukter och delar emissionerna från den integrerade anläggningen i proportion till deras energiinnehåll. Pellets bär i detta fall 59% av anläggningens totala emissioner. I det andra fallet allokeras endast 24% av emissionerna från kraftvärmeverket till ångan som används i pelletsprocessen. Dessutom krediteras pelletsen i detta fall för undvikta emissioner från den överskottsel som produceras i kraftvärmeverket på grund av ångleveransen till pelletsanläggningen. Om kraftvärmeverket enbart antas använda biomassa blir emissionerna i samma storleksordning som för de fristående pelletsanläggningarna, och skillnaderna mellan vald beräkningsmetod blir betydligt mindre.

Om fjärrvärme betraktas som en samprodukt eller inte har också stor betydelse för resultaten för denna typ av anläggning. Regeln i RED att emissioner skall allokeras mellan samprodukter i proportion till deras energiinnehåll (definierad av det lägre värmevärdet) är inte direkt tillämpbart på spillvärme och fjärrvärme eftersom dessa energiflöden saknar lägre värmevärde. I Sverige där fjärrvärme är en viktig huvudprodukt blir reglerna i RED irrelevanta i många fall om inte metodiken betraktar fjärrvärme som en samprodukt.

Som redan beskrivits finns det ett antal oklara paragrafer i beräkningsreglerna i RED vilket gör dem svåra att applicera i allmänhet och på fasta biobränslen i synnerhet. Det finns andra paragrafer som öppnar upp för olika tolkningar som kan få stor inverkan på resultatet. Några av dessa aspekter listas nedan:

- Vald elmix för köpt el är öppen för subjektiva tolkningar vilket kan ha stor inverkan på resultatet för vissa produktionskedjor
- §16-18 i Bilaga V, Del C beskriver hur emissionsbesparingar från överskottsel från kraftvärme skall beräknas, hur allokering av emissioner mellan samprodukter skall göras och vilka produkter som skall betraktas som samprodukter. Dessa paragrafer är svåra att tolka, är tvetydiga och måste omformuleras för att kunna tillämpas på fasta biobränslen.
- För energikombinat kan olika tolkningar av §16-18 ha stor inverkan på resultatet. Detta inkluderar om fjärrvärme skall betraktas som en samprodukt, om restprodukter från skogsbruket och sågverk skall anses ha noll emissioner fram till insamling samt hur systemgränser ska sättas för integrerade anläggningar.
- §14 kan tolkas som att CH_4- och N_2O-emissioner från all användning av biobränslen skall räknas som noll. Särskilt vid småskalig förbränning av fasta biobränslen kan dessa emissioner vara av betydelse för de totala växthusgasemissionerna. För en fullständig livscykelanalys bör dessa emissioner uppskattas och inkluderas.



Figur S1 Sammanfattning av resultat för de olika analyserade pelletskedjorna. Anläggning 1-3 innebär produktion i fristående pelletsanläggningar. I Anläggning 4 sker produktion i pelletsanläggning integrerad med ett kraftvärmeverk (KVV) där alt 1) hela anläggningen betraktas som ett energikombinat och alt 2) pellets-anläggningen och KVV betraktas som separata anläggningar. Följande antagande används om inget annat anges: svensk elmix; typiska värden för processeffektivitet (energi) och transportavstånd; emissioner från produktion av biprodukter från sågverk och förbränning av biomassa medräknas; biomassa används för torkenergi i Anläggning 1 och 3; i Anläggning 4 antas verklig bränslemix i KVV (26% torv och 74% biomassa) och fjärrvärme betraktas som samprodukt. Förklaringar: Bi-prod=0 då emissioner från sågverksbiprodukter räknas till noll, BC=0 då alla förbränningsemissioner för biomassa räknas till noll, Fjv betyder fjärrvärme.

Summary

The new Renewable Energy Directive (RED, Directive 2009/28/EC on the promotion of the use of energy from renewable sources) set out emission saving requirements that must be fulfilled for biofuels and other bioliquids and the methodology to be used for calculations of life cycle greenhouse gas emissions for biofuels (given in Annex V, Part C). The EU Commission has already announced that these criteria and corresponding calculation methodology also may apply for solid biofuels. This study includes calculations of typical life cycle emissions of greenhouse gases for representative Swedish pellet production chains according to the calculation rules in RED. As a basis for the national implementation of the directive the study also intends to analyse how the directive is applicable on solid biofuels in general and on wood pellet production in particular, and to identify such aspects of the methodology in RED that are associated with obscurities, problems or lead to misleading results compared to other life cycle analysis principles. The analysis is based on data from a large number of Swedish pellet plants in order to estimate default values for typical pellet production chains valid for Swedish conditions and to reflect the major range of production systems found in Sweden.

Calculations are done for pellet production from three basic types of raw material that are of interest in Sweden: wet raw material (sawdust), dry raw materials (cutterdust/dry saw mill chips) and roundwood. Most of the production occurs in stand-alone plants where pellets is the only product, and where any heat for drying is produced from biomass which is assumed in the main calculations. However, there are cases where also district heating (and electricity in special cases) is produced from recovered heat from the drying process, and where pellet production takes place in a pellet plant that is more or less integrated with a combined heat and power (CHP) plant or a saw mill. The methodology in RED is not very clear on how such plants shall be considered. This is illustrated by our calculations on pellet production in the Hedensbyn plant in Skellefteå, which is a pellet plant integrated with a CHP plant.

The report includes a large number of alternative calculations to show how different facts, assumptions and methodological choices affect the results. This includes the effect of what fuels are used for drying, different transport distances, assumed fuel mix for purchased electricity, the variance in efficiency between the investigated plants, as well as the effect of different interpretations of the RED methodology for greenhouse gas calculations.

The total greenhouse gas emissions for all analysed pellet chains are presented in Figure S1 (emissions from pellet combustion is not included).

The estimated typical emissions from Swedish pellet production in stand-alone plants (Plants 1-3 in the figure) are approximately 3-4 g $CO_{2eq}/MJ_{pellets}$ for all three types of raw materials analysed. If waste energy is used for drying or if heat recovery and district heating is included the emissions will be slightly lower. However, using oil for drying will increase the emissions significantly, to approximately 19 g $CO_{2eq}/MJ_{pellets}$. The pellet transport distances have some impact on the result since the transport distances can vary a lot between different pellet producers and different pellet users.

Our standard calculations are based on the assumption that sawdust, cutterdust and other saw mill by-products should share the emissions from the processing at the saw mill, and not be regarded as waste or residues. The calculation rules in RED are however vague on this point and may imply

that such materials shall be considered to have zero emissions up to collection. The latter interpretation can be adequate for residues or by-products that would have been generated even if they were not used as a fuel; such as saw mill residues or forest residues. This is thoroghly discussed in the report. Alternative calculations are therefore done where emissions from saw mill residues are regarded as zero up to collection. This interpretation would have a larger effect for pellet production from dry materials than from wet materials, as shown in Figure S1 (staples noted with By-prod=0). This is because the dry by-products are generated later in the saw mill process (after drying of sawn wood) and carries more of the saw mill emissions in the standard values.

Another obscurity of the calculation rules in RED is whether emissions of CH_4 and N_2O from combustion of solid biofuels, including pellets, shall be accounted for. In our primary calculations emissions from pellet combustion are excluded since this may be the strict intepretaton of the RED rules. If emissions from all biomass combustion from earlier stages in the process are excluded as indicated by the staples marked as BC=0 in Figure S1 the total emissions are slightly decreased. However, emissions from pellet combustion can be of importance in some cases, depending on type of boiler and combustion conditions, and those emissions should be included in a complete life cycle analysis. In the report the results are therefore also presented where emissions from large scale pellet combustion is included. Including large scale pellet combustion corresponds to an additional 0.2 g $CO_{2eq}/MJ_{pellets}$ for all pellet chains in Figure S1. Emissions of CH_4 and N_2O from small scale combustion of biomass can under certain circumstances be large, but since good measurements of especially N_2O from modern pellet combustion are lacking this was not assessed in the study. It is however imortant that such measurements are carried out.

The selected emission intensity assumed for purchased electricity is significant for the total emissions. The RED only states that the average emissions from electricity produced in a defined region shall be used. Our standard calculations are based on Swedish electricity mix data, but if electricity with higher emission intensity is assumed the emissions can increase six times in the worst case (pellet production from roundwood chips with electricity from coal) as shown in Figure S1. The effect of the selected electricity mix is largest for pellets from roundwood chips since the electricity consumption for raw material processing is higher.

For pellets produced in a poly-generation plant the selected calculation method based on different interpretations of RED will have a large impact on the result (Plant 4 in Figure S1). The calculations are based on a real case, the Hedensbyn plant in Skellefteå, where the original fuel mix in the CHP is made up by 26% peat and 74% biomass. This explains the higher emissions compared to the other plant types of the study. Since such a high share of peat is uncommon in Swedish CHP plants and not representative for other pellet poly-generation plants, calculations are also made where only biomass combustion is assumed. Assuming the original fuel mix, the total emissions for the pellet production chain will be more than three times higher for Alternative 1, where the whole plant is regarded as a poly-generation plant, compared to Alternative 2, where the pellet plant is regarded as a stand-alone plant which buys steam from the CHP plant. This is largely because the RED rules assign different value to the heat and electricity from the CHP in the two interpretations. In the former case pellets, electricity and district heating are all considered as co-products and carry the emissions from the integrated plant in proportion to their energy content. In this case the pellets will carry 59% of the total emissions. In the latter case, only 24% of the emissions from the CHP will be allocated to the steam used in the pellet process and in addition, emission savings from excess electricity due to the steam from cogeneration are credited to the pellets. If only biomass is assumed in the CHP, the total emissions are of the same magnitude as for the stand-alone pellet plants and the difference between the two calulation alternatives is much smaller.

Whether district heating is regarded as a co-product or not will also have a large impact on the results for this kind of plant. The RED rule on allocation between co-products in proportion to their energy content (defined by the lower heating value) is not strictly applicable to waste heat and district heating since these energy flows do not have a lower heating value. In Sweden, where district heating basically is a prerequisite for electricity production from biomass and thus an important main product, the calculation rules in RED are irrelevant in many cases if the methodology does not consider heat as a co-product.

As already indicated there are some unclear paragraphs in the RED calculation rules, which make them difficult to apply in general and on solid biofuels in particular and other paragraphs that open up for different interpretations which may have significant impacts on the result. Some of these aspects are listed below:

- The selected electricity mix assumed for purchased electricity is open for subjective interpretation which can have large impact on the result for some production chains
- §16-18 in Annex V, Part C describes how emission savings from excess electricity from cogeneration shall be calculated, how the allocation of emissions between co-products shall be done, and what products that shall be considered as co-products. These paragraphs are difficult to interpret, unclear and must be reformulated to apply for solid biofuels.
- For poly-generation plants different interpretations of §16-18 can have a large impact on the result. It includes whether district heating shall be regarded as a co-product, if forest residues and saw mill residues shall have zero emissions up to collection, and where the system boundaries for integrated plants shall be drawn.
- §14 may imply that emissions of CH_4 and N_2O from all end use of biofuels shall be taken as zero. For solid biofuels emissions from (small scale) combustion can be of importance for the total greenhouse gas emissions. For a complete life cycle analysis these emissions should be assessed and included.

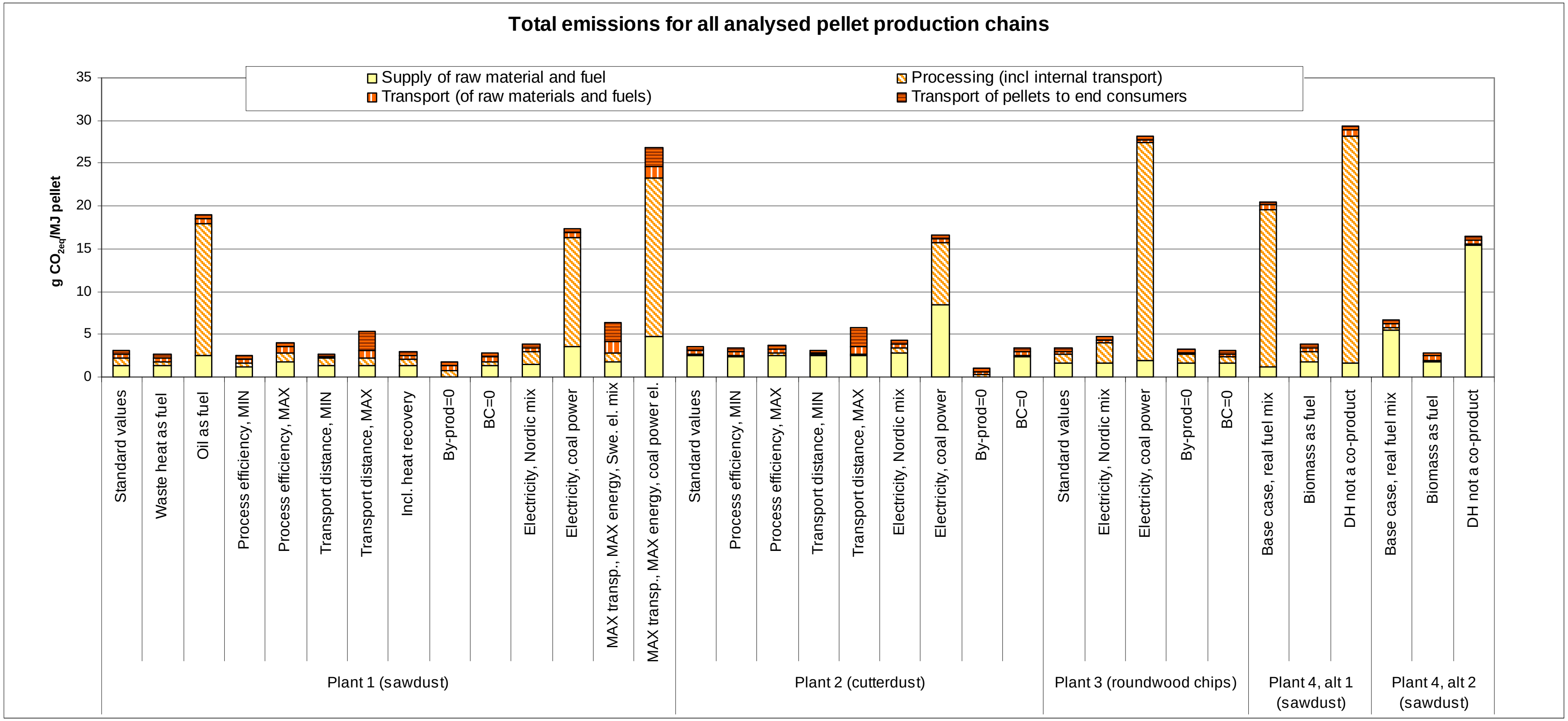


Figure S1 Summary of results for the different pellet production chains analysed. Plant 1-3 indicate production in stand-alone pellet plants. Plant 4 is production in a pellet plant integrated with a CHP plant (Hedensbyn) where alt 1) it is regarded as a poly-generation plant, and alt 2) the pellet plant and the CHP are regarded as separate plants. The following assumptions are used, if not otherwise stated: Swedish electricity mix; typical values for process efficiency (energy) and transport distances; emissions from production of saw mill by-products and biomass combustion are accounted for; biomass used for drying in Plant 1 and Plant 3; for Plant 4 the fuel mix in the CHP is 26% peat and 74% biomass and district heating is regarded as a co-product. Explanations: By-prod=0 when emissions from saw mill by-products are taken as zero; BC=0 when all emissions from biomass combustion is taken as zero. DH means district heating.

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1 Introduction

1.1 Background

In Article 17 of the new Directive 2009/28/EC on the promotion of the use of energy from renewable sources (RED) the so called 'sustainability criteria for biofuels and other bioliquids' are presented, which set the minimum greenhouse gas emission saving required for biofuels compared to utilisation of its fossil comparator. The methodology for calculation of greenhouse gas emissions of a biofuel is described in Annex V, Part C of the directive. The EU Commission has already announced that these criteria and corresponding calculation methodology may in the future also apply for solid biofuels. Typical values and default values for various solid biofuels will be calculated for this purpose, as is done for transportation biofuels and bioliquids in the present directive. The emissions for different biofuel production chains may vary between countries and between different process designs, used raw materials, type of energy supply, etc. Production systems for solid biofuels may also be different from production systems for transportation biofuels so that the directions in the present RED must be reformulated. With this background it is important to calculate typical greenhouse gas emissions from production chains of wood pellets based on Swedish conditions. As a basis for national implementation of the directive it is also of importance of analysing how the directive is applicable on solid biofuels in general and pellets in particular, and to identify such aspects of the methodology in RED that are associated with obscurities, problems or lead to misleading results compared to other life cycle analysis principles.

1.2 Aims and objectives

The aim of this study was to calculate default values of greenhouse gas emissions for different Swedish pellet production chains, according to the so called sustainability criteria in (RED)[2], and to identify and describe those variables that have the largest impact on the result. Another aim was to identify such aspects of the calculation rules of the directive that are associated with obscurities or problems during data collection, data processing or calculations or that lead to misleading results by comparison with other LCA calculation principles.

2 Method

Calculations of greenhouse gas emissions for Swedish wood pellet production and utilisation chains are based on the methodology given in Appendix V, part C in RED. Emissions are included of the greenhouse gases CO_2, N_2O and CH_4 from the whole life cycle of the fuel, from raw material production to final use. The analysis is done for pellet production chains valid for Swedish conditions, with respect to different raw materials and pellet plant design. Based on averages and best estimates from a large number of Swedish pellet plants, typical emissions (default values) for the different pellet chains have been calculated. In addition, a number of alternative calculations are done and presented in the sensitivity analysis and in the Appendix. This includes calculations on the

[2] RED = Renewable Energy Directive; Directive 2009/28/EC on the promotion of the use of energy from renewable sources

variance between individual plants (using minimum and maximum input data values from the pellet process), different types of heat and electricity supply and different transport distances for raw materials and pellet distribution. Different interpretations of obscurities in the methodology outlined in RED are also exemplified by alternative calculations.

Data on the year 2008 [3] were collected directly from 14 pellet plants through personal communication with the pellet producers. The calculations are based on the data from 11 of these. Some complementary information was found in Environmental reports for year 2008. Emission factors and data on typical material properties, etc., have been taken from scientific literature. Where the resulting data basis was poor, simplifications and assumptions have been used.

2.1 Methodology for greenhouse gas emission calculations according to RED

The calculations of greenhouse gas emissions are based on the methodology outlined in Annex V, Part C in the Directive 2009/28/EC (here after called RED). The RED is in its present form only valid for transport biofuels and other bioliquids, but is in this study applied on greenhouse gas emission calculations for wood pellets. Greenhouse gas emissions from the production and use of transport fuels, biofuels and bioliquids shall be calculated as (§1): [4]

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee} \qquad \text{(Eq. 1)}$$

where

E = total emissions from the use of the fuel;

e_{ec} = emissions from the extraction or cultivation of raw materials;

e_l = annualised emissions from carbon stock changes caused by land-use change;

e_p = emissions from processing;

e_{td} = emissions from transport and distribution;

e_u = emissions from the fuel in use;

e_{sca} = emission saving from soil carbon accumulation via improved agricultural management;

e_{ccs} = emission saving from carbon capture and geological storage;

e_{ccr} = emission saving from carbon capture and replacement; and

e_{ee} = emission saving from excess electricity from cogeneration.

Total greenhouse gas emissions from fuels, E, is expressed with grams of carbon dioxide equivalent per MJ of fuel, g CO_{2eq}/MJ (§2).

[3] For one of the plants (Hedensbyn, Skellefteå Kraft) calculations are based on data for 2007.
[4] Directive 2009/28/EC, Annex V, Part C, Point 1

The greenhouse gases taken into account are CO_2, N_2O and CH_4. For the purpose of calculating CO_2 equivalence, the following GWP-factors are used (§5): CO_2: 1, CH_4: 23, and N_2O: 296.

The resulting total emissions of pellet utilisation of this study can be used for calculation of the greenhouse gas emission saving from the use of the fuel compared to a fossil comparator. This shall be calculated as (§4):

$$SAVING = (E_F - E_B)/E_F, \qquad \text{(Eq. 2)}$$

where

E_B =total emissions from the fuel; and

E_F = total emissions from the fossil comparator

It is neither specified nor obvious what the fossil fuel comparator shall be for solid biofuels such as wood pellets, something that must be specified in a future RED applicable to solid biofuels. In Sweden, pellets may replace oil or direct electricity heating in small houses or oil, peat or heat pumps in large heat and power plants. Coal could be a relevant comparator for the whole EU, but it is not very common in Sweden. A calculation of the saving of greenhouse gas emissions by pellet utilisation is therefore left out in this study.

The complete calculation rules can be found in Directive 2009/28/EC, Annex V, Part C, but are not presented in this study. Methodological obscurities or important issues in the present calculation rules are, however, discussed throughout the report.

In cases where it is unclear how the methodology in RED should be interpreted, our own choices of what we believe is most appropriate is used in the calculations of the pellet chains. For some important issues where the selected method has significant impact on the result, parallel calculations are presented in the sensitivity analysis or in Appendix 2. For instance, whether raw material that are residues from saw mills should be considered to have zero emissions up to transportation to the pellet plant or share emissions from the saw mill is not well specified in RED. In this study we have by default accounted for all upstream emissions for raw materials also from saw mills, with the motivation that these raw materials often have alternative utilisation possibilities and a significant economical value. Alternative calculations for several pellet chains are presented in the Appendix, where emissions from saw mill residues are set to zero (transport to the pellet plant is still included). See Section 4.2.1 and 6.4 for further discussion on how residues from saw mills and forestry are considered in this study and arguments for alternative perspectives.

It is also not obvious if emissions of CH_4 and N_2O from biomass combustion shall be accounted for or excluded in the calculations. End use emissions of biofuels shall be taken as zero according to RED, why the results are presented both including and including combustion of pellets. However, as a default emissions of CH_4 and N_2O from other biomass combustion during the production chain are included in the calculations, but the effect of not including biomass combustion emissions is also calculated (see Appendix 2).

All results are presented as three different sums:

- total life cycle emissions (including use in large scale heating plant),
- total emissions from ”well to end user” (excluding end use emissions), and
- total emissions from ”well to gate” (excluding emissions from distribution and end use of pellets)

2.2 Fuel chains analysed

We calculate the emissions of greenhouse gases for pellet production chains based on three types of raw materials:

- wet wood residues from saw mills (raw sawdust/chips),
- dry wood residues from saw mills (cutterdust/dry chips), and
- roundwood chips.

Three standard types of stand-alone pellet plants were set up to represent typical Swedish pellet production from each raw material respectively. They were calculated as weighted averages of the data provided by the pellet producers, which should represent a Swedish average pellet plant of each type respectively:

1. Stand-alone pellet plant using wet saw dust/saw mill chips as raw material. A biomass boiler is used for drying.
2. Stand-alone pellet plant using dry cutterdust/chips from saw mills as raw material. No drying is needed.
3. Stand-alone pellet plant using roundwood chips as raw material. The same input data as for the standard plant based on wet sawdust/saw mill chips is assumed, but the raw material supply chain and raw material preparation is substituted to roundwood chips.

Input data for the stand-alone pellet plants are presented in Section 3.1. Emission factors and calculations are described in detail in Chapter 4 and in Appendices 1-3.

In the sensitivity analysis calculations based on max and min values of the three standard pellet plant types are done, based on the variance in process input data given by the producers. This represents the interval of emissions for Swedish pellet plants of each type respectively. Calculations are also done for Plant 1 assuming other heating supply for drying. Biomass combustion substituted by:

- waste heat (valid for a few Swedish pellet plants), and
- oil combustion (not used in Swedish pellet production, only for the purpose of sensitivity analysis in this study)

Besides the three stand-alone pellet plants described above, calculations are also done for a fourth type of pellet plant:

4. poly-generation plant consisting of a pellet plant integrated with a large combined heat-and-power (CHP) plant.

The calculations are in this case based on data from the Skellefteå Kraft plant in Hedensbyn. The input data for the poly-generation plant and the different calculations done for this plant type are presented in Section 3.2.

Calculations including end use emissions of CH_4 and N_2O are also done for all pellet production chains, but due to lacking measurements for small scale pellet combustion only emissions from large-scale combustion in a heating plant (~100 MW) are assessed.

3 Description of the pellet plant types used in the calculations

3.1 Stand-alone pellet plants

We used data collected from ten stand-alone pellet plants, where the only product is wood pellets, to calculate the performance typical Swedish standard plants. Raw material input, energy consumption and fuel mix for drying for the standard plants are shown in Table 1, calculated as weighted averages from the investigated plants.

Pellet plant 1 use wet saw mill residues as raw material, and the heat for drying is produced in a biomass boiler at the plant. The input data is based on data from seven Swedish pellet plants[5]. Two of these plants use purchased external heat[6], but the heat supply for these plants were converted to biomass boilers in the calculations using the average biomass mix of the other five plants. One of the plants[7] recovers some of the heat for district heating, but this is only taken into account in a sensitivity analysis (see Sections 3.1.1 and 5.2.6).

Pellet plant 2 use only dry saw mill residues as raw material and no drying is therefore needed. The input data is based on data from 3 pellet plants[8]. One of the plants[9] also produces dry wood bedding/scatter for horses, but the plant was resized to only produce pellets.

Pellet plant 3, which use roundwood chips as raw material, is based on the same data as for a pellet plant using raw sawdust (plant 1), except for some extra electricity consumption for grinding of the chips before drying. [10] Extra electricity for grinding is assumed to be 0.037 MJ/MJ pellets based on data from Laxå Pellets AB of electricity consumption for grinding of raw saw mill chips.

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[5] LaxåPellets AB (Laxå), HelsingePellets AB (Edsbyn), Bioenergi i Luleå AB (Luleå), SCA Bionorr (Härnösand), Neova (Vaggeryd, Främlingshem, Forsnäs)
[6] Helsinge Pellets plant in Edsbyn and Bioenergi i Luleå plant in Luleå
[7] SCA Bionorr in Härnösand
[8] Vida Pellets, SCA Bionorr (Stugun), Neova (Ljusne)
[9] Vida Pellets.
[10] No data from pellet plants using roundwood as raw material was available for 2008, to be used in this study. At least two plants have begun to use roundwood during 2009: Skellefteå Kraft in Storuman and LaxåPellets in Laxå. A new pellet plant using roundwood will be in operation from 2010 by Rindi Energi in Älvdalen.

Table 1 Typical energy and raw material consumption for 2008 in Swedish stand-alone pellet plants based on data from ten Swedish pellet producers. The fuel mix is the average of the plants that have their own biomass boiler[11]. The average values are used in the calculations of typical emissions from Swedish pellet chains. Min and max values are used in calculations to illustrate the variance in Swedish pellet plants, and are presented in the sensitivity analysis.

	1. Pellets from "wet" raw materials			2. Pellets from dry raw materials			3. Pellets from roundwood chips[1]		
[MJ / $MJ_{pellets}$]	Average, used value	Min	Max	Average, used value	Min	Max	Average, used value	Min	Max
Total input of raw material	0.88	0.80	1.09	0.96	0.94	0.97	0.88	0.80	1.09
Roundwood chips							*100%*		
Raw sawdust	*95%*								
Saw mill chips (wet)	*2%*								
Cutterdust (dry)	*3%*			*85%*					
Dry saw mill chips/cut-offs				*15%*					
Total fuel consumption for drying	0.20	0.14	0.26		No drying		0.20	0.14	0.26
Bark	*20%*						*20%*		
Residues from pellet production (wood powder)	*67%*						*67%*		
Dry saw mill chips	*9%*						*9%*		
Wood chips (from rot-defected roundwood)	*4%*						*4%*		
Electricity consumption	0.04	0.02	0.05	0.02	0.01	0.03	0.07	0.06	0.09
Diesel consumption (internal transport, etc)	0.002	0.002	0.004	0.001	0.001	0.002	0.002	0.002	0.004

Notes: 1) Input raw material is roundwood chips. Energy consumption and emissions for comminution to chips (assumed to be done in a mobile diesel crusher) are included in the raw material supply emissions based on Berg et.. al. (in press). Extra electricity consumption for grinding of chips is included in the electricity consumption of the plant. Same input data as for pellets from "wet" raw materials (plant 1) is otherwise assumed.

3.1.1 Stand-alone pellet plants with heat recovery and district heating production

There are a few plants that in addition to pellets also deliver district heating, thanks to a drying system with indirect dryers from which heat can be recovered. The pellet plant in Vansbro recovers

[11] Two of the investigated plants use external heat for dying instead of a biomass boiler, but has the same type of process otherwise. When calculating the values of the standard plants, the heat at these plants are assumed to be produced in a biomass boiler with the average fuel mix as in the other plants.

heat from the drying process which is sold to the local district heating network, but also has an extra boiler only for district heating production during winter (Rindi Energi, 2009). The pellet plant in Härnösand also recovers heat from the drying process, but only a third of the capacity can today be sold as district heating to the city's district heating network (SCA Bionorr, 2009).

To see the effect on total emissions for this kind of plant, a sensitivity analysis is carried through on a pellet plant using raw sawdust as raw material (based on Plant 1 described above), but including heat recovery and district heating production. The amount of district heating produced is assumed to be 0.055 MJ/MJ pellets based on the potential capacity of the plant in Härnösand (SCA Bionorr, 2009). The results are presented in Section 5.2.6.

The pellet plant in Derome also recovers heat, but instead of selling it as district heating they use it for pre-drying of the raw material. This makes the process more energy efficient. Some of the stand-alone pellet plant has indicated that they are looking into the possibility to make similar installations.

3.2 Pellet production in a poly-generation plant – case study of the Hedensbyn plant

The pellet plant in Hedensbyn, Skellefteå is more complex than most of the other Swedish pellet plants and deserves a chapter of its own. The plant is integrated with a large CHP plant. As shown in Table 2 the CHP in addition to steam for the pellet process also produces electricity and district heating. The pellet plant has a low-pressure turbine where electricity is generated from recovered heat from the drying process. "Cross-over" steam is also delivered from the CHP directly to the low-pressure turbine. The reason for this is to optimise the electricity production for the poly-generation plant.[12] This plant design lead to some methodological problems when calculating emissions for the pellet production according to the calculation rules in RED. There are, as we see it, two different ways to consider the plant according to the RED (described in §16-18). Calculations are done for these two principal perspectives:

1. The pellet plant and the CHP are considered as a poly-generation plant. Net electricity, district heating and pellets are thus considered as co-products within the same process. Emissions are thus allocated to the co-products in proportion to their energy content.
2. The pellet plant and the CHP are considered as separate plants. Since the heat used in the pellet plant is produced by cogeneration (of electricity and heat) in the CHP, emission savings from excess electricity[13] (that is produced thanks to the steam delivered to the pellet plant) shall be credited to the pellets according to RED.

As shown in Table 2, the CHP plant in Hedensbyn is associated with high greenhouse gas emissions from combustion, due to a fuel supply consisting of 26% peat and 0.5% oil. The high share of peat in Hedensbyn is neither very representative for Swedish heat and power plants nor for

[12] Skellefteå Kraft will also invest in a new heat recovery unit to also be able to produce district heating in the future from waste heat in the pellet plant (Skellefteå Kraft, 2009)

[13] Directive 2009/28/EC, Annex V, part C, point 16: *"Emission saving from excess electricity from cogeneration, e_{ee}, shall be taken into account in relation to the excess electricity produced by fuel production systems that use cogeneration. The greenhouse gas emission saving associated with that excess electricity shall be taken to be equal to the amount of greenhouse gas that would be emitted when an equal amount of electricity was generated in a power plant using the same fuel as the cogeneration unit. In accounting for that excess electricity, the size of the cogeneration unit shall be assumed to be the minimum necessary for the cogeneration unit to supply the heat that is needed to produce the fuel".*

future poly-generation plants with pellet production. This is an interesting case for illustrating how different methodological choices affect the result. However, for better comparison with the standard pellet plants of this study and a typical Swedish bio-CHP, calculations are also made where the peat and oil are replaced by biomass (tops and branches). The results of these two different calculations are presented in Table 15 (Alternative 1) and Table 16 (Alternative 2) in Section 5.3.

Table 2 Input data for calculations for pellets produced in a poly-generation plant (pellet plant integrated with a CHP plant). Data is from the plant in Hedensbyn, Skellefteå for year 2007 (Skellefteå Kraft, 2009).

The poly-generation plant at Hedensbyn, Skellefteå	**CHP + HP [GWh]**	**CHP only [GWh]**	**Pellet plant [GWh]**	**Poly-generation plant [GWh]**
Total input of raw material	n.a.	n.a.	523	523
Raw sawdust			*100%* [1]	
Total fuel/steam consumption	634	571	110	634
Steam			*100.0%*	
Bark	*43.8%*	*43.9%*		
Peat	*25.9%*	*26.0%*		
Wood chips (from rot-defected roundwood)	*13.9%*	*14.0%*		
Wood chips from tops and branches [2]	*15.9%*	*16.0%*		
Oil	*0.5%*	*0.2%*		
Electricity consumption	27	22	29	56
Diesel consumption (internal transport, etc) [3]	1.5	1.3	1.2	2.7
Products:				
Gross electricity	115	115	48	163
Net electricity	88	93	19	107
District heating	309	257		309
Steam (for pellet plant)	110	110		
Pellets			594	594

Abbrevations: CHP = Combined Heat and Power, HP = Heating plant. Notes: 1) Assumed in the calculations 2) Includes "other solid biofuels" 3) Estimated based on data for other pellet plants.

3.2.1 Alternative 1: pellet plant and CHP as a poly-generation plant

In this case the three different units of the Hedensbyn plant are considered as a poly-generation plant including the CHP plant, the heating plant (HP) and the pellet plant. The net production of pellets, electricity and district heating are considered as co-products. Total emissions for the whole plant were calculated and then allocated evenly between the different co-products in proportion to their energy content: 59% to pellets, 31% to district heating, and 10% to electricity[14].

There are reasons to consider the Hedensbyn plant as a poly-generation plant rather than two separate plants. The CHP plant was, when it was built, partly prepared for the future possibility to supply steam to a pellet plant, and the cross-over steam solution and the design of the two plants is

[14] In the case where district heating is not considered a co-product (see below) the corresponding numbers would be 85% to pellet, and 15% to electricity.

an optimisation both of the pellet production and the electricity output from the whole plant without increasing the production of district heating. This type of integration makes it somewhat difficult to separate the pellet process from the CHP process. However, it is not obvious that the heating plant shall be included in the calculations since it is not integrated directly with the pellet plant but only used for district heating. The consequences of not including the heating plant in this case are therefore also discussed (Section 5.3).

3.2.2 Alternative 2: pellet plant and CHP as separate plants

In this case the pellet plant is considered as a stand-alone pellet plant, buying steam from the CHP plant. The net electricity generated in the *pellet plant* is considered as a co-product of the pellet process, and emissions from the pellet process are divided between the pellets and the net electricity in proportion to their energy content. Emission savings from excess electricity produced in the CHP due to the steam delivered to the pellet plant is credited to the pellets. In this case the production and emissions associated with the heating plant (HP) are excluded from the calculations, since the steam used in the pellet plant is only supplied from the CHP plant. The oil consumption in the CHP during the summer months when the pellet plant is closed is also excluded.

When estimating emissions for the steam delivered to the pellet plant from the CHP plant, the CHP plant was scaled down to the size necessary to deliver the amount of steam used in the pellet plant (where 13% of the delivered steam is used in the low pressure turbine). All emissions from the resized plant were allocated to the steam at this stage. It was estimated that the steam delivered to the pellet plant makes it possible to produce electricity (=excess electricity) amounting to approximately 17% of the energy content of the steam used in the drying process and 20% of the energy content of the cross-over steam[15] (Hamrefors, 2009). The emissions that would have occurred if the excess electricity was instead produced in a condensing power plant with the same fuel mix as in the CHP plant was then calculated, assuming an efficiency of 35% in the coal power plant. The saved emissions for excess electricity were then subtracted from the total emissions for the pellet production chain[16].

3.2.3 Accounting for district heating in RED – two interpretations

Another important obscurity in the RED calculation rules is the treatment of district heating as a co-product. It is not clear whether district heating should be considered as a co-product (responsible for some of the emissions from the process) or if it should be considered as waste energy. According to §18 in RED, allocation of emissions shall be done in proportion to the energy content of the co-products, "*determined by lower heating value in the case of co-products other then electricity*". Heat does not have a lower heating value, just like electricity, but only electricity is mentioned in the text as an exception. This may imply that district heating shall not be considered as a co-product but considered as waste (with zero emissions).

[15] The cross-over steam used in the low pressure turbine is delivered to the pellet plant with a lower pressure than the steam used in the drying process. It is therefore possible to produce more electricity in the CHP plant for the steam delivered as cross-over steam.
[16] When calculating the excess electricity production we have in our calculations resized the CHP to the size necessary for the steam supply to the pellet plant. However, it is possible that the CHP should be resized only to the steam used in the drying process (excluding the cross-over steam) which would result in slightly higher emissions per MJ pellet than presented in the result chapter.

In Sweden, with many CHP plants constructed with the main purpose to supply district heating, it is reasonable to divide emissions between district heating and electricity. Allocating some of the pellet emissions to sold recovered heat would encourage energy efficiency and district heating production. The alternative source for heat would predominantly be heating boilers instead. In other parts of Europe where cogeneration plants are not that common the perspective may be different. In either way, it is appropriate for the Swedish circumstances to allocate emissions in poly-generation plants also to district heating. However, the different characteristics of electricity, district heating and pellets (in terms of energy "quality" and range of applications) motivate the use of another allocation method than allocation in proportion to the energy content. For instance the alternative production method[17] can be used, which is often used for production in CHP in Sweden; the emissions are then divided between district heating and electricity in proportion to the emissions that would be generated for respective energy carrier if the same amount of electricity and district heating were produced in separate plants. However, in this study we consequently use the energy method for allocation since we have considered this method prescribed in RED.

Because of the uncertainty in the interpretation of RED, the calculations for the poly-generation plant in Hedensbyn described above are also made with district heating not considered as a co-product (see Section 5.3). These calculations are made for the two alternatives above, but with the original fuel mix in the CHP and heating plant (26% peat).

3.3 Other Swedish pellet plant designs of interest for methodological issues in RED

A majority of Swedish pellet plants producing pellets from wet materials (mainly raw sawdust) which require drying. In most cases a biomass boiler at the pellet plant is used for heat production, mainly consisting of residues from the pellet production and residues from saw mills. Another significant part of the pellets is produced from dry materials (dry residues from saw mills) which does not require any further drying. In some plants the raw material is a combination of wet and dry materials. There are some exceptions from these standard type plants.

The pellet plant in Luleå buys hot gases and steam from the Luleå Energi CHP plant (Bioenergi i Luleå, 2009). However, all production in this CHP plant is based on industrial residue gases from large steel industries in the town, which can be considered as waste energy with zero emissions when combusted (Bioenergi i Luleå, 2009). Credits for emission savings from excess electricity from cogeneration will therefore also be zero in this case (see Section 3.2 for how excess electricity from cogeneration shall be accounted for according to RED) The pellet plant in Edsbyn (HelsingePellets, 2009) also buy steam needed from an external source.

The new pellet plant in Storuman operated by Skellefteå Kraft is a poly-generation plant that in addition to pellets produces district heating and electricity. In this case the electricity according to our interpretation of RED should be considered as a co-product, and thus fall under the scope of §17 and §18 in RED. Emissions from the pellet process should then be allocated to electricity, district heating[18] and pellets based on their energy content. Since no verified data was available for this plant by the time of this study, no calculations have been done based on the Storuman plant. The Storuman plant is built on the knowledge from the poly-generation plant in Hedensbyn.

[17] In English often referred to as the efficiency method
[18] If district heating shall be considered as a co-product according to RED even though it does not have a lower heating value

However, in the Storuman plant the poly-production is more integrated and it is not possible to separate the CHP plant and the pellet plant as in Hedensbyn. The relation between the co-products is also different with larger share of pellets and smaller share of heat and electricity in the Storuman plant. In some perspective the Storuman plant is more similar to a stand-alone pellet plant, but with extensive energy recovery with electricity and district heating as co-products.

In some cases the pellet production is localised close to saw mills, e.g. at Derome saw mill, BooForssjö saw mill and Stora Enso saw mill in Grums. The difference compared to the stand-alone pellet plants is mainly that the raw material (sawdust and cutterdust) can be more efficiently transported to these pellet plants and that the drying process can be integrated with the drying process at the saw mill, for instance by sharing the same boiler as is the case in Derome (Derome, 2009) These plants also usually use a mix of wet and dry raw material depending on the outcomes from the saw mills. The transport distances would be minimised if only local raw material were used. However, in most cases complementary raw material is bought from external saw mills. The transport distances is thus shorter than for stand-alone plants, but not zero. The shared energy supply usually use local saw mill residues for combustion which decrease total transports and increase the pellet production, since residues from the pelletizing process (wood powder) are recycled within the pellet process instead of being used for drying. The partly integration of raw material supply and energy supply between the saw mill and the pellet plant could motivate the plants to be considered as poly-generation plants according to the RED. However, for these cases it is relatively easy to separate the saw mill and the pellet plant, for calculation purposes. The share of the total fuel consumption in the common boiler that is used in the pellet process could relatively easy be determined. Our interpretation is that the pellet plants localised close to saw mills can be seen as stand-alone plants with short transport distances for raw material and fuel. With this background no separate calculations have been done for pellet plants integrated with saw mills, but the emission estimates for such plants should lay in the range of the other pellet chains analysed in this study.

The pellet plant at Stora Enso's saw mill in Grums is somewhat special since waste heat from the drying shed in the saw mill is used for drying in the pellet plant (95ºC hot water)[19]. This would result in zero emissions for the heat supply. However, the electricity consumption will probably increase for fans etc to circulate the moisture in the drying process. They started up production in 2009. Since no verified data was available for this plant by the time of this study, no calculations have been done based on the Grums plant.

4 Emission inventory and calculations

4.1 Properties and conversion factors of raw materials and fuels

The unit used in the calculations is energy content (based on lower heating value), expressed as MJ (or sometimes GWh). Properties and conversion factors presented in Table 3 have been used for conversion of input data from volume or mass of wood materials to energy content.

[19] The saw mill in Grumsuse "waste heat" in terms of 120ºC hot water from a nearby pulp and paper mill. It is of course an issue of political nature to decide what kind of energy source that shall be considered as waste energy (with zero emissions) and not.

Generally, it is difficult to calculate wood based raw materials or products in terms of energy content with reasonable accuracy. One main reason is that the amount of forest products are normally measured in different kinds of volume units (or sometimes ton) in the forest industry, without specification of the moisture content which can vary significantly. Assumptions on moisture content, density etc. will thus have an impact on the calculation results. For data taken from other studies, where another method of calculating the energy content of wood materials have been used, the numbers have been recalculated in the model to compensate for the difference as far as possible.

Table 3 Properties for raw materials and fuels used in the study.

	Moisture content [wt-%]	Source	Heating value [MWh/ ton]	Source	Heating value [MWh/ m3s]	Source
Saw timber	50%	Ringman (1995)	2.3	Ringman (1995)	n.u.	
Roundwood	50%	Ringman (1995)	2.3	Ringman (1995)	n.u.	
Tops and branches	50%	Ringman (1995)	2.5	Ringman (1995)	0.78	Info from Derome (2009)
Wood chips	50%	asumed same as tops and branches	2.5	asumed same as tops and branches	0.78	asumed same as tops and branches
Roundwood chips (from rot-defected roundwood)	50%	asumed same as tops and branches	2.5	asumed same as tops and branches	0.78	asumed same as tops and branches
Raw sawdust	53%	calculated based on used heat value	2.15	based on info from the pellet plants	0.65	Ringman (1995)
Raw saw mill chips	50%	asumed same as tops and branches	2.5	asumed same as tops and branches	n.u.	
Bark	55%	Ringman (1995)	1.55	Ringman (1995)	0.6	Ringman (1995)
Cutterdust	12%	Ringman (1995)	4.5	Ringman (1995)	0.43	Ringman (1995)
Dry saw mill chips	12%	assumed same as cutterdust	4.5	assumed same as cutterdust	0.78	Ringman (1995)
Saw mill cut-offs (avkap)	12%	assumed same as cutterdust	4.5	assumed same as cutterdust	0.78	Ringman (1995)
Pellets	8%	Ringman (1995)	4.8	based on info from the pellet plants	2.60	Ringman (1995)
Residues from pellet production (wood powder)	8%	assumed same as pellets	4.8	assumed same as pellets		
Oil	n.u.		n.u.		9.95	SPI (2009)
Diesel	n.u.		n.u.		9.8	SPI (2009)
Peat	n.u.		2.57	Särnholm (2005)	n.u.	

4.2 Emissions from extraction and production of raw materials and fuels

The raw material and fuels used in the different pellet production chains are described in Table 1 and Table 2 in Chapter 3. Estimates from Skogforsk (Berg et al., in press) of emissions from extraction, and production of Swedish forest products for energy production have been used for the raw materials or fuels residing directly from the forest. In Berg et al. (in press), the emissions from forest production up to the collection of stem wood and tops and branches are allocated between tops and branches and stem wood in relation to their mass of dry substance. How emissions from raw materials and fuels residing from saw mills (e.g. sawdust, cutterdust and bark) are accounted for in this study is described in Section 4.2.1 below, whereas detailed calculations are presented in Appendix 3. The emission estimates for extraction and production of the different raw materials and fuels used in this study are summarized in Table 4. Emissions from transport to the pellet plant are presented separately in Section 4.4, and are thus not included in these figures. See Section 4.2.1 and 6.4 for further discussion on how residues from saw mills and forestry are considered in this study and arguments for alternative perspectives.

Table 4 Emissions from extraction and production of raw materials and fuels (excl. transport if not stated).

Raw material or fuel	Emissions [mg/MJ]				Source	Comment
	CO_2	CH_4	N_2O	CO_{2eq}		
Saw timber[1]	1 455	1.90	0.05	1 513	Berg et al. (in press)	Round (stem) wood, incl. transport. Used as input for calculations of raw material from saw mills.
Roundwood	943	1.23	0.03	980	Berg et al. (in press)	Round (stem) wood
Roundwood chips	1 700	2.21	0.06	1 768	Berg et al. (in press)	Round (stem) wood, including comminution to chips
Tops and branches	1 655	2.16	0.06	1 721	Berg et al. (in press)	Tops and branches from final felling, including comminution to chips at roadside
Wood chips	1 655	2.16	0.06	1 721	Berg et al. (in press)	Assume the same as for tops and branches
Bark	1 389	0.18	0.02	1 399	Own calculations	Wet by-product from saw mill
Raw sawdust	1 394	0.21	0.02	1 405	Own calculations	Wet by-product from saw mill
Raw saw mill chips	1 394	0.21	0.02	1 405	Own calculations	Wet by-product from saw mill
Cutterdust/cutter shavings	2 381	1.39	0.55	2 576	Own calculations	Dry by-product from saw mill
Dry saw mill chips	2 381	1.39	0.55	2 576	Own calculations	Dry by-product from saw mill
Saw mill cut-offs ("avkap")	2 381	1.39	0.55	2 576	Own calculations	Dry by-product from saw mill
Residues from pellet production/wood powder	0	0	0	0	Own estimation	Dry by-product from pellet production used within the pellet plant
Oil	5 900	3.40	0.04	5 991	Uppenberg et al. (2001)	Incl. distribution
Diesel	3 500	2.00	0.00	3 546	Uppenberg et al. (2001)	Incl. distribution
Peat	1 200	-190	3.80	-2 045	Uppenberg et al. (2001)	Incl. distribution

[1] Saw timber includes transportation 40 km, as estimated in Berg et al. (in press). This transportation data is only used for the raw material to the saw mill (see Section 4.2.1 and Appendix 3). For other raw materials and fuels our own transport estimations are used, presented in Section 4.4.

4.2.1 Emissions from raw material residing from saw mills

It is not specified in the RED whether saw mill residues such as bark, sawdust and cutterdust should be considered as waste or residues (with zero emissions up to collection) or if all products from the saw mill with an economical value should share the emission burden of the saw mill (and upstream emissions from timber production and transportation). It is also not obvious how the emissions from the saw mill in that case should be allocated between sawn wood and the by-products. For this purpose we have chosen to make two parallel calculations:

1. Saw mill residues such as raw sawdust, cutterdust or bark that are used as raw materials (or as a fuel) for pellet production are considered as co-products of the saw mill, and should therefore bare some of the emissions associated with the saw mill. All emissions that occur in the life cycle up to the point in the saw mill process where the co-product is generated are allocated between the intermediate product and the co-product based on their energy content[20].
2. Saw mill residues are considered to have zero greenhouse gas emissions up to the collection of these materials, thus considered as waste or residues from the saw mill process. All emissions at the saw mill are thus allocated to the main product sawn wood.

The former calculation method can be motivated by the fact that all saw mill residues has an alternative use (for energy production or chipboard production) and today have a significant economic value. However, the latter can be motivated by the writings of §18 in the RED:

"Wastes, agricultural crop residues, including straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials."

The main issue here is whether sawdust, cutterdust, bark etc. shall be considered as waste or residues from processing of sawn wood, or as co-products. This must be clearly stated in a future RED applied also on solid biofuels, and it must also be clarified if the zero emission exception for residues from processing is restricted to processing of agricultural crops or also includes wood based materials. See general discussion in Section 6.4 about allocation issues for by-products and residues coming from production of other goods.

The emissions for saw mill residues have been estimated as described above from data for the Stora Enso saw mill in Gruvön (Miljörapport för Gruvöns sågverk 2008). The emissions associated with bark, raw sawdust/chips and dry cutterdust/chips used in this study are presented in Table 4 above. Most saw mills in Sweden use biomass or other residues from the saw mill process for heat production (Erlandsson, 2009). It is therefore in the calculations assumed that the heat consumption at the saw mill is produced from combustion of tops and branches instead of waste heat from nearby pulp mill as was the case at Gruvön saw mill 2008. The saw mill process has been separated into different stages and emissions generated up to each partial stage have been allocated to the different products based on their energy content. The calculations are described in detail in Annex 3.

[20] This allocation method is in accordance with §17 in the RED.

4.2.2 Emissions from carbon stock changes caused by land-use change

It has not been in the scope of this study to analyse carbon stock changes associated with wood raw material supply. It is a complex issue that should be treated carefully in a separate study. Some issues concerning how the carbon stock is affected by forestry and collection of forest residues have been analysed in a separate study by The Swedish University of Agricultural Sciences, SLU (Ågren et al., in press).

All raw materials of interest in this study (or the absolute major part) reside from Swedish forest land. It is reasonable, for the purpose of this study, to assume that no land-use changes have occurred for the production of Swedish wood materials and that active forestry have been carried out for many decades. In this study, emissions from carbon stock changes caused by land-use change for wood materials is assumed to be zero.

4.3 Emissions from pellet processing

4.3.1 Emissions from combustion of fuels for drying

The investigated pellet plants that process wet raw materials include drying units that use biomass, waste heat from industrial processes, and in one case heat from an adjacent CHP plant. In our primary calculations of stand-alone pellet plants, drying is done with a mix of solid biofuels (see Table 1 in Section 3.1). As stated in Section 2.2, additional calculations are carried out for a case where the biomass is replaced by oil combustion (assuming the same efficiency as in biomass boilers) and for a case where the heat is supplied by purchased waste heat. For the Skellefteå Kraft plant in Hedensbyn where the pellet plant is integrated with a CHP, the actual fuel mix in the CHP plant is used but also calculations where peat and oil is replaced by biomass (as described in Table 2 in Section 3.2). The CO_2 emissions from all solid biofuels are assumed to be zero during combustion, but there are some emissions of CH_4 and N_2O that are accounted for in the calculations. All emissions from combustion of fossil fuels are included. Emission factors for the different fuels used for combustion for pellet processing are based on Uppenberg et al. (2001) and are summarised in Table 5.

However, as stated in Section 2.1, in the current calculation rules in RED it is unclear whether any emissions at all should be accounted for from combustion of solid biofuels. §13 in RED states that "*emissions from the fuel in use (e_u) shall be taken as zero for biofuels and bioliquids*". If this shall apply literally also to solid biofuels, such as wood-based materials and pellets, it would mean that no emissions from any of the greenhouse gases shall be taken into account for combustion of biomass (since the combustion reasonably is to be considered as use of solid biofuels). However, even though the emissions of CH_4 and N_2O from biomass combustion are of biogenous origin, these emissions are the result of the combustion process, and would not have occurred in this form by other use of the wood material. We recommend in any LCA that emissions of CH_4 and N_2O are accounted for regardless of origin, and that the writings in RED therefore should be reformulated.

However, alternative calculations are made where all emissions from biomass combustion are excluded (Appendix 2).

Table 5 Emissions factors for fuel combustion (excl. production & distribution) used in the study.

Fuel	Emissions from combustion [mg/MJ]				Source
	CO_2	CH_4	N_2O	CO_{2eq}	
Roundwood chips (from rot-defected roundwood)	0	5.0	5.0	1 595	
Tops and branches	0	5.0	5.0	1 595	
Wood chips	0	5.0	5.0	1 595	
Bark	0	5.0	5.0	1 595	
Raw sawdust	0	5.0	5.0	1 595	Uppenberg et al. (2001)
Dry saw mill chips	0	5.0	5.0	1 595	
Residues from pellet production/wood powder	0	5.0	5.0	1 595	
Oil	76 000	0.5	0.5	76 160	
Diesel[1]	73 000	6.0	3.0	74 026	
Peat	103 000	5.0	11.0	106 371	

Notes: 1) For internal transports. Emission factor for heavy vehicles.

4.3.2 Emissions from electricity consumption

All electricity consumption in the pellet chains is assumed to be equal to the Swedish electricity production mix. Emission factors for electricity is based on the fuel mix in Sweden's electricity production year 2007 and calculated from emissions factors in Uppenberg et al. (2001).

According to the calculating rules in RED it is rather subjective what electricity mix that should be assumed for electricity consumption. The electricity "*shall be assumed to be equal to the average emission intensity of the production and distribution of electricity in a defined region*" (§11). Instead of the national electricity mix, the Nordic electricity mix would be possible for Swedish operators or even the EU mix since the electricity networks are connected. For better comparison between different emission calculations for biofuels, it should be better specified in the directive what electricity mix that should be used. Alternative calculations are carried out for some of the fuel chains where another emission intensity for purchased electricity is used: Nordic electricity mix and electricity from condensing coal power plants (η=35%). The emission factors used in this study is presented in Table 6.

Table 6 Emission factors for electricity (including production &distribution).

mg/MJ	Emissions CO_2	CH_4	N_2O	CO_{2eq}	Source
Swedish electricity mix	5 409	28.4	0.8	6 299	calculated for year 2007 based on Uppenberg et al (2001)
Nordic electricity mix	19 294	161.5	2.3	23 698	
Coal (η=35%)	269 143	3144.3	4.3	342 730	

4.3.3 Other emissions

There is a very small consumption of some chemicals in the pellet process, such as different kinds of oil for engines. Based on data from some of the pellet plants, the amounts are estimated to be too small to have an impact on the results and are therefore excluded in the calculations.

Combustion of solid biofuels generates ash that must be collected and transported to a landfill or for application as a fertilizer. The pellet production chains also generate other types of some wastes that must be taken care of. However, ash and waste generated in a pellet plant is not more than 2-3 kg per ton pellets of which 80% are ash (based on data from Neova, 2009). This waste is not likely to cause noticeable emissions of greenhouse gases, besides emissions from transport of the waste, and even these are negligible compared to other emissions in the pellet process. Emissions caused by transport and treatment of waste are therefore not included in the calculations.

4.4 Emissions from transport and distribution

Our calculations include emissions from transport and distribution of all raw material and fuels used in the pellet production, as well as transport of pellets to end users. We estimate the emissions mainly based on information given by the pellet producers and from a Skogforsk study from 2009 (Berg et al., in press). Additional assumptions are required in some cases (see Table 7).

Raw materials and fuels used in the pellet plants are transported from saw mills in the region or from nearby forests. Pellet plants situated adjacent to a large saw mill can have very short transport distance for most of the raw material and fuel, even though some materials must be transported from other places. However, the average transport distances are generally longer (70-85 km) since raw materials must often be collected from a couple of different saw mills in the region. The transport distance for fuels are estimated to be somewhat shorter, mainly because less biomass is required as fuel, making it easier to find it in the neighbourhood. Skogforsk (Berg et al., in press) has estimated the average distance for roundwood and tops and branches to be 40 km to industry or energy user. This estimate is used also in our study.

The estimated average transport distances and share of the return transport going empty presented in Table 7 are based on information from the pellet producers and from Skogforsk. Minimum and maximum distances represent the shortest and longest average distances respectively for the investigated plants and are used in the sensitivity analysis. Empty return transports are included in the calculations by accounting for the estimated share of the return distance the lorry is going empty (Table 7)[21].

[21] The fuel consumption from the empty transport is allocated to the transport of raw material, fuel or pellet that is included in this report. If 80% is indicated for empty transport in the table it means that 80% of the return transport is going empty for which emissions are allocated to the materials included in this report. The remaining 20% of the return transport other cargo is transported by the lorry, for which emissions are not accounted for.

Table 7 Estimated transport distances and degree of empty return transport for raw materials and fuels to the pellet plants. Min and max values are used in the sensitivity analysis, and represent the shortest and longest average distances respectively for the investigated plants.

Type of material	Transport distance (one way) Typical value [km]	Min [km]	Max [km]	Source	Share of distance driven as full transport %	Share of distance driven as empty return transport %	Source
Raw sawdust/saw mill chips	85	30	150	Estimated from info from pellet producers	100%	80%	Estimated from info from pellet producers
Cutterdust	70	5	150		100%	80%	
Dry saw mill chips	70	5	150		100%	100%	
Pellets	150	100	750[1]		100%	66%	
Saw timber	Used for transport to saw mill and is set to 40 km by Skogforsk (Berg et al., in press)				100%	100%	
Round wood	40	20	100	Berg et al. (in press) and assumptions	100%	100%	
Tops and Branches	40	20	100		100%	100%	
Bark	40	5	100		100%	100%	

Notes: 1) Approximated from data from Bioenergi i Luleå (2009). The estimated equivalent distance of road transport for a case where the pellets is transported 180 km by road and 1500 km by boat, accounting for the more efficient boat transport (in terms of fuel consumption per ton pellets). Based on fuel consumption for a dry bulk boat with max cargo capacity of 8455 ton and cargo utilisation of 67% (NTM, 2007b). Emission factors for road transport are then assumed.

A 60 ton lorry (Euro class III) with a maximum cargo capacity of 40 ton is assumed for all transports. The estimated typical cargo for cutterdust and dry saw mill chips are 18 ton and 27 ton respectively, whereas for all other materials the estimated typical cargo is 37 ton (out of the maximum cargo capacity of 40 ton) based on information from the pellet producers.

Fuel consumption and emission factors for a full and empty lorry respectively are presented in Table 8. The fuel consumption increases approximately linearly with heavier load; the fuel consumption (FC) of the lorry as a function of the actual cargo weight have been approximated by Equation 3 below (NTM, 2007a):

$$FC_{CCU} = FC_{empty} + (FC_{full} - FC_{empty}) * CCU_{weight(phys)} \quad \text{(Eq. 3)}$$

where

FC_{CCU} = fuel consumption at the actual cargo capacity utilisation
$CCU_{weight(phys)}$ = Cargo Capacity Utilisation, defined as cargo weight/ weight capacity.

Table 8 Fuel consumption and emissions for road transport of materials used in the calculation.

Type of lorry	Cargo capacity [ton]	Fuel consumption [(l/km]	[kWh/km]	Source	Emissions CO_2 [g/km]	CH_4 [g/km]	N_2O [g/km]	Source
Lorry+trailer 60ton (full)	40	0.49	4.80	NTM (2007a)	1 322	0.14	0.05	calc. from Uppenberg et al. (2001)
Lorry+trailer 60ton (empty)	0	0.33	3.20	NTM (2007a)	883	0.09	0.03	

Transport emissions of fossil fuels and peat[22] are included in the emission factors given in Table 4.

4.5 Emissions from pellet combustion

The calculation rules in RED can be interpreted as stating that all greenhouse gas emissions from the combustion of pellets shall be assumed to be zero (see Section 2.1). Therefore results are presented both including and excluding pellet combustion. This intepretation may also apply for all biomass combustion. Appendix 2 therefore also presents alternative results that exclude emissions from all biomass combustion during the production chain, not only pellet combustion.

The emissions of CH4 and N2O from pellet combustion depend on the type of combustion installation and the combustion conditions. Since few measurements are made for these emissions it was difficult to find reliable data, especially for small scale combustion. For large scale combustion, emission measurements at a couple of Swedish heating plants show that emissions are rather low. The numbers used for large scale combustion in **Error! Not a valid bookmark self-reference.** are associated with uncertainties but they should be a rather good approximation for large scale combustion in Sweden.

For small scale boilers the emissions can differ a lot between individual boilers and depend on how the combustion is performed. CH4 emissions for combustion in small scale pellet boilers have been measured to between 0.76 and 14 mg CH4/MJ in Cooper et al (2003). No measurements for N2O emissions in small boilers were found. The emission factor used in the Swedish National Inventory of 5 mg N_2O/MJ is valid for pellet combustion and some other wood fuels for other use than for district heating or electricity production (Swedish EPA, 2009). But this value is not based on measurements from modern pellet combustion but from other wood combustion and should probably more be seen as a potential emission during certain combustion conditions. Due to lack of reliable data for small scale combustion, no calculations for this end use option is done. Since both N_2O and CH_4 emissions from residential use are potentially significant it is important that new measurements are carried out.

Table 9 Emissions from pellet combustion for two end use options.

[mg/MJ]	Emissions from pellet combustion				Source
	CO_2	CH_4	N_2O	CO_{2eq}	
Use in large scale heating plant (~100MW)	0	0.03	0.6	178	CH_4: Fortum Värme (2009) N_2O: Öresundskraft (2008)

[22] Only used in the calculations for the poly-generation plant in Hedensbyn, Skellefteå.

5 Results and discussion

5.1 Total life cycle emissions from pellets produced in Swedish stand-alone pellet plants

Total life cycle emissions of greenhouse gases for average Swedish stand-alone pellet plants (default values) are presented in Table 10. The results are given for combustion in a large heating plant. Results are also given where emissions from pellet transportation and end use emissions are excluded. Typical transport distances are assumed and purchased electricity is defined as Swedish electricity mix. Saw mill residues used as raw material for pellet production are in these calculations considered as "co-products" of the saw mill and thus share some of the saw mill emissions.

When biomass is used for drying (which is most common in Swedish pellet plants), there is very little difference between pellets produced from raw sawdust, dry cutterdust/chips and roundwood, respectively. The total emissions are estimated to 3.3-3.7 gCO_{2eq}/MJ pellets depending on raw material. The reason for this is that more or less the same emissions occur for pellets from wet raw materials as from dry raw materials, but they occur at different stages of the life cycle. For wet raw materials (saw dust, etc.) most emissions (from drying, electricity consumption, internal transport, etc.) occur at the pellet plant whereas for dry raw materials (cutterdust, etc.) they occur at the saw mill (compare the emission for the different stages in Table 17 in Appendix 1). Roundwood requires more electricity for processing but assuming Swedish electricity mix this has limited effect. It should be noted that a shorter transport distance is assumed for roundwood (40 km) than for sawdust and cutterdust (85 and 70 km respectively).

Combustion emissions of CH_4 and N_2O in large scale heating plants are small (only approximately 5% of total emissions). If pellets is used in small houses the combustion emissions may be significantly higher, but good measurements are lacking.

Table 10 Typical life cycle greenhouse gas emissions for Swedish pellet production chains from different raw materials. Heat is produced from biomass combustion.

Total emissions [g CO_{2eq} / MJ pellets]	1. Pellet plant using wet raw material (sawdust) Biomass used for drying	2. Pellet plant using dry raw material (cutterdust / dry chips) No drying	3. Pellet plant using wet raw material (roundwood chips) Biomass used for drying
End use - large scale heating plant	3.35	3.74	3.60
Excl. end use emissions	3.17	3.56	3.43
Excl. distribution of pellets and end use emissions	2.73	3.12	2.98

It should be noted that these results take into account emissions from the production of forest residues and saw mill residues.[23] If the climate impact of saw mill residues are considered to be zero up to transport to the pellet plant, the difference in total emissions for pellets from different raw

[23] As discussed in Section 4.2.1 the calculation rules in RED can be interpreted as if raw material that are by-products from saw mills shall have zero emissions up to collection.

material will be larger. The total emissions would be approximately 1.4 gCO_{2eq} lower per MJ pellets for pellets from sawdust and 2.5 gCO_{2eq} lower for pellets from cutterdust (see calculations in Table 21, Table 22 and Table 23 in Appendix 2). Since the calculations for pellets from roundwood are hardly affected in this case, emissions from roundwood pellets will be 1.5 and 2.2 gCO_{2eq} higher per MJ than pellets from sawdust or cutterdust respectively. Considering saw mill residues to be co-products from the saw mill (sharing a part of the life cycle emissions for sawn wood) thus has an impact on the result.

The results in Table 10 also take into account emissions of CH_4 and N_2O from biomass combustion.[24] If all emissions from biomass combustion are excluded the total emissions for pellets from sawdust or roundwood would be approximately 0.5 gCO_{2eq} lower per MJ for pellets combusted in large-scale plants (Table 21 and Table 23 in Appendix 2). For pellets from cutterdust the corresponding figures are 0.3 gCO_{2eq} lower per MJ pellets (Table 22 in Appendix 2).

5.2 Sensitivity analysis

5.2.1 Stand-alone plants with other fuels used for drying

As shown in Table 11, the total emissions for pellets produced in a stand-alone plant will be significantly higher if heat for drying is produced from oil instead of biomass. Total emissions will increase from approximately 3 to 19 gCO_{2eq}/MJ pellets.

Table 11 Typical life cycle greenhouse gas emissions for Swedish pellet production chains from raw sawdust with different types of heat supply for drying: from biomass, waste heat and oil respectively.

1. Pellet plant using wet raw material (sawdust)	**Biomass used for drying**	**Waste heat used for drying**	**Oil used for drying**
	Total emissions [g CO_{2eq} / MJ pellets]		
End use - large scale heating plant	3.35	2.90	19.11
Excl. end use emissions	3.17	2.72	18.93
Excl. distribution of pellets and end use emissions	2.73	2.27	18.49

5.2.2 The effect of different transport distances

Since very little fossil energy is used in the processes of the pellet production chains and emissions from electricity are small (assuming Swedish electricity mix), the transport of raw materials and fuels to the plant and pellets to the consumer stands for a large part of total emissions (approximately 30% of the emissions up to end use for average Swedish pellet production chains). If the estimated maximum transport distances to and from the investigated pellet plants are used the total emissions up to end use will increase by approximately 60-70%, according to Table 12 and Table 13 below. The transport of pellets to the end user has the largest impact; here, the maximum value includes export with boat from northern Sweden to central Europe. However, even with long transport distances the total emissions for typical Swedish pellet chains is not likely to be higher

[24] As discussed in Section 2.1 the calculation rules in RED can be interpreted as if no emissions from use (=combustion) of biofuels shall be included.

than 5-6 gCO_{2eq}/MJ pellets given the calculation prerequisites of this study. However, if also another emission intensity for electricity is assumed, and data for the most inefficient plant is used the potential maximum greenhouse gas emissions can of course be higher (see Section 1.1.1).

Table 12 The effect of different transport distances on total emissions for typical pellet production from sawdust where biomass combustion is used for drying.

1. Pellet plant using wet raw material (sawdust)	Transport distance		
	Typical	MIN	MAX
	[g CO_{2eq} / MJ pellets]		
TRANSPORT EMISSIONS ONLY			
Transport of raw materials to the pellet plant	0.52	0.18	0.93
Transport of fuels to the pellet plant	0.02	0.00	0.06
Transport and distribution of pellets to consumers	0.45	0.30	2.23
TOTAL EMISSIONS			
End use - large scale heating plant	3.35	2.84	5.57
Excl. end use emissions	3.17	2.66	5.39
Excl. distribution of pellets and end use emissions	2.73	2.36	3.17

Table 13 The effect of different transport distances on total emissions for typical pellet production from dry materials (cutterdust/dry chips).

2. Pellet plant using dry raw material (cutterdust/dry chips)	Transport distance		
	Typical	MIN	MAX
	[g CO_{2eq} / MJ pellets]		
TRANSPORT EMISSIONS ONLY			
Transport of raw materials to the pellet plant	0.40	0.03	0.86
Transport of fuels to the pellet plant	-	-	-
Transport and distribution of pellets to consumers	0.45	0.30	2.23
TOTAL EMISSIONS			
End use - large scale heating plant	3.74	3.22	5.98
Excl. end use emissions	3.56	3.04	5.80
Excl. distribution of pellets and end use emissions	3.12	2.75	3.58

5.2.3 Efficiency variance between individual stand-alone plants

There are some differences in energy efficiency between the investigated stand-alone pellet plants, from the input data provided by the pellet producers. Given the variance in process data from the investigated pellet plants the total emissions for pellets leaving the pellet plant (excluding distribution and utilisation) are between 2 and 4 gCO_{2eq}/MJ pellets for pellets from wet material (Figure 1) and between 3 and 3.5 gCO_{2eq}/MJ pellets for pellets from dry material (Figure 2). Pellet plants using dry materials show a smaller range of emissions since no drying process is involved. However, the input data for some of the pellet plants are estimated to be somewhat high or low because of poor data quality and difficulty to apply the right conversion factors (see Section 4.1). The variance illustrated by the figures are probably somewhat overstated. The typical values used in the main calculations are however estimated to be representative, if any somewhat understated. Since Swedish pellet production is almost entirely a biomass based system, with corresponding small greenhouse gas emissions involved, differences between individual production systems (in terms of efficiency etc.) will have little impact on total emissions. If fossil heat energy or electricity with higher emission intensity is assumed (see Section 5.2.1, 5.2.4 and 5.2.5), the difference in efficiency between production systems would have greater effect on the resulting greenhouse gas emissions.

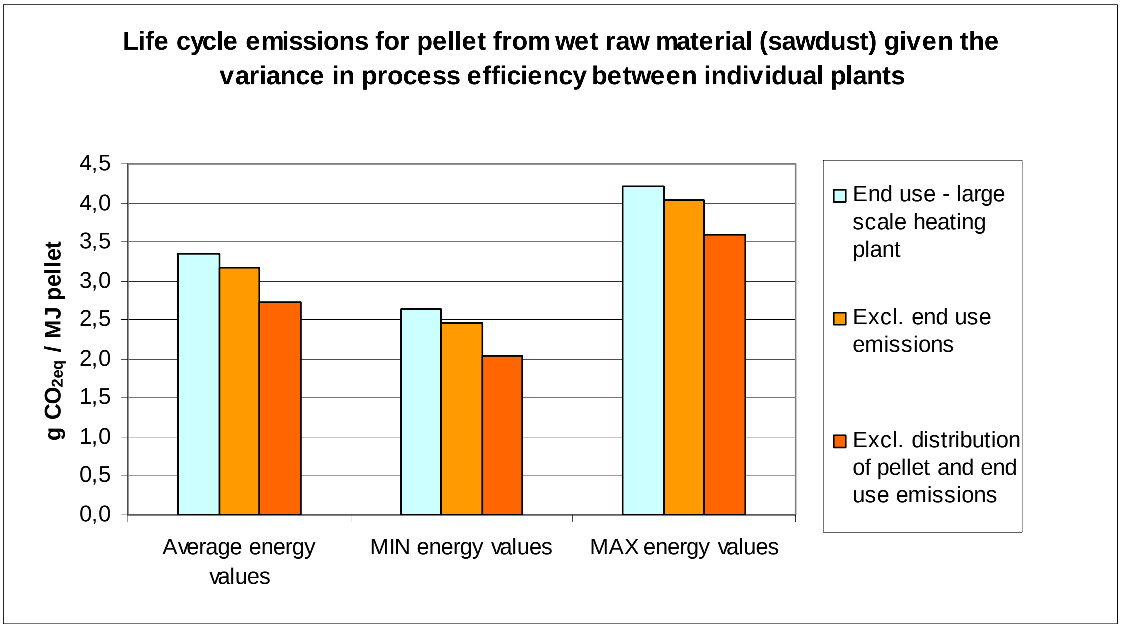

Figure 1 Emissions given the variance in process efficiency between individual plants where pellets is produced from raw sawdust and biomass is used for drying. Typical transport distances are assumed.

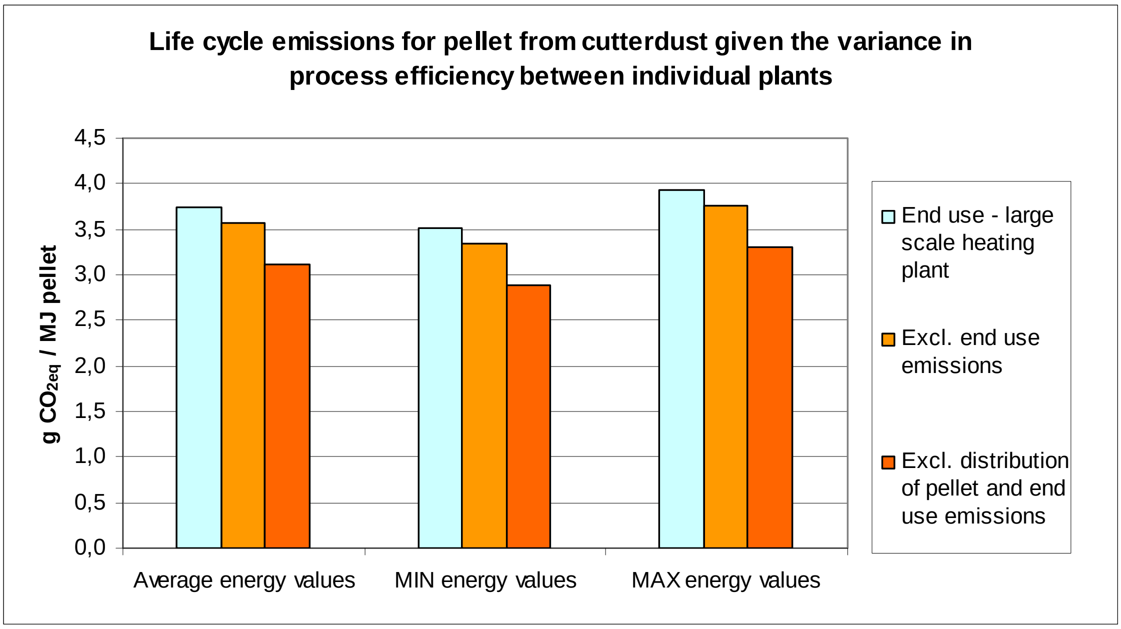

Figure 2 Emissions given the variance in process efficiency between individual plants where pellets is produced from dry materials (cutterdust) and biomass is used for drying. Typical transport distances are assumed.

5.2.4 Stand-alone pellet plant with different electricity origin

The selected electricity production mix assumed for purchased electricity has a large impact on the result as shown in Figure 3. For pellets from roundwood chips, where the electricity consumption is higher, the total emissions will be six times higher if coal power is assumed instead of Swedish electricity mix. The calculation rules in RED do not specify which electricity mix that shall be used, other than it shall be the average emissions from electricity production in a defined region.

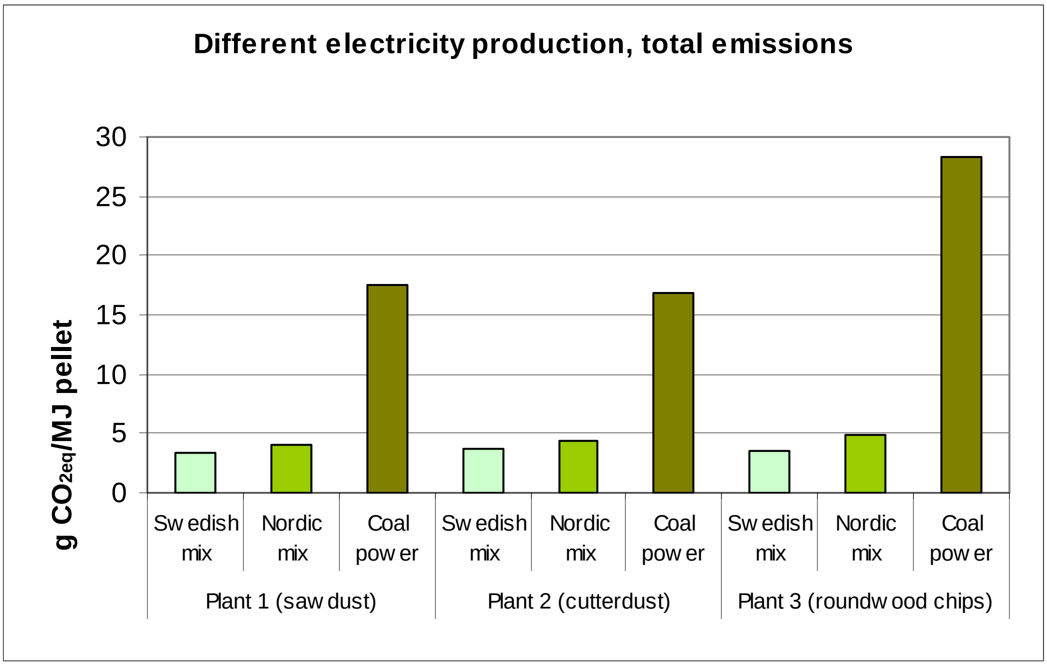

Figure 3 Total emissions for pellet production in stand-alone plants assuming different emission intensity for purchased electricity. Including end use in large scale heating plant.

5.2.5 Stand-alone pellet plant with max scenario

If both maximum values from the investigated plants in terms of energy efficiency (i.e. low efficiency) and maximum transport distances are assumed, the emissions will be about 100% higher than the typical emissions for pellet production from sawdust in a stand-alone plant (Figure 4). If also coal power is assumed instead of Swedish electricity mix for purchased electricity, the emissions will be about eight times higher than the typical emissions in the main scenario.

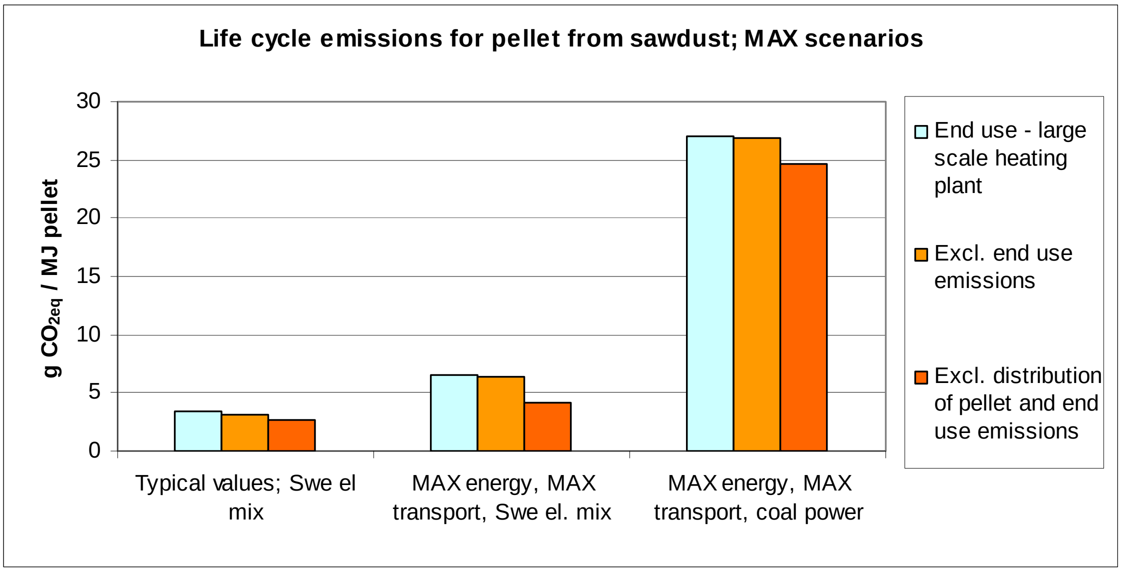

Figure 4 MAX scenarios for pellet production from sawdust in a stand-alone plant (Plant 1). For MAX energy is the maximum value for use of energy in investigated pellet plants used (i.e. low efficiency) and for MAX transport are the maximum transport distances of raw materials, fuels and pellets used. Two different emission intensity for purchased electricity.

5.2.6 Stand-alone pellet plant with district heating production from heat recovery

For pellet plants that have a drying process (pellets from wet material) heat recovery is possible, which become more common in new plants. If district heating is produced through heat recovery in an average stand-alone plant (based on the possible heat recovery at the plant in Härnösand) the total emissions would decrease somewhat per MJ pellets (Table 14) as long as district heating is regarded as co-product in RED.

Table 14 Comparison of total greenhouse gas emissions for pellet production from raw sawdust for 1) only pellet production and 2) including district heating production from heat recovery.

1. Pellet plant using wet raw material (sawdust)	Normal case	District heating as co-product
	Total emissions [g CO_{2eq} / MJ pellets]	
End use - large scale heating plant	3.35	3.21
Excl. end use emissions	3.17	3.03
Excl. distribution of pellets and end use emissions	2.73	2.59

5.3 Total life cycle emissions from pellets produced in a poly-generation plant

As shown in Table 15 and Table 16 it is of great importance for total greenhouse emissions for pellets produced in a poly-generation plant whether the different plants (in this case a CHP plant, a heating plant (HP) and a pellet plant) are considered as one common poly-generation plant (Alternative 1) or as separate stand-alone plants (Alternative 2). The total emissions for pellets produced in the Hedensbyn plant in Skellefteå (with original fuel mix: 26% peat and 74% biomass) will be approximately three times higher if it is considered as a poly-generation plant than if the pellet plant is considered to be a stand-alone plant which buy steam from the CHP. The reason for this is mainly that the fuel consumption for the pellet production is only 20% of the energy content in the pellets. In the stand-alone plant (Alternative 2) the emissions allocated to the steam are about 24% of the emissions in the CHP plant. In the case of a poly-generation plant (Alternative 1) the combined emissions from the CHP plant, the heating plant and the pellet plant are allocated between the co-products in proportion to their energy content. In this case pellets accounts for 59% of the total co-products in terms of energy content and therefore a larger part of the emissions are allocated to pellets. On top of that, in the stand-alone plant case are emission savings from excess electricity credited to the pellets, which it is not in the poly-generation plant case.

The difference between the poly-generation plant and the stand-alone plant is less if only biomass is used in the CHP or the HP. The emissions generated in the CHP and HP are then allocated in the same way as explained above, but since the emissions are much lower the effect will be smaller. There are also specific emissions at the pellet plant regardless of fuel used in the CHP that are the same in both cases. More detailed results of the two different alternative calculations for Hedensbyn are presented in Table 19 and Table 20 in Appendix 1.

It is also important for the results whether district heating shall be considered as a co-product (to which a share of the emissions then is allocated) or not, since the district heating stands for 60% of total net output from the CHP. When the pellet plant is considered as part of a poly-generation plant (Table 15) the total emissions for pellets are approximately 50% higher if district heating is not considered as a co-product. When the pellet plant is considered as a stand-alone plant (Table 16) the total emissions for pellets are more than 120% higher if district heating is not considered as a co-product. The reason for this is that in the poly-generation case (Alternative 1) the total output of products to which total emissions are divided between are reduced from 1 010 GWh to 701 GWh when district heating is excluded, a decrease with about 31%. The total emissions in the poly-generation plant can still be divided by almost 70% of the previous amount of co-products. In Alternative 2, when the CHP plant and the pellet plant are considered as separate stand-alone units the effect will be larger. In the CHP plant the output of products to be accounted for will decrease from 460 to 203 GWh, a decrease with about 56%. The emissions in the CHP plant can only be divided on less than 50% of the previous co-products. Since the combustion emissions in the CHP amounts to a large part of the total emissions for the pellet chains (due to the 26% peat in the fuel mix in these cases), a 225% increase (including the effect of excess electricity) of the emissions for the purchased steam in the stand-alone plant case will have a large effect.

As explained in Section 3.2.1, the heating plant in Hedensbyn is only used for district heating and is not integrated with the pellet production. If the heating plant and the oil consumption in the CHP during the summer month are excluded also in the calculations for the poly-generation case, the total emissions will be somewhat lower. The corresponding figures in Table 15 will be 1.09, 0.06 and 3.03 g CO_{2eq} lower per MJ pellets for the three different cases(indicated by the columns), respectively.

Table 15 Total greenhouse gas emissions for pellets produced in a poly-generation plant (Hedensbyn), calculated as poly-generation plant (Alternative 1). The effect of 1) replacing peat and oil with biomass in the CHP and heating plant and 2) not considering district heating as a co-product.

4. Poly-generation plant using wet raw material (sawdust).	**Calculated as poly-generation plant (alternative 1)**		
	Original fuel mix in CHP+HP. District heating is co-product	**Peat and oil replaced by biomass in CHP+HP. District heating is co-product**	**Original fuel mix in CHP+HP. District heating not a co-product.**
	Total emissions [g CO_{2eq} / MJ pellets]		
End use - large scale heating plant	20.71	4.06	29.57
Excl. end use emissions	20.53	3.88	29.39
Excl. distribution of pellets and end use emissions	20.10	3.44	28.95

Table 16 Total greenhouse gas emissions for pellets produced in a poly-generation plant (Hedensbyn), calculated as a stand-alone pellet plant (Alternative 2). The effect of 1) replacing peat and oil with biomass in the CHP and 2) not considering district heating as a co-product.

4. Poly-generation plant using wet raw material (sawdust).	**Calculated as stand-alone pellet plant (alternative 2)**		
	Original fuel mix in CHP. District heating is co-product	**Peat and oil replaced by biomass in CHP. District heating is co-product**	**Original fuel mix in CHP. District heating not a co-product.**
	Total emissions [g CO_{2eq} / MJ pellets]		
End use - large scale heating plant	6.84	3.06	16.66
Excl. end use emissions	6.66	2.89	16.48
Excl. distribution of pellets and end use emissions	6.22	2.45	16.04

6 Applicability of the RED methodology

Some important aspects of the calculating rules for greenhouse gas emissions in RED (Directive 2009/28/EC, Annex V, Part C) have been discussed throughout the report.: certain parts of RED are difficult to interpret, some parts open up for subjective interpretations and others must be reformulated to also be applicable on production chains for solid biofuels, such as wood pellets. There are also parts of the calculation rules that, as we see it, treat important issues of fuel production chains in a strange way. We have tried to show these obscurities by exemplifying with alternative calculations or comments whenever needed in the report. This chapter summarises some of these aspects.

6.1 Emissions from electricity production

The production of purchased electricity is to be modelled as average production and distribution of electricity in a given region (§11). This rule is vague primarily because the emissions from electricity production can depend heavily on whether the chosen region is a country (e.g., Sweden), an electricity market (e.g., NordPool), etc. There is also a difference between the electricity produced in a region and the electricity distributed to users in that region, because of imports and exports. The vagueness of §11 is not specific to pellet production, but it becomes problematic when the methodology is applied in Sweden, where the difference is large between the production within the country and in neighbouring countries. Our calculations are based on data on average Swedish electricity production (see Section 4.3.2). However, as shown in the sensitivity analysis it is of great importance for the total emissions for a pellet chain what emission intensity that is assumed for purchased electricity.

The rules for modelling of electricity production are inconsistent (this problem is also not specific to pellet production):

- purchased electricity is modelled as the average electricity for a defined region (§11),
- excess electricity from heat produced in cogeneration (CHP) with a specific fuel is assumed to replace electricity produced from the same type of fuel, for which avoided emissions are credited to the biofuel production chain (§16), and
- excess electricity from fuel production is assigned emissions in proportion to its share of the total energy output from that process (§17).

Due to this inconsistency, the interpretation of the process concept can have a large impact on the results, as demonstrated by the calculations of this study (see Sections 3.2 and 5.3). A pellet plant integrated with a CHP plant may be considered as an integrated process for fuel production, where emissions for the whole plant are divided between the different co-products pellets, electricity and district heating in proportion to their energy content (according to §17). But the pellet plant may also be considered as a stand-alone process that buys heat from the CHP plant, for which emission savings from excess electricity shall be credited to the pellets (according to §16).

6.2 Emission savings from excess electricity

It requires some effort to achieve clear understanding of the Swedish version of §16, which deals with excess electricity from CHP (see Appendix 4). The English version is different or more vague: it states that heat from CHP production cannot be credited with emissions avoided through the electricity production if the CHP fuel is a "co-product other than an agricultural crop residue". The Swedish interpretation is that this holds only for co-products from the production of the investigated fuel, but the text can also be interpreted to hold for co-products in general. The difference can be important, because fuel oil, natural gas and solid biofuel can all be considered co-products (from refineries, combined oil and gas extraction, forestry, etc.). The Swedish interpretation seems to be the most sensible. A significant problem with it is that it is difficult to interpret. This problem is, of course, not specific to pellet production.

6.3 Allocation between co-products

The rule for allocation at fuel production (§17) is applicable for combustible co-products and electricity; however, it is not strictly applicable to waste heat and district heating, since these energy flows do not have a lower heating value. The rule is also not applicable to co-products that are not energy carriers. These limitations are not specific to pellet production, but the first limitation might be particularly problematic in Sweden, where the use of waste heat for district heating is common. This limitation can be simply resolved by adding "…och värme" at the end of the paragraph. The second limitation can be of importance for some bio refineries such as ethanol production plants which produce distiller's waste and maybe also fertilizers that do not have lower heating value. This limitation is perhaps unavoidable in the attempt to define an allocation method where the results are robust over time and perceived as reasonable in most cases, but it is unfortunate since it does not fully acknowledge benefits of bio refineries or poly-generation plants.

The allocation procedure is described more in detail in §18. The Swedish version of the first part of §18 includes several concepts that are unclear in this context: "samprodukter" that "redan har fått en sådan tilldelning", "senaste processteget", "mellanliggande bränslet". Again, this problem is not specific to pellet production. The English version is more intelligible, and we have used that as a basis for understanding the Swedish text (see Appendix 4).

The second part of §18 is explicitly limited to transportation biofuels and liquid biofuels in the Swedish version. This text needs to be modified to include biofuels in general to be applicable also to pellet production (or other solid biofuels).

The RED methodology specifies the approach to allocation problems at CHP production (§16) and fuel production (§17). It does not specify the allocation method for other co-production processes (forestry, saw mills, etc.). This is a problem when applying the method to pellet production, at least as long as forest residues and saw dust are not regarded as waste or residues (cf. §18 and Section 6.4). In this study the energy method have been applied in all calculations. However, for wood products with varying moisture content and heating value allocation based on the energy content involves difficulties and uncertainties, as described in Section 4.1. An alternative would be allocation per mass unit dry substance, but this also includes uncertainties.

6.4 The definition of waste and residue

The third part of §18 states that for wastes, agricultural crop residues, and residues from processing, no emissions that occur prior to collection should be included in the calculation. To apply this rule on pellet production, it must be decided whether forest residues should be considered as waste, or have the same standing as crop residues. It must also be clarified if the zero emission exception for residues from processing is restricted to processing of agricultural crops or also includes wood based materials such as saw dust, cutterdust etc. The Swedish and English texts are both vague and the two versions are somewhat inconsistent. It is, however, important that the rules allow equal treatment of different types of biofuels

Our primary calculations are based on the assumption that saw dust (and other saw mill by-products) is not regarded as waste or residues, and thus share the emissions from the processing at the saw mill (see Section 4.2.1). This interpretation can be justified by the fact that all saw mill residues has an alternative use (for energy conversion, particle board or chipboard production) and today have a significant economic value. The effect on the result of including or excluding emissions from saw mill residues are of more importance for dry materials such as cutterdust which are associated with higher emissions from the saw mill process than wet materials (see Appendix 2).

The question of what should be regarded as waste or residues (with zero emissions up to collection) from the production of other goods is essential for LCA calculations for biofuels. It is important that the calculation rules are clear and comparable between different raw materials and different fuel chains. It is also important that the RED rules encourage efficient use of residues and biomass resources. It is clear obvious that activities causing emissions of greenhouse gases should be accounted for, but the question is to which product or products the emissions should be allocated. The market value of the products is one possible basis for such considerations. An alternative starting point could be the questions – what is the main driving force for the activity where the material is generated and what would happen if the material was not collected and used for energy purposes? In the saw mill case, the production of sawn wood is the main driving force. Saw dust and cutterdust would be generated, probably to a similar extent, even if it was not utilised. It can therefore be argued that all emissions up to the collection of these materials should be allocated to the main product, i.e. sawn wood. This reasoning is valid as long as the economic value of the “residues” are limited compared to the main product. When the economic value of the residues become comparable to the main product, the driving force of the activity has changed. In this case sawn wood, saw dust and cutterdust should be regarded as co-products and the emissions associated with the activity should, logically, also be divided between the products.

This discussion support the view that, from an LCA perspective, the most accurate way would be to allocate emissions between the products based on their economical value. However, since the economical value will change over time, the calculations will get complicated and hard to compare from year to year. It may be possible to use for instance five-year averages of the economical value as a basis for the calculations, but it will still be rather demanding. For the purpose of the RED, it may be more appropriate to define what shall be regarded as waste or residues (with zero emissions up to collection) and use physical allocation between products that are not regarded as waste or residues. If the driving force of an activity is severely changed, the classification of a material as waste may also be changed.

Forest residues such as tops and branches and rot-defected roundwood are also results of the production of other goods (timber and pulp wood), which would still continue if those fractions were not collected for energy purposes. It is also in this case reasonable to consider tops and branches and rot-defected roundwood as waste or residues with zero emissions up to collection. However, any additional emissions due to the collection and utilisation of the residues should thus be estimated compared to the reference case and included. This includes for instance decreased build-up of the soil carbon stock. Removal of tops and branches is, however, estimated to have small influence on the carbon stock (Ågren et al., in press). As discussed above, when the economic value of energy wood increases and when a larger part of the stem wood is used as a fuel, this reasoning no longer holds, and part of the emissions should be allocated to the fuel fractions.

There is another important drawback with this way of allocating all emissions to the main product of an activity, and in the case where more than one "main product" is produced using energy allocation. For biofuel production in poly-generation plants, for instance ethanol plants, a prerequisite for good environmental performance and high overall efficiency of the fuel, is that the by-products are accounted for. Should distiller's waste (drank) that is dried and sold as animal fodder be considered as waste or residues and thus not share any of the emissions? If it can be regarded as a co-product, is it possible to use energy allocation of emissions even though the fodder is not an energy product? The use of the by-products from biofuel plants are of importance for the overall climate impact of the fuel chain, and should somehow be accounted for. This could be done by allowing allocation of some of the emissions to the by-products.

In at least some of the cases above, an alternative approach would be to expand the system investigated to include the affecting production of goods that compete with the by-product and that is most likely to be used instead of using the by-product (e.g., soy protein is the competing product to fodder from ethanol plants, less saw dust used in particle boards means an increase in production of other materials). This would eliminate the allocation problem from the analysis, but new allocation problems and new uncertainties might be introduced instead.

6.5 CH_4 and N_2O emissions from biofuel combustion

According to §13 emissions from the fuel in use shall be assumed to be zero for biofuels and bioliquids. This rule is only applicable on transportation biofuels and bioliquids and should be reformulated to include also solid biofuels.

It is not obvious if this rule applies also to emissions of CH_4 and N_2O, which can be significant for combustion of solid biofuels under certain conditions, especially in small scale installations. End use emissions of CH_4 and N_2O can have a large impact on the result depending on type of boiler and combustion conditions. We recommend that CH_4 and N_2O emissions regardless origin shall be included in a LCA, and that new emission measurements are carried out for small scale combustion..

6.6 Carbon-stock changes

Calculating annualised emissions from carbon-stock changes caused by changes in land use (e_l) requires a well defined method for calculation of the carbon stock (§7). The Commission is to present guidelines on such calculations this year (§10). Until these have been presented, the calculations of e_l can be preliminary only. This limitation is not specific to pellet production.

A complex and important issue is how biomass residing from forestry on drained peatland shall be considered. In this case the allocation principles between residues and main products as discussed in Section 6.4 will be very important. If the biomass is regarded as waste or residue the emissions are considered to be zero up to collection and it is not neccessary to deal with GHG fluxes caused by the forestry. However, if it is regarded as one of the main products it must be carefully analysed how GHG fluxes are affected by the fuel production and how allocation shall be done. It is, however, outside the scope of this study and should be carefully analysed in a separate study.

6.7 Accounting for CCS

The RED methodology accounts for carbon capture and storage (CCS) at the extraction, transport, processing, and distribution of the fuel. It does not account for CCS at the use of the fuel (§14). This limitation is justified in assessments of transportation biofuels, since CCS is not a realistic option in vehicles. However, it is not justified when the methodology is applied on solid biofuels such as pellets, since pellets can be used in large scale, stationary plants.

6.8 Fossil comparator for utilisation of solid biofuels

It is not specified nor obvious what the fossil fuel comparator shall be for solid biofuels such as wood pellets, something that must be specified in a future RED applicable to solid biofuels (§4). Calculation of the saving of greenhouse gas emissions by pellet utilisation is therefore omitted from this study.

7 Conclusions

The results from all the different pellet chains analysed in this study are summarised in Figure 5 below. Typical life cycle emissions (exclusive end use emissions) from pellet production in Swedish stand-alone plants are estimated to approximately 3-4 g CO_{2eq}/MJ, with small differences between different raw materials. The factors with the highest impact on the result are assumed electricity mix and choice of fuel for drying. Variance of efficiency between individual plants has some impact on the result and variance in transport distances has a somewhat larger impact on the result, especially for distribution of pellets to consumers. In our MAX scenario, where low efficiency (MAX energy use), maximum transport distances and coal power is assumed, the emissions are approximately 27 g CO_{2eq}/MJ. Assuming fossil fuel for drying would of course increase emissions further, but it is not a very realistic case in Swedish stand-alone pellet plants.

For the standard pellet chains, emissions from raw material and fuel supply are the main emission sources. If fossil oil is used for drying or another more emission intense electricity mix is assumed, the process emissions will be dominant.

The alternative calculations that have been done based on different interpretations of the calculation rules in RED are also shown in the figure. If emissions from by-products from saw mills are taken as zero (By-prod=0 in the figure), the emissions will decrease for pellets from sawdust and especially cutterdust, but stay almost unaffected for pellets from roundwood. Cutterdust share a larger part of emissions from the saw mill since it is generated later in the process. If emissions from biomass combustion are excluded (BC=0 in the figure) will somewhat decrease the emissions, mainly due to CH_4 and N_2O emissions from solid biofuels.

If end use emissions from pellet combustion in large scale heating plants were included the total life cycle emissions would increase by approximately 0.2 g CO_{2eq}/MJ for all analysed pellet chains. Emissions from small scale combustion may potentially be much higher, but due to lack of reliable data it was not calculated in this study.

For pellet production in integrated plants (consisting of a pellet plant and a CHP) indicated by Plant 4 in the figure, the selected method for the calculations is of great importance. If only biomass is assumed in the CHP plant, the emissions are of the same magnitude as for the stand-alone plants. However, if the original fuel mix in Hedensbyn CHP plant is assumed (26% peat) the interpretation of RED is determinant. If the Hedensbyn plant is regarded as a poly-generation plant where pellets, electricity and district heating are co-products (Alternative 1) the emissions will be three times higher than if the pellet and the CHP plant are regarded as separate stand-alone plants. It is also of great importance if district heating is included as a co-product (main case) or if it is regarded as waste energy as shown in the figure for Plant 4.

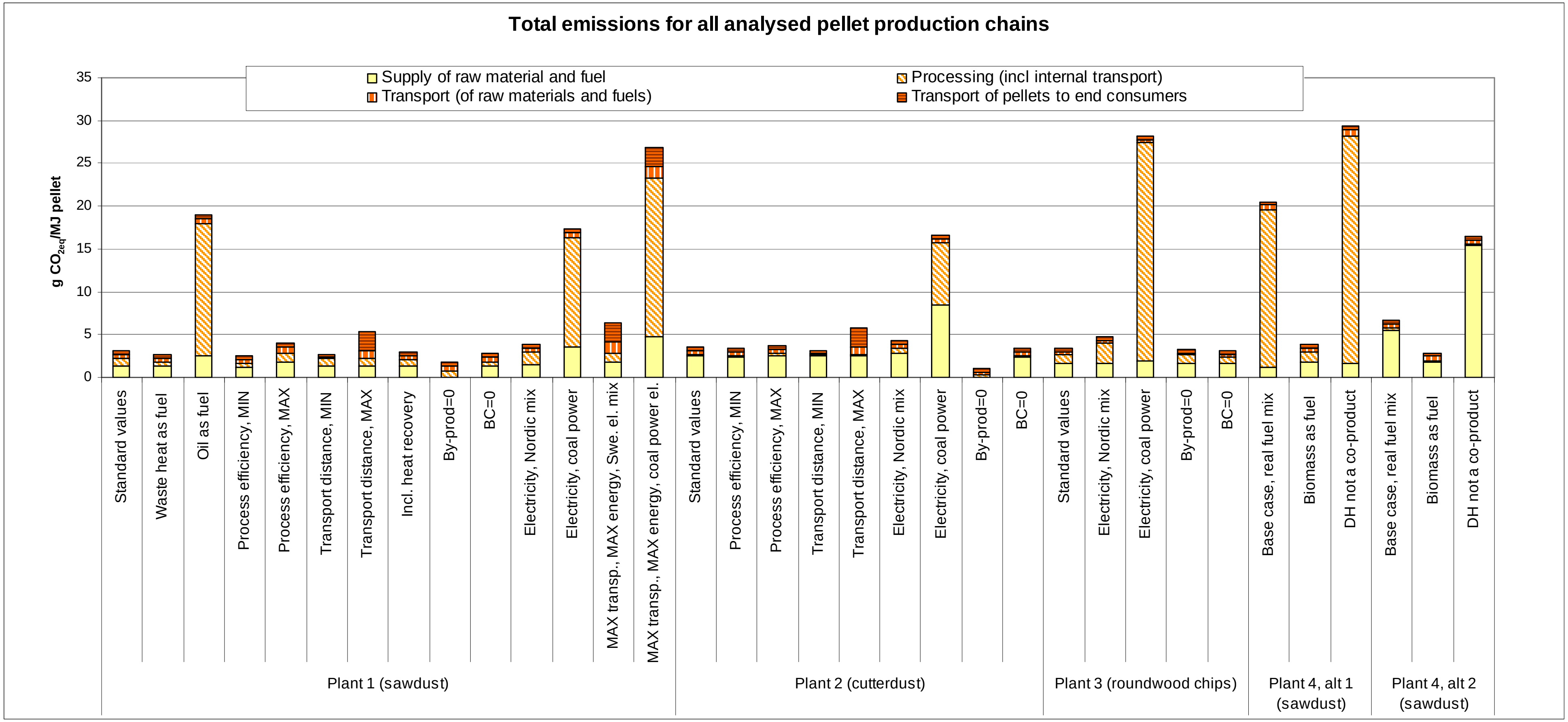

Figure 5 Summary of results for the different pellet production chains analysed. Plant 1-3 indicate production in stand-alone pellet plants. Plant 4 is production in a pellet plant integrated with a CHP plant (Hedensbyn) where alt 1) it is regarded as a poly-generation plant, and alt 2) the pellet plant and the CHP are regarded as separate plants. The following assumptions are used, if not otherwise stated: Swedish electricity mix; typical values for process efficiency (energy) and transport distances; emissions from production of saw mill by-products and biomass combustion are accounted for; biomass used for drying in Plant 1 and Plant 3; for Plant 4 the fuel mix in the CHP is 26% peat and 74% biomass and district heating is regarded as a co-product. Explanations: By-prod=0 when emissions from saw mill by-products are taken as zero; BC=0 when all emissions from biomass combustion is taken as zero. DH means district heating.

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Appendix 1 Detailed results

Table 17 Typical life cycle greenhouse gas emissions for Swedish pellet production chains from different raw materials. Heat is produced from biomass combustion.

		1. Pellet plant using wet raw material (sawdust)					2. Pellet plant using dry raw material (cutterdust / dry chips)					3. Pellet plant using wet raw material (roundwood chips)				
		Biomass used for drying					No drying					Biomass used for drying				
	Emissions per MJ pellets	MJ	g CO_2	mg CH_4	mg N_2O	g CO_{2eq}	MJ	g CO_2	mg CH_4	mg N_2O	g CO_{2eq}	MJ	g CO_2	mg CH_4	mg N_2O	g CO_{2eq}
RAW MATERIAL SUPPLY	Total raw material input	0.88					0.96					0.88				
	Production/extraction of raw materials		1.3	0.2	0.0	1.27		2.3	1.3	0.5	2.48		1.5	2.0	0.1	1.56
	Transport of raw materials to the pellet plant		0.5	0.1	0.0	0.52		0.4	0.0	0.0	0.40		0.3	0.0	0.0	0.25
PROCESSING AND FUEL SUPPLY	Production/exctraction of fuels		0.1	0.0	0.0	0.11							0.1	0.0	0.0	0.11
	Combustion of fuels	0.20	0.0	1.0	1.0	0.31						0.20	0.0	1.0	1.0	0.31
	Transport of fuels to the pellet plant		0.0	0.0	0.0	0.02							0.0	0.0	0.0	0.02
	Net electricity consumption	0.04	0.2	1.0	0.0	0.22	0.02	0.1	0.6	0.0	0.13	0.07	0.4	2.1	0.1	0.46
	Internal transports etc.(diesel)		0.2	0.0	0.0	0.25		0.1	0.0	0.0	0.11		0.2	0.0	0.0	0.25
END USE EMISSIONS	Transport and distribution of pellets to consumers		0.4	0.0	0.0	0.45		0.4	0.0	0.0	0.45		0.4	0.0	0.0	0.45
	Use in large scale heating plant (~100MW)		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18
TOTAL	End use - large scale heating plant		2.8	2.4	1.7	3.35		3.3	2.1	1.2	3.74		3.0	5.2	1.7	3.60
	Excl. end use emissions		2.8	2.4	1.1	3.17		3.3	2.0	0.6	3.56		3.0	5.2	1.1	3.43
	Excl. distribution of pellets and end use emissions		2.4	2.3	1.1	2.73		2.9	2.0	0.6	3.12		2.5	5.1	1.1	2.98

Table 18 Typical life cycle greenhouse gas emissions for Swedish pellet production chains from raw sawdust with different types of heat supply for drying: from biomass, waste heat and oil respectively.

		1. Pellet plant using wet raw material (sawdust)														
		Biomass used for drying					Waste heat used for drying					Oil used for drying				
	Emissions per MJ pellets	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**
RAW MATERIAL SUPPLY	Total raw material input	0.88					0.88					0.88				
	Production/extraction of raw materials		1.3	0.2	0.0	1.27		1.3	0.2	0.0	1.27		1.3	0.2	0.0	1.27
	Transport of raw materials to the pellet plant		0.5	0.1	0.0	0.52		0.5	0.1	0.0	0.52		0.5	0.1	0.0	0.52
PROCESSING AND FUEL SUPPLY	Production/exctraction of fuels		0.1	0.0	0.0	0.11		0.0	0.0	0.0	0.00		1.2	0.7	0.0	1.18
	Combustion of fuels	0.20	0.0	1.0	1.0	0.31	0.20	0.0	0.0	0.0	0.00	0.20	15.0	0.1	0.1	15.03
	Transport of fuels to the pellet plant		0.0	0.0	0.0	0.02		0.0	0.0	0.0	0.00		0.0	0.0	0.0	0.00
	Net electricity consumption	0.04	0.2	1.0	0.0	0.22	0.04	0.2	1.0	0.0	0.22	0.04	0.2	1.0	0.0	0.22
	Internal transports etc.(diesel)		0.2	0.0	0.0	0.25		0.2	0.0	0.0	0.25		0.2	0.0	0.0	0.25
END USE EMISSIONS	Transport and distribution of pellets to consumers		0.4	0.0	0.0	0.45		0.4	0.0	0.0	0.45		0.4	0.0	0.0	0.45
	Use in large scale heating plant (~100MW)		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18
TOTAL	End use - large scale heating plant		2.8	2.4	1.7	3.35		2.7	1.4	0.7	2.90		18.8	2.2	0.8	19.11
	Excl. end use emissions		2.8	2.4	1.1	3.17		2.7	1.4	0.1	2.72		18.8	2.1	0.2	18.93
	Excl. distribution of pellets and end use emissions		2.4	2.3	1.1	2.73		2.2	1.3	0.1	2.27		18.4	2.1	0.2	18.49

Table 19 Total greenhouse gas emissions for pellets produced in a poly-generation plant (Hedensbyn), calculated as poly-generation plant (Alternative 1). The effect of 1) replacing peat and oil with biomass in the CHP and 2) not considering district heating as a co-product.

		4. Poly-generation plant using wet raw material (sawdust). Calculated as poly-generation plant (Alternative 1)														
		Original fuel mix in CHP, district heating is co-product					**Peat and oil replaced by biomass in CHP, district heating is co-product**					**Original fuel mix in CHP, district heating is not co-product**				
	Emissions per MJ pellets	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**
RAW MATERIAL SUPPLY	Total raw material input	0.88					0.88					0.88				
	Production/extraction of raw materials		0.7	0.1	0.0	0.73		0.7	0.1	0.0	0.73		1.0	0.2	0.0	1.05
	Transport of raw materials to the pellet plant		0.3	0.0	0.0	0.31		0.3	0.0	0.0	0.31		0.4	0.0	0.0	0.45
PROCESSING AND FUEL SUPPLY	Production/exctraction of fuels		0.9	-30.4	0.6	0.40		1.0	0.8	0.0	0.99		1.3	-43.8	0.9	0.57
	Combustion of fuels	0.63	17.0	3.1	4.1	18.25	0.62	0.0	3.1	3.1	1.00	0.90	24.4	4.5	5.9	26.29
	Transport of fuels to the pellet plant		0.2	0.0	0.0	0.21		0.2	0.0	0.0	0.21		0.3	0.0	0.0	0.30
	Net electricity consumption	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.00
	Internal transports etc.(diesel)		0.2	0.0	0.0	0.21		0.2	0.0	0.0	0.21		0.3	0.0	0.0	0.30
END USE EMISSIONS	Transport and distribution of pellets to consumers		0.4	0.0	0.0	0.44		0.4	0.0	0.0	0.44		0.4	0.0	0.0	0.44
	Use in large scale heating plant (~100MW)		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18
TOTAL	End use - large scale heating plant		19.7	-27.0	5.4	20.71		2.8	4.2	3.8	4.06		28.2	-39.0	7.5	29.57
	Excl. end use emissions		19.7	-27.0	4.8	20.53		2.8	4.2	3.2	3.88		28.2	-39.0	6.9	29.39
	Excl. distribution of pellets and end use emissions		19.3	-27.1	4.8	20.10		2.4	4.1	3.2	3.44		27.8	-39.0	6.9	28.95

Table 20 Total greenhouse gas emissions for pellets produced in a poly-generation plant (Hedensbyn), calculated as a stand-alone pellet plant (Alternative 2). The effect of 1) replacing peat and oil with biomass in the CHP and 2) not considering district heating as a co-product.

		4. Poly-generation plant using wet raw material (sawdust). Calculated as stand-a-lone pellet plant (alternative 2)														
		Original fuel mix in CHP, district heating is co-product					**Peat and oil replaced by biomass in CHP, district heating is co-product**					**Original fuel mix in CHP, district heating is not a co-product**				
	Emissions per MJ pellets	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**
RAW MATERIAL SUPPLY	Total raw material input	0.88					0.88					0.88				
	Production/extraction of raw materials		1.2	0.2	0.0	1.20		1.2	0.2	0.0	1.20		1.2	0.2	0.0	1.20
	Transport of raw materials to the pellet plant		0.5	0.1	0.0	0.51		0.5	0.1	0.0	0.51		0.5	0.1	0.0	0.51
PROCESSING AND FUEL SUPPLY	Production/exctraction of fuels		0.0	0.0	0.0	0.00		0.0	0.0	0.0	0.00		0.0	0.0	0.0	0.00
	Combustion of fuels	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.00
	Transport of fuels to the pellet plant		0.0	0.0	0.0	0.00		0.0	0.0	0.0	0.00		0.0	0.0	0.0	0.00
	Purchased steam/heat		6.7	-9.9	1.8	7.04		0.5	1.7	1.2	0.92		16.1	-23.6	4.2	16.86
	Net electricity consumption	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.00
	Internal transports etc.(diesel)		0.2	0.0	0.0	0.15		0.2	0.0	0.0	0.15		0.2	0.0	0.0	0.15
	Excess electricity from cogeneration		-2.6	3.9	-0.7	-2.68		-0.2	-0.6	-0.5	-0.33		-2.6	3.9	-0.7	-2.68
END USE EMISSIONS	Transport and distribution of pellets to consumers		0.4	0.0	0.0	0.44		0.4	0.0	0.0	0.44		0.4	0.0	0.0	0.44
	Use in large scale heating plant (~100MW)		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18
TOTAL	End use - large scale heating plant		6.4	-5.7	1.8	6.84		2.6	1.5	1.4	3.06		15.9	-19.4	4.2	16.66
	Excl. end use emissions		6.4	-5.7	1.2	6.66		2.6	1.5	0.8	2.89		15.9	-19.5	3.6	16.48
	Excl. distribution of pellets and end use emissions		6.0	-5.7	1.1	6.22		2.2	1.4	0.8	2.45		15.4	-19.5	3.6	16.04

Appendix 2 Alternative calculations

Table 21 Alternative calculations for pellets from raw sawdust, where i) climate impact from saw mill residues = 0 and ii) biomass combustion emissions = 0.

		1. Pellet plant using wet raw material (sawdust), biomass used for drying														
		Main case					**By-products from saw mill = 0 climate impact**					**Emissions from combustion of biomass = 0**				
	Emissions per MJ pellets	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**
RAW MATERIAL SUPPLY	Total raw material input	0.88					0.88					0.88				
	Production/extraction of raw materials		1.3	0.2	0.0	1.27		0.0	0.0	0.0	0.00		1.3	0.2	0.0	1.27
	Transport of raw materials to the pellet plant		0.5	0.1	0.0	0.52		0.5	0.1	0.0	0.52		0.5	0.1	0.0	0.52
PROCESSING AND FUEL SUPPLY	Production/exctraction of fuels		0.1	0.0	0.0	0.11		0.0	0.0	0.0	0.01		0.1	0.0	0.0	0.11
	Combustion of fuels	0.20	0.0	1.0	1.0	0.31	0.20	0.0	1.0	1.0	0.31	0.20	0.0	0.0	0.0	0.00
	Transport of fuels to the pellet plant		0.0	0.0	0.0	0.02		0.0	0.0	0.0	0.02		0.0	0.0	0.0	0.02
	Net electricity consumption	0.04	0.2	1.0	0.0	0.22	0.04	0.2	1.0	0.0	0.22	0.04	0.2	1.0	0.0	0.22
	Internal transports etc.(diesel)		0.2	0.0	0.0	0.25		0.2	0.0	0.0	0.25		0.2	0.0	0.0	0.25
END USE EMISSIONS	Transport and distribution of pellets to consumers		0.4	0.0	0.0	0.45		0.4	0.0	0.0	0.45		0.4	0.0	0.0	0.45
	Use in large scale heating plant (~100MW)		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18		0.0	0.0	0.0	0.00
TOTAL	End use - large scale heating plant		2.8	2.4	1.7	3.35		1.4	2.2	1.7	1.97		2.8	1.4	0.1	2.85
	Excl. end use emissions		2.8	2.4	1.1	3.17		1.4	2.1	1.1	1.80		2.8	1.4	0.1	2.85
	Excl. distribution of pellets and end use emissions		2.4	2.3	1.1	2.73		1.0	2.1	1.0	1.35		2.4	1.3	0.1	2.40

Table 22 Alternative calculations for pellets from cutterdust/dry chips, where i) climate impact from saw mill residues = 0 and ii) biomass combustion emissions = 0.

		2. Pellet plant using dry raw material (cutterdust / dry chips)														
		Main case					**By-products from saw mill = 0 climate impact**					**Emissions from combustion of biomass = 0**				
	Emissions per MJ pellets	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**
RAW MATERIAL SUPPLY	Total raw material input	0.96					0.96					0.96				
	Production/extraction of raw materials		2.3	1.3	0.5	2.48		0.0	0.0	0.0	0.00		2.3	0.9	0.1	2.32
	Transport of raw materials to the pellet plant		0.4	0.0	0.0	0.40		0.4	0.0	0.0	0.40		0.4	0.0	0.0	0.40
PROCESSING AND FUEL SUPPLY	Production/exctraction of fuels		0.0	0.0	0.0	0.00		0.0	0.0	0.0	0.00		0.0	0.0	0.0	0.00
	Combustion of fuels	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.00
	Transport of fuels to the pellet plant		0.0	0.0	0.0	0.00		0.0	0.0	0.0	0.00		0.0	0.0	0.0	0.00
	Net electricity consumption	0.02	0.1	0.6	0.0	0.13	0.02	0.1	0.6	0.0	0.13	0.02	0.1	0.6	0.0	0.13
	Internal transports etc.(diesel)		0.1	0.0	0.0	0.11		0.1	0.0	0.0	0.11		0.1	0.0	0.0	0.11
END USE EMISSIONS	Transport and distribution of pellets to consumers		0.4	0.1	0.0	0.45		0.4	0.1	0.0	0.45		0.4	0.1	0.0	0.45
	Use in large scale heating plant (~100MW)		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18		0.0	0.0	0.0	0.00
TOTAL	End use - large scale heating plant		3.3	2.1	1.2	3.74		1.1	0.7	0.7	1.27		3.3	1.6	0.1	3.41
	Excl. end use emissions		3.3	2.0	0.6	3.57		1.1	0.7	0.1	1.09		3.3	1.6	0.1	3.41
	Excl. distribution of pellets and end use emissions		2.9	2.0	0.6	3.12		0.6	0.7	0.0	0.64		2.9	1.5	0.1	2.97

Table 23 Alternative calculations for pellets from roundwood chips, where i) climate impact from saw mill residues = 0 and ii) biomass combustion emissions = 0.

		3. Pellet plant using wet raw material (roundwood chips)														
		Main case					**By-products from saw mill = 0 climate impact**					**Emissions from combustion of biomass = 0**				
	Emissions per MJ pellets	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**	**MJ**	**g CO_2**	**mg CH_4**	**mg N_2O**	**g CO_{2eq}**
RAW MATERIAL SUPPLY	Total raw material input	0.88					0.88					0.88				
	Production/extraction of raw materials		1.5	2.0	0.1	1.56		1.5	2.0	0.1	1.56		1.5	2.0	0.1	1.56
	Transport of raw materials to the pellet plant		0.3	0.0	0.0	0.25		0.3	0.0	0.0	0.25		0.3	0.0	0.0	0.25
PROCESSING AND FUEL SUPPLY	Production/exctraction of fuels		0.1	0.0	0.0	0.11		0.0	0.0	0.0	0.01		0.1	0.0	0.0	0.11
	Combustion of fuels	0.20	0.0	1.0	1.0	0.31	0.20	0.0	1.0	1.0	0.31	0.20	0.0	0.0	0.0	0.00
	Transport of fuels to the pellet plant		0.0	0.0	0.0	0.02		0.0	0.0	0.0	0.02		0.0	0.0	0.0	0.02
	Net electricity consumption	0.07	0.4	2.1	0.1	0.46	0.07	0.4	2.1	0.1	0.46	0.07	0.4	2.1	0.1	0.46
	Internal transports etc.(diesel)		0.2	0.0	0.0	0.25		0.2	0.0	0.0	0.25		0.2	0.0	0.0	0.25
END USE EMISSIONS	Transport and distribution of pellets to consumers		0.4	0.0	0.0	0.45		0.4	0.0	0.0	0.45		0.4	0.0	0.0	0.45
	Use in large scale heating plant (~100MW)		0.0	0.0	0.6	0.18		0.0	0.0	0.6	0.18		0.0	0.0	0.0	0.00
TOTAL	End use - large scale heating plant		3.0	5.2	1.7	3.60		2.9	5.2	1.7	3.50		3.0	4.2	0.1	3.11
	Excl. end use emissions		3.0	5.2	1.1	3.43		2.9	5.1	1.1	3.32		3.0	4.2	0.1	3.11
	Excl. distribution of pellets and end use emissions		2.5	5.1	1.1	2.98		2.4	5.1	1.1	2.88		2.5	4.1	0.1	2.66

Appendix 3 Calculations of emissions from saw mill residues

Pellets is mostly produced from by-products from saw mills. This section presents calculations of emissions from a Swedish saw mill (Gruvön Sågverk). All products and by-products (sawn wood, raw sawdust/chips, cutterdust/dry chips and bark) are here considered as co-products. The saw mill process was divided into different stages based on data from the Environmental report 2008 (only total numbers presented here). Accumulated emissions up to the stage where a co-product is generated are divided between the co-product and the intermediate product based on their energy content, in accordance with the calculation rules in RED. The intermediate product continues to the next process stage where a co-product 2 is generated. The fraction of the emissions from stage 1 that have been allocated to intermediate product 1 plus new generated emissions in stage 2 are then divided between co-product 2 and intermediate product 2, and so on. Emissions from production and transport of timber to the saw mill as well as more general emissions such as emissions from pumps, lightning, comfort heating etc. have been allocated to all products at the end of the calculations (based on their energy content). This allocation method is explained in Figure 6 in Appendix 4.

The total energy and material flows of the Gruvön saw mill are shown in Table 24. Heat for the drying shed is in Gruvön supplied from waste heat from an adjacent pulp and paper mill together with peak heat from oil. In these calculations the heat is assumed to be produced from biomass (tops and branches) since this is assumed to be more common in Swedish saw mills. However, substituting the waste heat and oil by combustion of tops and branches practically gives the same result (see Table 27).

Table 24 Total energy and material flows in Gruvön saw mill (calculated from the Environmental Report of Gruvön saw mill 2008). Two options of heat supply are given: the actual with waste heat (and small amount of oil) and a fictive with combustion of tops and branches.

	Amount		**Conversion factors**	
	[m3]	**[GWh]**	**[ton DS/m3]**	**[GJ/ton DS]**
Input, timber [m3sub]	739 540			
Output, products:				
Sawn wood	371 060	865	0.44	19.2
Raw sawdust/raw chips	299 766	655	0.41	19.2
Bark	71 465	122	0.32	19.2
Dry chips/cutter dust/cutter shavings	39 467	84	0.40	19.2
Total electricity consumption		21.1		
Diesel consumption for internal transports		6,2		
Total heat consumption in saw mill		86.7		
Heat is produced by:				
Actual case: Waste heat and small oil boiler				
Steam/hot water (waste heat), input		84.1		
Fuel oil, total input		3.3		
Assumed in the calculations: Biomass boiler				
Tops and branches, total input		96.3		

The energy content of the different products were estimated from assumptions of typical moisture content (see Table 3) and typical dry density and heating value per mass unit dry substance (given in Table 24). Emission factors for fuels and electricity (incl. emissions from production, distribution and combustion) and for saw timber (incl. production and transport to saw mill) used in the calculations are shown in Table 25. The total energy consumption of the saw mill allocated to the different products according to the method described above is presented in Table 26 and the resulting total emissions associated with each product are shown in Table 27.

Table 25 Emission factors for fuels, electricity and raw material supply used for the saw mill calculations.

[mg/MJ]	Emissions factors from production, distribution & combustion				
	CO_2	N_2O	CH_4	CO_{2eq}	Source
Saw timber (excl. combustion)				1 513	Berg et al. (in press)
Tops and branches	2 175	5	8	3 856	Uppenberg et al. (2001) & Berg et al. (in press)
Oil	81 900	1	4	82 151	Uppenberg et al. (2001)
Diesel	76 500	3	8	77 572	Uppenberg et al. (2001)
Swedish electricity mix	5 409	1	28	6 299	Calc. from Uppenberg et al. (2001)

Table 26 Allocated energy consumption per product in the saw mill.

Energy consumption in saw mill allocated to products	Electricity [MJ/MJ]	Heat [MJ/MJ]	Diesel [MJ/MJ]
Bark	0.005	0.002	0.002
Raw sawdust/raw chips	0.006	0.002	0.002
Dry chips/cutter dust/cutter shavings	0.018	0.090	0.011
Sawn wood	0.017	0.090	0.005

Table 27 Resulting total greenhouse gas emissions for saw mill products for two different heat supply options. The emissions according to Case 2 (heat is produced from combustion of tops and branches) are used in the calculations for the pellet chains.

[mg/MJ]	Total emissions per product (incl. emissions from timber supply)							
	Case 1: Heat from waste heat[1]				*Case 2: Heat from combustion of tops and braches*			
	CO_2	CH_4	N_2O	CO_{2eq}	CO_2	CH_4	N_2O	CO_{2eq}
Bark	1390	0.17	0.01	1396	1389	0.18	0.02	1399
Raw sawdust/raw chips	1395	0.19	0.01	1402	1394	0.21	0.02	1405
Dry chips/cutterdust	2441	0.62	0.05	2470	2381	1.39	0.55	2576
Sawn wood	1955	0.53	0.03	1976	1895	1.30	0.53	2083

[1] Inclusive small amount of peak oil combustion

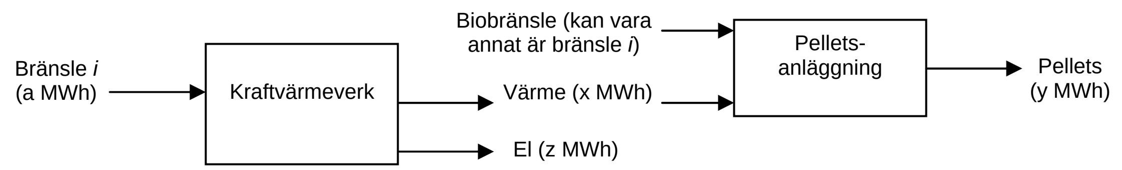
Emissions associated with the use of chemicals or other products in the saw mill are estimated to be very small compared to other emissions and are therefore not included. Emissions from management of ashes and other waste flows are also estimated to be negligible.

Appendix 4 Tolkning av §16-18 i RED

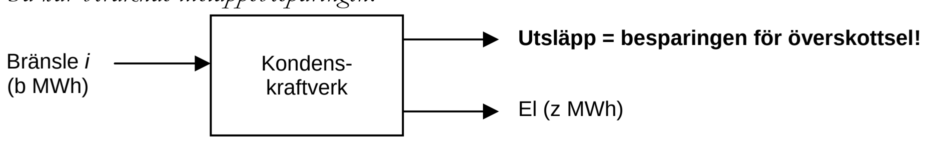
Den svenska texten i §16 i RED (Bilaga V, Del C) är svår att tyda. Vi har kommit fram till följande tolkning:

- Emissionsbesparingar från ”excess electricity” (överskottsel) ska beräknas om pelletsen är producerad med värme från en kraftvärmeprocess.
- Bränslet till kraftvärmeprocessen får inte vara en ”samprodukt” som bildas vid pelletstillverkningen.
    - Pelletssmul är alltså inte OK som bränsle för att överskottselen skall beaktas. Tolkningen ger dock ett märkligt budskap – att ett bra utnyttjande av samprodukter från processen missgynnas.
- Texten om att skörderester från jordbruket undantas är inte relevant i något av de fall som vi studerar (skörderester från jordbruket ingår ju inte i vårt projekt)
- Se även figur nedan: Emissionsbesparingen från överskottsel ska beräknas utifrån hur stort utsläppet hade varit om motsvarande mängd el som produceras i kraftvärmeverket (med ett bränsle i) tack vare att en viss mängd värme (x) behövs för pelletsproduktionen, istället hade producerats med samma bränsle (bränsle i) i ett kondenskraftverk. Det innebär att överskottselen krediteras pga att pelletsproduktionen ger ett utökat värmeunderlag (klassiskt exempel på ”undvikta emissioner”).

Så här produceras den pellets för vilken utsläppsbesparing från överskottsel ska beräknas:



Så här beräknas utsläppsbesparingen:

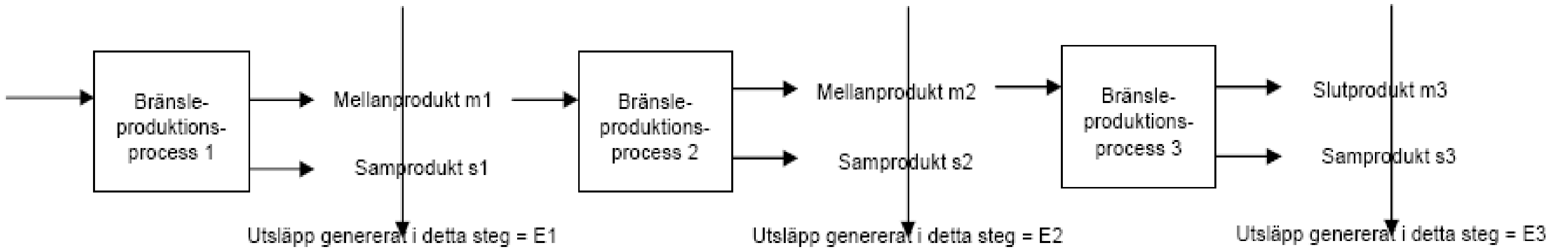


Den engelska versionen av RED är något annorlunda, eller åtminstone vagare: där kan det tolkas som att alla samprodukter utom jordbruksrester undantas. Det gör stor skillnad eftersom många bränslen är samprodukter (från oljeraffinaderier, skogsbruk, etc.).

Den svenska texten i §17-18 i RED (Bilaga V, Del C) är hopplös att förstå utan den engelska versionen som vägledning. Vår tolkning (främst baserad på den engelska versionen):

- Tänkbara samprodukter vid pelletstillverkning borde kunna vara:
    - pelletssmul (hur allokeras emissioner till detta smul annars) eftersom det får anses ha en användning
    - el (t.ex. Hedensbynexemplet med turbin efter torkningssteget)
    - bark mm.
    - Fjärrvärme verkar i den nuvarande skrivningen inte kunna anses vara en samprodukt, då den saknar lägre värmevärde

Tolkning av hur allokering av emissioner skall gå till framgår av Figure 6 på nästa sida:



Följande beteckningar används nedan för tolkningen:

E_i = Utsläpp för steg $i = e_{ec} + e_l + e_p + e_{td} - e_{ee}$

E_{xx} = Utsläpp som ska allokeras till mellanprodukt eller samprodukt xx

Y_{xx} = Energimängd för samprodukt eller mellanprodukt xx baserat på det lägre värmevärdet

Såhär tolkar vi det hela för steg 1:

$$E_{m1} = E_1 * \frac{Y_{m1}}{Y_{m1} + Y_{s1}}$$

$$E_{s1} = E_1 - E_{m1}$$

Såhär tolkar vi det för steg 2 och framåt (exempel för steg 2):

$$E_{m2} = (E_2 + E_{m1}) * \frac{Y_{m2}}{Y_{m2} + Y_{s2}}$$

$$E_{s1} = (E_2 + E_{m1}) - E_{m2}$$

Observera att det alltså att förutom nya genererade utsläpp från det specifika steget (steg 2 i detta fall) också ska allokeras den emissionsfraktion som kvarstår från steg 1 (dvs. E_{m1}). Dessa båda ska fördelas mellan mellamprodukt *m2* och samprodukt *s2* (rätt självklart egentligen)

Figure 6 Tolkning av RED (§17-18), allokering mellan produkter