MODEL FOR CALCULATION OF KEY ENERGY PERFORMANCE INDICATORS FOR PULP AND PAPER MILLS

Integrated mechanical pulp and paper mill (TMP, CTMP, groundwood pulp)

The same calculation procedure is used for the production of TMP, CTMP and groundwood pulp since the energy flows are, in principle, the same. The key performance indicators calculated by the model can, however, only be used for comparison between mills producing the same type of mechanical pulp.

Reading instructions - how to use the calculation model.

The calculation model consists of three parts

• General description, see separate PM
• This PM, which includes descriptions of how the model is structured for this specific type of mill, together with the equations used for the calculations
• Calculation sheet in Excel where the input data is entered, and the calculations are made.

In principle, it is possible to go directly to the Excel file, enter input data and obtain calculated values for the key energy performance indicators. However, we recommend that you read Chapter 2 of this PM first, which explains the assumptions behind the calculations, and provides guidelines for data collection and interpretation of results. When providing input data to the Excel file, the definitions of input parameters stated in the introduction to Sections 3.1 – 3.5 of this PM can provide further guidance on how to interpret the different input parameters.

However, it is not necessary to go through all the equations found in this PM before you start using the calculation sheet. An alternative way of following the calculations is to trace formulas directly in Excel (‘Formula Auditing’ => ‘Trace Precedents’ or ‘Trace Dependents’).

A graphical overview of the calculations is available in the Appendix of this PM.

Contents

1. Flowchart

Figure 1 shows a flowchart for an integrated mechanical pulp and paper mill. The main and typical process units are included. The purpose of the flowchart is to illustrate the main energy flows included in the calculation model.

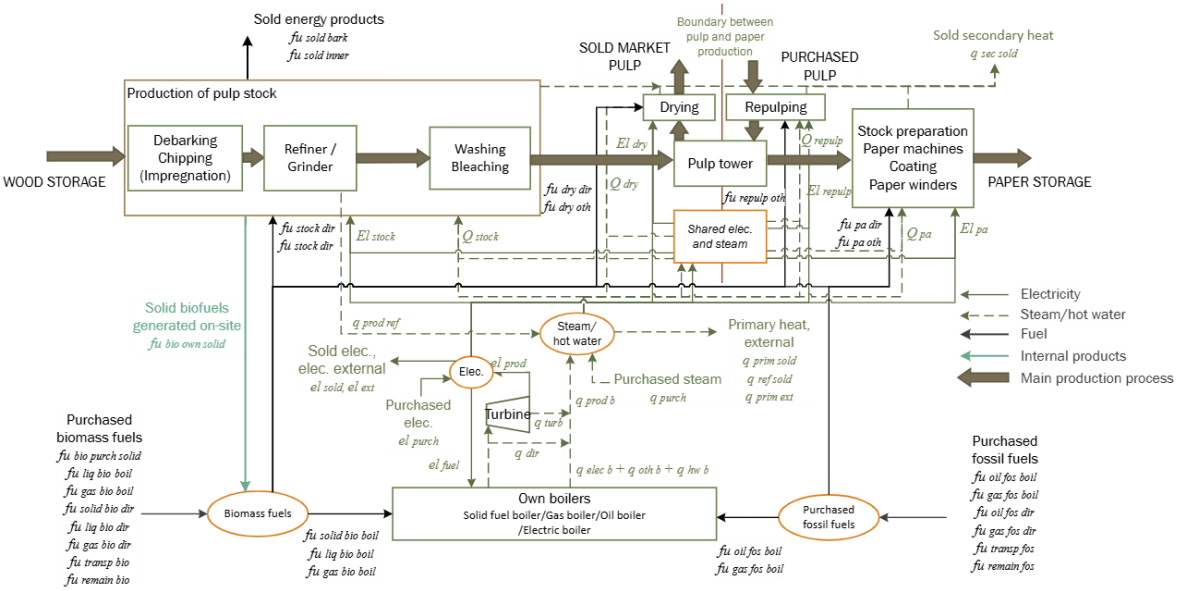


Figure 1. General flowchart for an integrated mechanical pulp and paper mill. (see Appendix for the same figure in a larger format)

2. Description of the calculation model

This PM describes the calculation of key performance indicators (KPIs) for energy consumption related to the production of mechanical pulp (TMP, CTMP or groundwood pulp) and paper/cardboard at an integrated mill (note: for simplicity, only the term "paper" is used in the formulas, which includes all surface weights, i.e. also "cardboard"). The produced volume refers to all salable products, and follows the definition of Net Production in the BREF document, i.e., for paper production the system boundaries are drawn *before* potential downstream converting.

Since there are almost always notable differences between specific integrated mills, e.g. with regards to how much pulp is purchased or sold, it is rarely possible to compare one integrated mill to another integrated mill in terms of overall energy use. For this reason, the calculation is divided into energy use for pulp production and energy use for paper production, respectively. The boundary between pulp and paper production is set at the pulp tower. If, on the other hand, it is of interest to follow a specific mill over time, the pulp and paper production does not need to be separated. However, this assumes that the proportion of purchased pulp and sold pulp is unchanged over time.

For integrated mills, it is not possible to separate the energy use for pulp production from that of paper production directly based on the total purchased, produced and delivered quantities of electricity, heat and fuel. The calculation must instead be based on measurements of how much electricity or steam is consumed in different parts of the production.

For some integrated mills, part of the pulp is also sold as market pulp while for some mills, additional pulp may be imported from other mills.

- For the production of market pulp, the energy consumed for *Drying* should be reported separately. Here, this is defined to include all energy used for the entire process from pulp stock to market pulp ready for delivery, and thereby includes also, e.g., baling and other post-treatment.
- For purchased pulp, the energy consumed for *Repulping* should be reported separately. Here, this is defined to include all energy used for slushing and defibration from the point where the pulp arrives at the mill until it is mixed with the pulp stock produced on-site.

2.1. Metadata to guide the interpretation of results

The purpose of the calculation model is to ensure that consumption values and KPIs calculated for different mills or for different time periods are based on the same definitions and system boundaries so that they can be compared. However, the model does not consider differences in pulp and paper quality or other production conditions. To draw conclusions regarding the energy efficiency of a certain mill, other information is also required. Such information can be provided in a special section in the calculation tool Excel file. These data are consequently not used for the actual calculations but is an important supplement when interpreting the results. The metadata does not necessarily capture all relevant information but can provide an overview of the most important factors.

In addition to differences in feedstock and products, the Meta Data section can preferably also be used to describe how input data is generated (e.g. continuous measurements or estimations based on common operating conditions and limited measurements, see also Section 2.2 below). In Meta Data, it should also be noted if there are other conditions that affect the energy consumption, e.g. flexible operation.

2.2. General notes regarding input data

The formulas for the KPIs include a number of parameters representing key information about different parts of the energy system. The parameters are defined to make it clear which flows should be included for the calculation of the KPIs. Note, however, that it is not necessarily required to provide measurement data for all individual parameters. Wisely assumed/calculated values based on modelling and campaign measurements can suffice if continuous measurements are lacking for some energy flows. In the model, some parameter values are summed to calculate a total flow, which in turn is the value used in the formula for the KPI. If you measure the total flow, the values of the individual parameters are not needed. The model will provide the same end result, although the calculation sheet will contain less detailed information about the background to the measured value.

For example, steam that has been expanded in a back pressure turbine as well as steam that has been expanded through a pressure reduction valve are both included in the KPI for heat consumption, and consequently it is not necessary to have measurement values for each of the steam flows if there is a measurement available of the total steam flow to the process.

However, it may be that some of the data included in a summation is also included in another calculation, in which case it would still be needed. To check this, you can use the Excel command ‘Formula Auditing => Trace Dependents’, to see where the data in a certain cell is used.

Some specific comments:

- All input data is given on an annual basis and the calculated KPIs therefore apply to the current year. Which year is referred to is specified in the metadata section of the Excel file.
- Input data for consumption of electricity, heat and fuel are given with an accuracy of at least full integers, and in the unit TJ. KPIs are calculated with two decimal places.
- In the Excel file, a number of control values are calculated, which should be zero. This is to check the consistency of entered input data.
- Depending on where the measurements are located, total electricity, heat, and fuel flows can be determined in different ways. For example, the total heat production can be obtained by summing the heat production in all boilers or, alternatively, if there is a measurement for the total heat flow from the boilers, this can be entered directly. However, it is important to document how the input data has been determined.
- The turbine in the flow chart represents all back pressure and condensing turbines in the mill. Note in the metadata which type of turbines are used.
- Energy used for side processes that are common for mechanical pulp and paper mills should be included. This also applies if the side processes are owned and operated by another company (outsourced), e.g. production of coating agents, oxygen or syngas for drying of paper.
- However, energy used for processes outside the system boundaries of the defined, conventional pulp/paper production should not be included. This is the case, for example, for energy used for potential downstream converting of paper/cardboard products. Such energy consumption is provided separately and is deducted from the total energy supply, when the consumption of heat, electricity and fuel used for the pulp and paper production is calculated in the model.
- For a combined pulp and sawmill site with shared wood handling, only the share of energy use that relates to the wood consumption at the pulp mill should be included in the model.

2.3. Internal energy flows

Internally circulating energy flows (i.e., flows that are generated and used within the same part of the process) are not normally considered in the definition of the energy KPIs. In particular, this principle should be noted for:

- Steam for soot blowing – this is a circulating energy flow (generated and used within the boiler system) and should therefore not be included in the reported steam production from each boiler. If steam production is measured before the extraction of soot blowing steam, soot blowing steam should be subtracted from the total steam flow. Otherwise, if steam production is measured downstream the soot blowing steam extraction, no adjustment is needed.

Secondary heat recovery also follows the same principle that energy flows within the same process section should not be included in the KPIs. For more details on how this is handled in the model, see Section 2.6 'Recovery of secondary heat'.

Whether falling bark and other biofuels generated in the wood handling plant are considered as internal flows depends on the applied system boundary. See Section 2.7 'Fuel consumption' for further explanations.

Steam generated through heat recovery from refiners is indeed part of an internal energy recovery system that involves conversion between different forms of energy (electricity and

heat). However, if only considering the consumption of heat, the energy of the refiner steam is not circulated and, consequently, the total heat consumption includes all primary heat, including refiner steam. Nevertheless, KPIs for heat consumption are calculated both including and excluding refiner steam, see also Section 2.4 Heat.

2.4. Heat

For primary heat production, the energy flow is specified based on steam flow and enthalpy difference between the steam supply and boiler feed water. Note that for steam passing through a back-pressure turbine, the steam supply to the process should be specified based on the steam flow properties after the turbine.

Heat consumption is determined based on the enthalpy difference between supply steam and return condensate. For consumers without condensate return, the calculation is made based on the enthalpy of make-up water independently of the enthalpy of outgoing condensate. In this way, the heat loss caused by condensate loss is also included in the consumption.

The equations in the figure below illustrate how the energy flows (Q) of produced and consumed steam should be determined based on mass flows (m) and enthalpies (h).

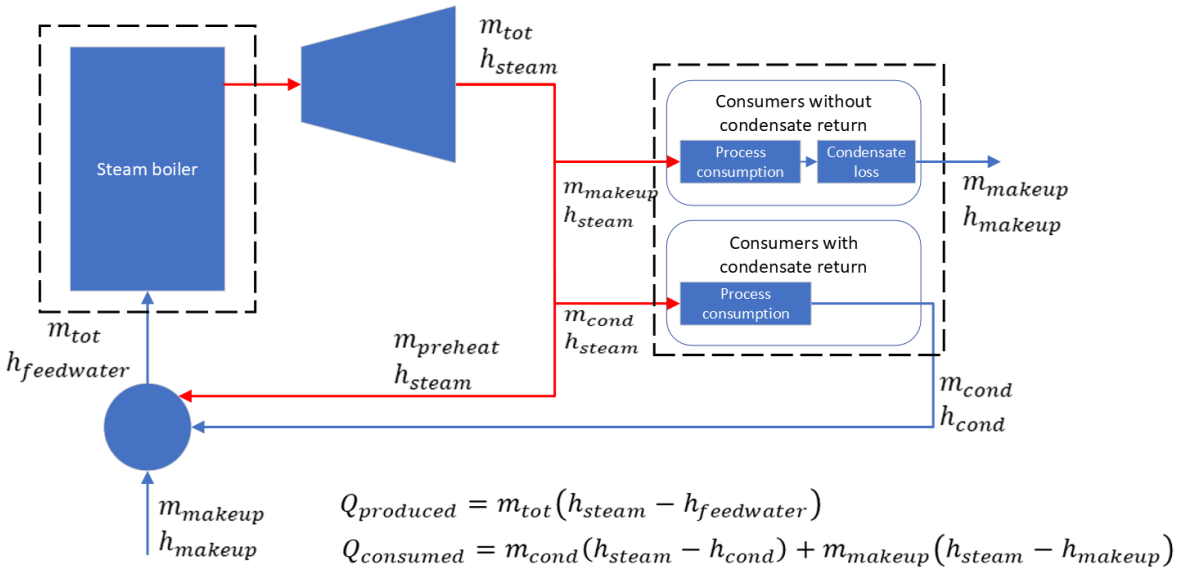


Figure 2. Scheme for determining and calculating heat flows

Furthermore, the following should be noted regarding heat consumption:

- Venting of steam occurs due to the difficulties of balancing steam production with steam consumption. This could be seen as a loss from the boiler system, and therefore considered as a reduction in boiler efficiency, but we chose to include the loss in the process heat consumption. In this way, improvements in steam control will be shown in the KPI as a lower heat consumption.
- Preheating of combustion air with flue gases leads to higher boiler efficiency. The recovery of heat from the flue gases will be accounted for as a reduction in the KPI for fuel consumption.
- Primary heat (steam and hot water) and secondary heat (hot water) delivered to external users are subtracted from the measured heat consumption. This also applies to heat that is used for own processes but which are outside the system boundaries for the pulp/paper production, e.g., converting of paper and cardboard.

- Differences in steam pressure are not taken into account in the calculations, but please note the steam pressures used in different process sections in the metadata.
- Total heat consumption includes steam that has been generated through heat recovery from refiners and used at the mill. However, in input data, refiner steam is separated from other heat production and KPIs are calculated both including and excluding refiner steam.
- The model includes a balance term that captures any potential difference between the specified production and consumption of primary heat ($q_{bal} = Q_{prod} - Q_{consumed}$). The balance error may, e.g., be due to losses or measurement uncertainties. A positive balance term implies that the reported production is greater than the reported consumption, and vice versa. Note that the KPIs for total heat consumption are always based on the specified heat production. The consumption values are used to distribute the heat consumption between different process sections, see Section 2.5.
- The balance term in the primary heat balance is affected particularly by potential preheating of make-up water and/or condensate using process excess heat (secondary heat). This means that less primary heat is needed for condensate and make-up water preheating. With reference to the notation in the figure above, this leads to a lower value for $m_{preheating}$ and thus also for m_{tot} (because the preheated condensate is returned at a higher enthalpy than $h_{condensate}$, which leads to a lower value for Q_{prod}. Since the consumption is determined in the same way independently of process heat recovery for condensate preheating (i.e. $Q_{consumed}$ is not affected), the balance term will be lower and may in some cases become negative.
- The calculation model includes a parameter for steam used to produce electricity in a condensing turbine. This steam use is not included in the KPIs for heat consumption, but it is needed when calculating the KPIs for fuel consumption, see Section 2.7 'Fuel consumption'. The energy flow of steam to the turbine must be determined based on the flow of turbine condensate and the enthalpy difference between turbine inlet steam and turbine condensate. Here, inlet steam refers to steam entering the first of the turbine stages passed by the steam flowing through the condensing stage. Steam used to heat the condensate return must be included in the steam consumption for the condensing turbine.

2.5. Allocation of electricity and heat used in site-wide support systems and electricity for heat production

For both electricity and heat, there are parameters for measured consumption that is not specifically linked to any of the processes. This input parameter is primarily intended for shared utilities and support functions such as raw water supply, wastewater treatment, office heating or maintenance workshops. However, measured process consumption for which there is a lack of data to determine which part of the process the energy use should be attributed to can also be included in this parameter.

Energy balances are formulated in the calculation model for both electricity and heat. Any deviation between total consumption and total production and trade is added to a balance term.

Site consumption not attributed to any individual process section plus the balance term should then be allocated to the different process sections, i.e. to pulp production, repulping of purchased pulp, drying of market pulp, or paper production.

If possible, the allocation of the shared consumption should be made in a way that reflects the use of the shared functions and utilities by the different processes. For example, the electricity

consumption for wastewater treatment could be allocated between the pulp mill and the paper mill based on their shares of the generated amount of organic matter (COD or TOC). Any residual shared consumption that cannot be clearly attributed to a specific process section is allocated by the calculation model in proportion to the electricity or heat consumption directly measured for the process section. Refer to the detailed formulas in the calculation sections below for further details.

Electricity used for heat production is distributed in proportion to the heat consumption in the respective process sections.

Alternatively, special KPIs for electricity are calculated where electricity used for heat production in electric boilers is excluded.

2.6. Recovery of secondary heat

Heat consumption refers to the consumption of primary heat in the form of steam or hot water from boilers and refiners or purchased heat from an external supplier. Besides steam that has been generated in refiners, it could be possible to recover heat from other parts of the process in the form of warm or hot water (secondary heat) to be used, e.g., for preheating in other parts of the process.

If the secondary heat is generated and used within a single process section (e.g. within the pulp drying section), it is considered an internal circulating flow and should not affect the calculation of KPIs for heat consumption. If, on the other hand, the net flow of secondary heat goes from one process section to another, it should, in principle, be counted as a negative contribution for the process section from which the secondary heat is delivered and as a positive contribution for the process section where the secondary heat is used. If, e.g., secondary heat is delivered from the pulping process to the drying process, it should be deducted from the heat consumption of the pulping process (reduced heat consumption) and added to that of the drying process (increased heat consumption).

In a pulp and paper mill, however, it can be difficult to determine the net flows of secondary heat between different parts of the process. In the calculation sheet, it is therefore possible to specify the (total) use of secondary heat for different process sections and for external deliveries (e.g. district heating) without specifying where the heat comes from. To attempt obtaining correct energy balances, one should then also estimate how the secondary heat production is distributed over the different process sections. If it is not possible to specify the production of secondary heat completely, the difference is added to a balance term which is allocated among the process sections in the same way as other shared heat consumption. This procedure makes it possible to consider significant secondary heat flows in the calculation model without requiring complete data for the heat recovery system at the mill.

It should be noted that the balance term for secondary heat is not a control sum. Most likely there will be a significant lack of data for some parts of the secondary heating system. The balance term enables a direct redistribution of heat consumption between different process sections based on known secondary heat flows while maintaining total heat balances. It is therefore not necessary to set up a total balance, but the ambition should be to capture the major secondary heat flows.

Even if more secondary heat is collected than what is actually used in the mill, e.g. if warm and hot water tanks overflow and go to the drain, the total heat consumption will not be affected. Instead, the heat loss from not being able to utilize the heat will be allocated as an increase in net heat consumption across all parts of the process (while the generation of the

secondary heat leads to a reduction of the net heat consumption specifically for the process section where the heat is generated).

2.7. Fuel consumption

Fuel consumption is based on fuel purchased for or sold from the mill, as well as internal fuels generated in the wood handling plant (e.g. falling bark).

Deductions are made for fuel used to produce primary heat that goes to external consumers or condensing power production.

Regarding the use of bark and other solid biofuels generated during wood handling, the calculation includes two cases defined by different system boundaries.

- Inner system boundary: The wood yard, debarking and chipping plant are considered to be outside the system boundaries. In this case, the bark combusted in the mill's own boiler is counted as fuel consumption for the pulp mill, regardless of whether it is generated at the site or purchased externally.
- Outer system boundary: The wood yard, debarking and chipping plant are considered to be inside the system boundaries. Consequently, the bark generated there is considered an internal flow.

The first case (inner system boundary) is the main option and the one used when calculating KPIs for fuel consumption, see *Appendix – Balance for solid biofuels*.

Also note that:

- No deduction is made for fuel used for drying of bark that is sold to the market. Instead, the mill is credited by a greater deduction from the bark sales in the KPIs for fuel use because the heating value of the bark will be higher.
- Fuel used for heat production in boilers is distributed proportionally to the heat consumption of a process section. For example, if 60% of the heat goes to pulp production, 60% of the fuel used for heat production will be allocated to pulp production.
- The calculations include fuels used for the production of steam, hot water, electricity, direct heat, or as fuel in:
    - Solid fuel boiler
    - Oil boiler
    - Natural gas boiler
    - Other boilers
    - Direct heating processes
    - Internal vehicles
- If the mill is integrated with a sawmill and they share the wood handling plant, the wood consumption of the sawmill and the pulp mill is used to distribute bark flows between the sawmill and the pulp/paper mill. More specifically, the amount of self-generated and sold bark to be credited to the pulp mill is determined in proportion to the share of the wood consumption.

The main KPIs for fuel consumption include fuel consumed for all types of purposes. As a complement, an alternative KPI is also calculated that only includes fuel consumed for direct heating, for vehicles, or for other purposes than heat production. Consequently, this KPI excludes the fuel used for the production of steam or hot water.

3. Calculation procedure for Key Performance Indicators (KPIs)

3.1. Production

Pu_{stock}	=	production of av pulp stock (including pulp stock dried to market pulp)	ADt (90 % DS)	P1
Pu_{market}	=	sold market pulp	ADt (90 % DS)	P2
Pu_{purch}	=	purchased pulp	ADt (90 % DS)	P3
Pa_{tot}	=	production of paper and board (salable product, before potential converting)	ton (92 % DM)	P4

Final prod	=	$Pu_{market} + Pa_{tot}$	ton	P5

Comment: According to industry practice, ADt (Air-Dried tons, 90% Dry Solids) is used for pulp while 92% Dry Matter is used for paper. For the total end product, market pulp and paper are added to "tons".

3.2. Electricity consumption

For a graphical overview over the calculation procedure, see *Appendix – Allocation of electricity consumption*.

3.2.1. Input data

el_{purch} = electricity, purchased (electricity from own power production outside the mill's system boundary, e.g. wind and solar power, is also counted as purchased electricity)

$el_{prod\ bpt}$ = electricity produced as back-pressure power in turbines at the mill [1)]

$el_{prod\ ct}$ = electricity produced as condensing power in turbines at the mill [2)]

el_{sold} = electricity sold to the grid

el_{ext} = electricity used for own processes outside the system boundaries of conventional pulp/paper production (e.g. for paper converting)

$el_{stock\ meas}$ = measured electricity consumption for *pulp stock production*

$el_{dry\ meas}$ = measured electricity consumption for *drying of pulp stock to market pulp* and subsequent handling

$el_{repulp\ meas}$ = measured electricity consumption for *repulping of purchased pulp*

$el_{pa\ meas}$ = measured electricity consumption for the *actual paper production*

$el_{site\ meas}$ = measured electricity consumption for *shared site functions*, i.e. electricity used for e.g. water treatment, offices, maintenance workshops and not used in electric boilers for heat production

el_{fuel} = electricity consumption for the production of heat in electric boilers and electricity for other boiler operation (use of electricity as "fuel")

$el_{shared\ attr\ stock}$ = part of shared electricity consumption (incl. total balance term) that can be attributed to *the production of pulp stock* based on reasonable assumptions and estimates [3)]

$el_{shared\ attr\ dry}$ = part of shared electricity consumption (incl. total balance term) that can be attributed to *the drying of pulp stock to market pulp* based on reasonable assumptions and estimates [3)]

$el_{shared\ attr\ repulp}$ =part of shared electricity consumption (incl. total balance term) that can be attributed to *the repulping of purchased pulp* based on reasonable assumptions and estimates [3)]

$el_{shared\ attr\ pa}$ = part of shared electricity consumption (incl. total balance term) that can be attributed to *the actual paper production* based on reasonable assumptions and estimates [3)]

1) *If some of the steam flow from the back-pressure turbine is passed to a condensing tail, the electricity production corresponding to that proportion of steam must not be included in the back-pressure parameter value but in the parameter for condensing power production.*

2) *This parameter must include all electricity produced from the steam flow that ultimately passes through a condensing stage, including electricity produced in previous turbine stages or a separate back-pressure turbine.*

3) *The distribution may, e.g., be based on own model calculations or allocation based on mass flows or similar. The residual consumption, which cannot be attributed to any specific process section will be allocated by the model proportionally to the directly measured electricity consumption in each process section. Please refer to Equations E6-E10 below, and to Section 2.5 above.*

3.2.2. Calculations

$El_{tot\ supply}$ = Total electricity consumption in the pulp and paper mill calculated from production and trade (supply side)

$El_{tot\ supply}$	=	$el_{purch} + el_{prod\ bpt +} el_{prod\ ct} - el_{sold} - el_{ext}$	TJ	E1

$el_{proc\ meas}$ = total electricity consumption measured specifically for the different process sections

$el_{proc\ meas}$	=	$el_{stock\ meas} + el_{dry\ meas} + el_{repulp\ meas} + el_{pa\ meas}$	TJ	E2

$El_{tot\ meas}$ = Total measured consumption of electricity in the pulp and paper mill

$El_{tot\ meas}$	=	$el_{proc\ meas} + el_{site\ meas} + el_{fuel}$	TJ	E3

el_{bal} = balance term for electricity, deviation between supply and measured use (e.g. includes losses, unmeasured consumption, measurement errors, etc.)

el_{bal}	=	$El_{tot\ supply} - El_{tot\ meas}$	TJ	E4

el_{shared} = electricity consumed for shared site functions or included in the total balance term

el_{shared}	=	$el_{site\ meas} + el_{bal}$	TJ	E5

Allocation of el $_{shared}$

$el_{shared\ res}$	=	$el_{shared} - el_{shared\ attr\ stock} - el_{shared\ attr\ dry} - el_{shared\ attr\ repulp} - el_{shared\ attr\ pa}$	TJ	E6
$el_{stock\ shared}$	=	$el_{shared\ attr\ stock} + el_{shared\ res} * el_{stock\ meas} / el_{proc\ meas}$	TJ	E7
$el_{dry\ shared}$	=	$el_{shared\ attr\ dry} + el_{shared\ res} * el_{dry\ meas} / el_{proc\ meas}$	TJ	E8
$el_{repulp\ shared}$	=	$el_{shared\ attr\ repulp} + el_{shared\ res} * el_{repulp\ meas} / el_{proc\ meas}$	TJ	E9
$el_{pa\ shared}$	=	$el_{shared\ attr\ pa} + el_{shared\ res} * el_{pa\ meas} / el_{proc\ meas}$	TJ	E10

$el_{shared\ res}$ = residual shared electricity consumption that cannot be clearly allocated to specific process sections

$el_{stock\ shared}$ = shared electricity consumption that has been attributed or allocated to *the production of pulp stock*

$el_{dry\ shared}$ = shared electricity consumption that has been attributed or allocated to *the drying of pulp stock to market pulp*

$el_{repulp\ shared}$ = shared electricity consumption that has been attributed or allocated to *the repulping of purchased pulp*

$el_{pa\ shared}$ = shared electricity consumption that has been attributed or allocated to *the actual paper production*

Allocation of el $_{fuel}$

The allocation is based on the heat consumption (Q) in each process section. Definitions and calculations of Q are given in Section 3.3.

$el_{stock\ fuel}$	=	$el_{fuel} * Q_{stock} / Q_{tot\ net}$	TJ	E11
$el_{dry\ fuel}$	=	$el_{fuel} * Q_{dry} / Q_{tot\ net}$	TJ	E12
$el_{repulp\ fuel}$	=	$el_{fuel} * Q_{repulp} / Q_{tot\ net}$	TJ	E13
$el_{pa\ fuel}$	=	$el_{fuel} * Q_{pa} / Q_{tot\ net}$	TJ	E14

$el_{stock\ fuel}$ = electricity used for heat production allocated to the *production of pulp stock*

$el_{dry\ fuel}$ = electricity used for heat production allocated to the *drying of pulp stock to market pulp*

$el_{repulp\ fuel}$ = electricity used for heat production allocated to the *repulping of purchased pulp*

$el_{pa\ fuel}$ = electricity used for heat production allocated to the *actual paper production*

El $_{stock}$ = Consumption of electricity for production of pulp stock

El_{stock}	=	$el_{stock\ meas} + el_{stock\ shared} + el_{stock\ fuel}$	TJ	E15

El $_{dry}$ = Consumption of electricity for drying of pulp stock to market pulp

El_{dry}	=	$el_{dry\ meas} + el_{dry\ shared} + el_{dry\ fuel}$	TJ	E16

El $_{repulp}$ = Consumption of electricity for repulping of purchased pulp

El_{repulp}	=	$el_{repulp\ meas} + el_{repulp\ shared} + el_{repulp\ fuel}$	TJ	E17

El $_{pa}$ = Consumption of electricity for production of paper from pulp

El_{pa}	=	$el_{pa\ meas} + el_{pa\ shared} + el_{pa\ fuel}$	TJ	E18

3.2.3. KPIs: Specific electricity consumption

3.2.3.1. KPIs for electricity consumption, alternative 0: total electricity consumption, incl electricity to electric boilers

Electricity consumption, in total for the mill, per ton of final product

$= El_{tot\ supply} / Final\ prod$	***GJ/ton***	***E19***

This KPI can only be used to follow up the performance of a given mill over time.

Electricity consumption per ton of pulp stock produced

$= El_{stock} / Pu_{stock}$	***GJ/ADt***	***E20***

This KPI is used to compare the consumption to that of other integrated mills' own production of pulp stock and to that of non-integrated pulp mills where the drying of the market pulp is excluded.

Electricity consumption for drying per ton of market pulp produced

$= El_{dry} / Pu_{market}$	***GJ/ADt***	***E21***

This KPI is used to compare the consumption for pulp drying to that of other integrated and non-integrated pulp mills.

Electricity consumption per ton of market pulp produced

$= El_{stock} / Pu_{stock} + El_{dry} / Pu_{market}$	***GJ/ADt***	***E22***

This KPI is used to compare the consumption to that of other integrated mills' production of market pulp and to that of non-integrated market pulp mills.

Electricity consumption per ton of paper produced from pulp stock

$= El_{pa} / Pa_{tot}$	***GJ/ton***	***E23***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from own pulp stock and to that of non-integrated paper mills where the repulping of purchased pulp is excluded.

Electricity consumption per ton of paper produced from purchased pulp

$= El_{repulp} / Pu_{purch} + El_{pa} / Pa_{tot}$	***GJ/ton***	***E24***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from purchased pulp and to that of non-integrated paper mills.

Degree of self-sufficiency in electricity supply

$= (el_{prod\ bpt} + el_{prod\ ct}) / El_{tot\ supply}$	***%***	***E25***

3.2.3.2. KPIs for electricity consumption, alternative 1: excluding electricity used for heat production in electric boilers

Electricity consumption, in total for the mill, per ton of final product

$= (El_{tot\ supply} - el_{fuel}) / Final\ prod$	***GJ/ton***	***E26***

This KPI can only be used to follow up the performance of a given mill over time.

Electricity consumption per ton of pulp stock produced

$= (el_{stock\ meas} + el_{stock\ shared}) / Pu_{stock}$	***GJ/ADt***	***E27***

This KPI is used to compare the consumption to that of other integrated mills' own production of pulp stock and to that of non-integrated pulp mills where the drying of the market pulp is excluded.

Electricity consumption for drying, per ton of market pulp produced

$= (el_{dry\ meas} + el_{dry\ shared}) / Pu_{market}$	***GJ/ADt***	***E28***

This KPI is used to compare the consumption for pulp drying to that of other integrated and non-integrated pulp mills.

Electricity consumption per ton of market pulp produced

$= (el_{stock\ meas} + el_{stock\ shared}) / Pu_{stock} + (el_{dry\ meas} + el_{dry\ shared}) / Pu_{market}$	***GJ/ADt***	***E29***

This KPI is used to compare the consumption to that other integrated mills' production of market pulp and to that of non-integrated market pulp mills.

Electricity consumption per ton of paper produced from pulp stock

$= (el_{pa\ meas} + el_{pa\ shared}) / Pa_{tot}$	***GJ/ton***	***E30***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from own pulp stock and to that of non-integrated paper mills where the repulping of purchased pulp is excluded.

Electricity consumption per ton of paper produced from purchased pulp

$= (el_{repulp\ meas} + el_{repulp\ shared}) / Pu_{purch} + (el_{pa\ meas} + el_{pa\ shared}) / Pa_{tot}$	***GJ/ton***	***E31***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from purchased pulp and to that of non-integrated paper mills.

Degree of self-sufficiency in electricity supply

$= (el_{prod\ bpt} + el_{prod\ ct}) / (El_{tot\ supply} - el_{fuel})$	***%***	***E32***

3.3. Heat consumption

For a graphical overview over the calculation procedure, see *Appendix – Allocation of electricity consumption*.

3.3.1. Input data

q_{turb} = steam supplied to the process as extraction or back-pressure steam from turbines, i.e. steam from turbines connected to a solid fuel boiler or another boiler[1)]

q_{dir} = direct reduction of steam supplied to the process from a solid fuel boiler or another boiler via expansion valves, i.e., without passing through a back-pressure turbine[1)]

$q_{elec\ b}$ = steam produced in an electric boiler

$q_{other\ b}$ = steam produced in another boiler, not connected to turbine

$q_{hw\ b}$ = hot water produced in a boiler on-site (e.g. oil boiler or electric boiler) and condensate from condensing turbine if used for process heating

$q_{prod\ ref}$ = steam produced in refiners (energy content is determined in the same way as steam produced in boilers, see figure in section 2.4 'Heat').

q_{purch} = steam or hot water purchased from an external supplier

$q_{prim\ sold}$ = primary heat (excl. refiner steam) sold to external consumers (energy content is determined in the same way as for internal steam consumers, with consideration to whether condensate is returned or not, see figure in section 2.4 'Heat')

$q_{ref\ sold}$ = refiner steam sold to external consumers (energy content is determined in the same way as for internal steam consumers, with consideration to whether condensate is returned or not, see figure in section 2.4 'Heat')

$q_{prim\ ext}$ = primary heat used at the mill, but outside the system boundaries of conventional pulp/paper production (e.g. for paper converting)

$q_{prim\ ct}$ = steam used for power generation in a condensing turbine

$q_{sec\ sold}$ = secondary heat[2)] from the mill sold to external consumers

$q_{sec\ ext}$ = secondary heat[2)] from the mill, used at the mill but outside the system boundaries of conventional pulp/paper production (e.g. for paper converting)

$q_{stock\ meas}$ = measured consumption of primary heat[3)] for the *production of pulp stock*

$q_{dry\ meas}$ = measured consumption of primary heat[3)] for the *drying of pulp stock to market pulp*

$q_{repulp\ meas}$ = measured consumption of primary heat[3)] for the *repulping of purchased pulp*

$q_{pa\ meas}$ = measured consumption of primary heat[3)] for the *actual paper production*

$q_{site\ meas}$ = measured consumption of primary heat[3)] for *shared site functions* (e.g. water treatment, office heating, maintenance workshops). Includes all measured primary heat consumption that cannot be directly attributed to any specific part of the production or to steam venting

$q_{vent\ meas}$ = measured venting of steam, which is thereby not utilized for process heating [3)]

$q_{stock→sec}$ = secondary heat[2)] recovered from the *production of pulp stock, excluding refiner steam*
$q_{dry→sec}$ = secondary heat[2)] recovered from the *drying of pulp stock to market pulp*
$q_{repulp→sec}$ = secondary heat[2)] recovered from the *repulping of purchased pulp*
$q_{pa→sec}$ = secondary heat[2)] recovered from the *actual paper production*

$q_{sec→stock}$ = secondary heat[2)] used for the *production of pulp stock*
$q_{sec→dry}$ = secondary heat[2)] used for the *drying of pulp stock to market pulp*
$q_{sec→repulp}$ = secondary heat[2)] used for the *repulping of purchased pulp*
$q_{sec→pa}$ = secondary heat[2)] used for the *actual paper production*

$q_{shared\ attr\ stock}$ = part of shared heat consumption (incl. steam venting and total balance term) that can be attributed to the *production of pulp stock* based on reasonable assumptions and estimates [4)]
$q_{shared\ attr\ dry}$ = part of shared heat consumption (incl. steam venting and total balance term) that can be attributed to *drying of pulp stock to market pulp* based on reasonable assumptions and estimates [4)]
$q_{shared\ attr\ repulp}$ = part of shared heat consumption (incl. steam venting and total balance term) that can be attributed to *repulping of purchased pulp* based on reasonable assumptions and estimates [4)]
$q_{shared\ attr\ pa}$ = part of shared heat consumption (incl. steam venting and total balance term) that can be attributed to the *actual paper production* based on reasonable assumptions and estimates [4)]

1) *If there is no measurement data for turbine extractions, steam supply can be determined based on measured steam production from boilers with deductions for steam estimated to be used for electricity production. This can make it difficult to distinguish between steam from turbines, q_{turb}, and steam from direct reductions, q_{dir}. However, it is always the total steam production (steam supplied to the process) that is important to estimate as correctly as possible, while the distribution between turbine steam and direct reduction steam is less important.*

   Steam used for the production of power in condensing turbines is not included because this steam is not supplied to the process as heat.

   Soot blowing steam is not included in the produced steam.

2) *Recovered heat from the mill's processes, in the form of warm or hot water.*

3) *Here, this includes all primary heat consumed, including refiner steam.*

4) *The distribution may, e.g., be based on own model calculations or allocation based on mass flows or similar. The residual consumption that cannot be attributed to any specific process section will be allocated by the model proportionally to the directly measured heat consumption in each process section. Please refer to Equations Q10-Q13 below, and to Section 2.5 above.*

3.3.2. Calculations

q_{prod} = Heat production on site including refiner steam

$q_{prod\ b}$	=	$q_{turb} + q_{dir} + q_{elec\ b} + q_{other\ b} + q_{hw\ b}$	TJ	Q1
$q_{prod\ tot}$	=	$q_{prod\ b} + q_{prod\ ref}$	TJ	Q2

Q_{tot} = Total heat consumption at the pulp and paper mill, calculated from heat production

$Q_{tot\ gross}$	=	$q_{prod} + q_{purch} - q_{prim\ sold} - q_{ref\ sold} - q_{prim\ ext}$	TJ	Q3
$Q_{tot\ net}$	=	$Q_{tot\ gross} - q_{sec\ sold} - q_{sec\ ext}$	TJ	Q4

$q_{proc\ meas}$ = Total primary heat consumption measured specifically for the different process sections

$q_{proc\ meas}$	=	$q_{stock\ meas} + q_{dry\ meas} + q_{repulp\ meas} + q_{pa\ meas}$	TJ	Q5

$Q_{tot\ meas}$ = Total measured primary heat consumption

$Q_{tot\ meas}$	=	$q_{proc\ meas} + q_{site\ meas} + q_{vent\ meas}$	TJ	Q6

$q_{prim\ bal}$ = Balance term for primary heat, deviation between production and measured consumption (includes losses, unmeasured consumption, measurement errors, etc.)

$q_{prim\ bal}$	=	$Q_{tot\ gross} - Q_{tot\ meas}$	TJ	Q7

$q_{sec\ bal}$ = Balance term for secondary heat

$q_{sec\ bal}$	=	$(q_{stock\rightarrow sec} + q_{dry\rightarrow sec} + q_{repulp\rightarrow sec} + q_{pa\rightarrow sec}) -$ $(q_{sec\rightarrow stock} + q_{sec\rightarrow dry} + q_{sec\rightarrow repulp} + q_{sec\rightarrow pa}) - q_{sec\ sold}$ $- q_{sec\ ext}$	TJ	Q8

q_{shared} = Heat consumed for shared site functions or included in the total balance term

q_{shared}	=	$q_{site\ meas} + q_{vent\ meas} + q_{prim\ bal} + q_{sec\ bal}$	TJ	Q9

Allocation of q_{shared}

$q_{shared\ res}$	=	$q_{shared} - q_{shared\ attr\ stock} - q_{shared\ attr\ dry} - q_{shared\ attr\ repulp} -$ $q_{shared\ attr\ pa}$	TJ	Q10
$q_{stock\ shared}$	=	$q_{shared\ attr\ stock} + q_{shared\ res} * q_{stock\ meas} / q_{proc\ meas}$	TJ	Q11
$q_{dry\ shared}$	=	$q_{shared\ attr\ dry} + q_{shared\ res} * q_{dry\ meas} / q_{proc\ meas}$	TJ	Q12
$q_{repulp\ shared}$	=	$q_{shared\ attr\ repulp} + q_{shared\ res} * q_{repulp\ meas} / q_{proc\ meas}$	TJ	Q13
$q_{pa\ shared}$	=	$q_{shared\ attr\ pa} + q_{shared\ res} * q_{pa\ meas} / q_{proc\ meas}$	TJ	Q14

$q_{shared\ res}$ = residual shared heat consumption that cannot be clearly attributed to production of pulp stock, drying of pulp, repulping of purchased pulp or actual paper production

$q_{stock\ shared}$ = shared heat consumption that has been attributed or allocated to the *production of pulp stock*

$q_{dry\ shared}$ = shared heat consumption that has been attributed or allocated to the *drying of pulp stock to market pulp*

$q_{repulp\ shared}$ = shared heat consumption that has been attributed or allocated to the *repulping of purchased pulp*

$q_{pa\ shared}$ = shared heat consumption that has been attributed or allocated to the *actual paper production*

Q_{stock} = Consumption of heat for production of pulp stock

Q_{stock}	=	$q_{stock\ meas} + q_{stock\ shared} + q_{sec \rightarrow stock} - q_{stock \rightarrow sec}$	TJ	Q15

Q_{dry} = Consumption of heat for drying of market pulp

Q_{dry}	=	$q_{dry\ meas} + q_{dry\ shared} + q_{sec \rightarrow dry} - q_{dry \rightarrow sec}$	TJ	Q16

Q_{repulp} = Consumption of heat for repulping of purchased pulp

Q_{repulp}	=	$q_{repulp\ meas} + q_{repulp\ shared} + q_{sec \rightarrow repulp} - q_{repulp \rightarrow sec}$	TJ	Q17

Q_{pa} = Consumption of heat for production of paper from pulp stock

Q_{pa}	=	$q_{pa\ meas} + q_{pa\ shared} + q_{sec \rightarrow pa} - q_{pa \rightarrow sec}$	TJ	Q18

3.3.3. KPIs: Specific heat consumption

3.3.3.1. KPIs for heat consumption, alternative 0: including refiner steam

Heat consumption, in total for the mill, per ton of final product

$= Q_{tot\ net}$ / Final prod	***GJ/ton***	***Q19***

This KPI can only be used to follow up the performance of a given mill over time.

Heat consumption per ton of pulp stock produced

$= Q_{stock} / Pu_{stock}$	***GJ/ADt***	***Q20***

This KPI is used to compare the consumption to that of other integrated mills' own production of pulp stock and to that of non-integrated pulp mills where the drying of the market pulp is excluded.

Heat consumption for drying, per ton of market pulp produced

$= Q_{dry} / Pu_{market}$	***GJ/ADt***	***Q21***

This KPI is used to compare the consumption for drying of market pulp to that of other integrated and non-integrated pulp mills.

Heat consumption per ton of market pulp produced

$= Q_{stock} / Ma_{stock} + Q_{dry} / Pu_{market}$	***GJ/ADt***	***Q22***

This KPI is used to compare the consumption to that of other integrated mills' production of market pulp and to that of non-integrated market pulp mills.

Heat consumption per ton of paper produced from pulp stock

$= Q_{pa} / Pa_{prod}$	***GJ/ton***	***Q23***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from own pulp stock and to that of non-integrated paper mills where the repulping of purchased pulp is excluded.

Heat consumption per ton of paper produced from purchased pulp

$= Q_{repulp} / Pu_{purch} + Q_{pa} / Pa_{prod}$	***GJ/ton***	***Q24***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from purchased pulp and to that of non-integrated paper mills.

3.3.3.2. KPIs for steam recovery from refiners

Share of total heat consumption covered by refiner steam

$= (q_{prod\ ref} - q_{ref\ sold}) / Q_{tot\ net}$	**%**	**Q25**

This KPI can only be used to follow up the performance of a given mill over time.

Steam generated through heat recovery from refiners per ton of market pulp produced

$= q_{prod\ ref} / Pu_{stock}$	**GJ/ADt**	**Q26**

This KPI is used to compare the steam recovery to that of other integrated mills' production of market pulp and to that of non-integrated market pulp mills.

3.3.3.3. KPIs for heat consumption, alternative 1: excluding refiner steam

Heat consumption, in total for the mill, per ton of final product, excluding refiner steam

$= (Q_{tot\ net\ netto} - (q_{prod\ ref} - q_{ref\ ext})) / Final\ prod$	**GJ/ton**	**Q27**

This KPI can only be used to follow up the performance of a given mill over time.

Heat consumption per ton of pulp stock produced, excluding refiner steam

$= (Q_{stock} - (q_{prod\ ref} - q_{ref\ ext})) / Pu_{stock}$	**GJ/ADt**	**Q28**

This KPI is used to compare the consumption to that of other integrated mills' own production of pulp stock and to that of non-integrated pulp mills where the drying of the market pulp is excluded.

Heat consumption per ton of market pulp produced

$= (Q_{stock} - (q_{prod\ ref} - q_{ref\ ext})) / Ma_{stock} + Q_{dry} / Pu_{market}$	**GJ/ADt**	**Q29**

This KPI is used to compare the consumption to that of other integrated mills' production of market pulp and to that of non-integrated market pulp mills.

3.4. Total fuel consumption

For a graphical overview over the calculation procedure, see *Appendix – Allocation of fuel consumption*.

3.4.1. Input data

Solid biofuels – overall balance

$fu_{bio\ own\ solid}$ = solid biofuels (e.g. falling bark) generated at the mill site but outside the "internal system boundary" (i.e. in the debarking and chipping plant)

$fu_{bio\ purch\ solid}$ = purchased bark, wood chips and other solid biofuels

$fu_{sold\ solid}$ = sold bark and other solid fuels generated in the wood handling plant

Fuel used for the production of steam and hot water in own boilers [1)]

$fu_{solid\ bio\ boil}$ = self-generated and purchased bark and other solid biofuels

$fu_{liq\ bio\ boil}$ = purchased liquid biofuels

$fu_{gas\ bio\ boil}$ = purchased biogas

$fu_{oil\ fos\ boil}$ = fossil fuel oil

$fu_{gas\ fos\ boil}$ = other fossil fuels, e.g. LPG and natural gas

η_{ext} = efficiency of bark boiler or other power boiler that produce steam that is delivered externally or used at the mill but in processes outside the system boundaries for conventional pulp/paper production. If the efficiency of the boiler is not known, a standard value of 85% is used.

η_{ct} = efficiency of bark boiler or other power boiler that produce steam for condensing power production. If the efficiency of the boiler is not known, a standard value of 85% is used.

Fuel used for direct heating[1)]

$fu_{solid\ bio\ dir}$ = self-generated or purchased solid biofuels (e.g., wood powder from bark or saw dust)

$fu_{liq\ bio\ dir}$ = purchased liquid biofuels

$fu_{gas\ bio\ dir}$ = purchased biogas

$fu_{oil\ fos\ dir}$ = fossil fuel oil

$fu_{gas\ fos\ dir}$ = other fossil fuels, e.g. LPG and natural gas

$fu_{dry\ dir}$ = fuel used for direct heating in the *drying of market pulp*, e.g. in direct-fired flake dryers

$fu_{pa\ dir}$ = fuel used for direct heating in the *actual paper production*, e.g. for drying of paper or coating

Fuels used for transports and other purposes than indirect or direct heating[1)]

$fu_{transp\ bio}$ = biofuels used for on-site transports e.g. renewable transportation fuels such as biodiesel and ethanol

$fu_{transp\ fos}$ = fossil fuels used for on-site transports, e.g. petrol and diesel

$fu_{remain\ bio}$ = any remaining fuel use for other purposes, bio

$fu_{remain\ fos}$ = any remaining fuel use for other purposes, fossil

$fu_{stock\ oth}$ = transportation fuels and other fuels used in operations that can be attributed to the *production of pulp stock*, e.g. trucks in the woodyard

$fu_{dry\ oth}$ = transportation fuels and other fuels used in operations that can be attributed to *pulp drying* and subsequent steps, e.g. trucks for handling finished product

$fu_{repulp\ oth}$ = transportation fuels and other fuels used in operations that can be attributed to *repulping of purchased pulp*, e.g. in the unloading of purchased pulp

$fu_{pa\ oth}$ = transportation fuels and other fuels used in operations that can be attributed to *actual paper production*, e.g. trucks for handling finished product

Sold energy products, generated within the inner system boundary

$fu_{sold\ inner}$ = sold energy products (e.g., biogas), excl. bark and other solid biofuels generated from debarking and chipping

[1] *Biofuels generated and used within the inner system boundary are considered to be internally circulating and should not be included. However, bark and other solid biofuels that have been generated on-site but outside the inner system boundary (typically during debarking and chipping) should be included.*

3.4.2. Calculations

3.4.2.1. Calculations for fuel consumption, alternative 0: total fuel consumption, inner system boundary

The main alternative for calculating KPIs for fuel consumption is based on an inner system boundary. In this case, the wood yard, debarking and chipping plant are considered to be outside the system boundaries. This implies that all bark combusted in the mill's own boiler is counted as fuel consumption for the pulp mill, regardless of whether it was generated at the site or purchased externally.

$Fu_{bio\ solid\ inner}$ = Consumption of bark and other solid biofuels used for heat production at the mill (combusted in boilers or used for direct heating)

$Fu_{bio\ solid\ inner}$	=	$fu_{bio\ own\ solid} + fu_{bio\ purch\ solid} - fu_{sold\ solid}$	TJ	F1

Fu_{boil} = Consumption of fuel used in boilers to produce heat in the form of steam or hot water for the process and for the production of power in condensing turbines

$Fu_{boil\ inner\ gross}$	=	$fu_{solid\ bio\ boil} + fu_{liq\ bio\ boil} + fu_{gas\ bio\ boil} + fu_{oil\ fos\ boil} + fu_{gas\ fos\ boil}$	TJ	F2
$fu_{sold\ prim\ heat}$	=	$q_{prim\ sold} / \eta_{ext}$	TJ	F3
$fu_{ext\ prim\ heat}$	=	$q_{prim\ ext} / \eta_{ext}$	TJ	F4
fu_{ct}	=	$q_{prim\ ct} / \eta_{ct}$	TJ	F5
$Fu_{boil\ inner\ net}$	=	$Fu_{boil\ inner\ gross} - fu_{sold\ prim\ heat} - fu_{ext\ prim\ heat} - fu_{ct}$	TJ	F6

Fu_{dir} = Fuel used for direct heating

$Fu_{dir\ inner}$	=	$fu_{solid\ bio\ dir} + fu_{liq\ bio\ dir} + fu_{gas\ bio\ dir} + fu_{oil\ fos\ dir} + fu_{gas\ fos\ dir}$	TJ	F7
$Fu_{dir\ inner}$	=	$fu_{dry\ dir} + fu_{pa\ dir}$	TJ	F8

Fu_{other} = Fuel used for internal transports or other purposes than indirect and direct heating

Fu_{other}	=	$fu_{transp\ bio} + fu_{transp\ fos} + fu_{remain\ bio} + fu_{remain\ fos}$	TJ	F9
Fu_{other}	=	$fu_{stock\ oth} + fu_{dry\ oth} + fu_{repulp\ oth} + fu_{pa\ oth}$	TJ	F10

Fu_{tot} = Total consumption of fuels at the pulp and paper mill (excl. internal fuel flows within the inner system boundary)

$Fu_{tot\ inner\ net}$	=	$Fu_{boil\ inner\ net} + Fu_{dir\ inner} + Fu_{oth} - fu_{sold\ inner}$	TJ	F11

Allocation of fuel used in boilers for the production of steam or hot water

$fu_{stock\ boil}$	=	$Fu_{boil\ inner\ net} * (Q_{stock} - (q_{prod\ ref} - q_{ref\ sold})) / (Q_{tot\ net} - (q_{prod\ ref} - q_{ref\ sold}))$	TJ	F12
$fu_{dry\ boil}$	=	$Fu_{boil\ inner\ net} * Q_{dry} / (Q_{tot\ net} - (q_{prod\ ref} - q_{ref\ sold}))$	TJ	F13
$fu_{repulp\ boil}$	=	$Fu_{boil\ inner\ net} * Q_{repulp} / (Q_{tot\ net} - (q_{prod\ ref} - q_{ref\ sold}))$	TJ	F14
$fu_{pa\ boil}$	=	$Fu_{boil\ inner\ net} * Q_{pa} / (Q_{tot\ net} - (q_{prod\ ref} - q_{ref\ sold}))$	TJ	F15

$fu_{stock\ boil}$ = fuel used to produce heat in the form of steam or hot water allocated to the *production of pulp stock*

$fu_{dry\ boil}$ = fuel used to produce heat in the form of steam or hot water allocated to the *drying of pulp stock to market pulp*

$fu_{repulp\ boil}$ = fuel used to produce heat in the form of steam or hot water allocated to the repulping of *purchased pulp*

$fu_{pa\ boil}$ = fuel used to produce heat in the form of steam or hot water allocated to the actual paper production

Fu_{stock} = Consumption of fuel for the production of pulp stock

Fu_{stock}	=	$fu_{stock\ boil} + fu_{stock\ oth} - fu_{sold\ inner}$	TJ	F16

Fu_{dry} = Consumption of fuel for drying of market pulp

Fu_{dry}	=	$fu_{dry\ boil} + fu_{dry\ dir} + fu_{dry\ oth}$	TJ	F17

Fu_{repulp} = Consumption of fuel for repulping of purchased pulp

Fu_{repulp}	=	$fu_{repulp\ boil} + fu_{repulp\ oth}$	TJ	F18

Fu_{pa} = Consumption of fuel for the production of paper itself

Fu_{pa}	=	$fu_{pa\ boil} + fu_{by\ dir} + fu_{pa\ oth}$	TJ	F19

3.4.2.2. Calculations for fuel consumption, alternative 1: only including fuel for other purposes than for heat production in boilers, inner system boundary

Used for KPIs excluding fuel for boilers.

Fu_{tot} = Consumption of fuel at the pulp and paper mill (excl. fuels for boilers)

$Fu_{tot\ inner\ net\ alt}$	=	$Fu_{dir\ inner} + Fu_{oth}$	TJ	F20

Fu_{stock} = Consumption of fuel for production of pulp stock (excl. fuels for boilers)

$Fu_{stock\ alt}$	=	$fu_{stock\ oth}$	TJ	F21

Fu_{kiln} = Consumption of fuel for drying of market pulp (excl. fuels for boilers)

$Fu_{dry\ alt}$	=	$fu_{dry\ dir} + fu_{dry\ oth}$	TJ	F22

Fu_{uppsl} = Consumption of fuel for repulping of purchased pulp (excl. fuels for boilers)

$Fu_{repulp\ alt}$	=	$fu_{repulp\ oth}$	TJ	F23

Fu_{pa} = Consumption of fuel for actual paper production (excl. fuels for boilers)

$Fu_{pa\ alt}$	=	$fu_{pa\ dir} + fu_{pa\ oth}$	TJ	F24

3.4.2.3. Calculations for fuel consumption, alternative 2: total fuel consumption, outer system boundary

These fuel consumption values are not used as input to any KPIs

The outer system boundary is drawn so that the wood yard, debarking and chipping plant are considered to be inside the system boundaries. In this case, the bark generated there is considered to be an internal flow and is not included in the consumption.

$x_{bio\ own}$ = Share of total solid biofuel use that were generated at the mill

$x_{bio\ own}$	=	$fu_{bio\ own\ solid} / Fu_{bio\ solid\ inner}$	TJ	F25

Fu_{outer} = Fuel consumption for heat production in boilers, direct heating and in total calculated with outer system limit

$Fu_{boil\ outer\ gross}$	=	$Fu_{boil\ inner\ gross} - x_{bio\ own} * fu_{solid\ bio\ boil}$	TJ	F26
$Fu_{boil\ outer\ net}$	=	$Fu_{boil\ outer\ gross} - fu_{sold\ prim\ heat} - fu_{ext\ prim\ heat} - fu_{ct}$	TJ	F27
$Fu_{dir\ outer}$	=	$Fu_{dir\ inner} - x_{bio\ own} * fu_{solid\ bio\ dir}$	TJ	F28
$Fu_{tot\ outer}$	=	$Fu_{boil\ outer\ net} + Fu_{dir\ outer} + Fu_{oth} - fu_{sold\ inner}$	TJ	F29

3.4.3. KPIs: Specific fuel consumption

3.4.3.1 KPIs for fuel consumption, alternative 0: total consumption of fuel including fuel for boilers, inner system boundary

Fuel consumption, in total for the mill, per ton of final product

= Fu $_{tot\ inner\ net}$ / Final prod	***GJ/ton***	***F30***

This KPI can only be used to follow up the performance of a given mill over time.

Fuel consumption per ton of pulp stock produced

= Fu $_{stock}$ / Pu $_{stock}$	***GJ/ADt***	***F31***

This KPI is used to compare the consumption to that of other integrated mills' production of pulp stock and to that of non-integrated pulp mills where the drying of the market pulp is excluded.

Fuel consumption for drying, per ton of market pulp produced

= Fu $_{dry}$ / Pu $_{market}$	***GJ/ADt***	***F32***

This KPI is used to compare the consumption for drying of market pulp to that of other integrated and non-integrated pulp mills.

Fuel consumption per ton of market pulp produced

= Fu $_{stock}$ / Pu $_{stock}$ + Fu $_{dry}$ / Pu $_{market}$	***GJ/ADt***	***F33***

This KPI is used to compare the consumption to that of other integrated mills' production of market pulp and to that of non-integrated market pulp mills.

Fuel consumption per ton of paper produced from purchased pulp

= Fu $_{repulp}$ / Pu $_{purch}$ + Fu $_{pa}$ / Pa $_{tot}$	***GJ/ton***	***F34***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from purchased pulp and to that of non-integrated paper mills.

Fuel consumption per ton of paper produced from pulp stock

= Fu $_{pa}$ / Pa $_{tot}$	***GJ/ton***	***F35***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from own pulp stock and to that of non-integrated paper mills where the repulping of purchased pulp is excluded.

3.4.3.2. KPIs for fuel consumption, alternative 1: excluding fuel for boilers, inner system boundary

Fuel consumption for direct heating and as transportation fuel, in total for the mill per ton of final product

= Fu $_{tot\ inner\ net\ alt}$ / Final prod	***GJ/ton***	***F36***

This KPI can only be used to follow up the performance of a given mill over time.

Fuel consumption for direct heating and as transportation fuel per ton of pulp stock produced

= Fu $_{stock\ alt}$ / Pu $_{stock}$	***GJ/ADt***	***F37***

This KPI is used to compare the consumption to that of other integrated mills' production of pulp stock and to that of non-integrated pulp mills where the drying of the market pulp is excluded.

Fuel consumption for direct heating and as transportation fuel, for drying, per ton of market pulp produced

= Fu $_{dry\ alt}$ / Pu $_{market}$	***GJ/Adt***	***F38***

This KPI is used to compare the consumption for drying of market pulp to that of other integrated and non-integrated pulp mills.

Fuel consumption for direct heating and as transportation fuel per ton of market pulp produced

= Fu $_{stock\ alt}$ / Pu $_{stock}$ + Fu $_{dry\ alt}$ / Pu $_{market}$	***GJ/Adt***	***F39***

This KPI is used to compare the consumption to that of other integrated mills' production of market pulp and to that of non-integrated market pulp mills.

Fuel consumption for direct heating and as transportation fuel per ton of paper produced from purchased pulp

= Fu $_{repulp\ alt}$ / Pu $_{purch}$ + Fu $_{pa\ alt}$ / Pa $_{tot}$	***GJ/ton***	***F40***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from purchased pulp and to that of non-integrated paper mills.

Fuel consumption for direct heating and as transportation fuel per ton of paper produced from pulp stock

= Fu $_{pa\ alt}$ / Pa $_{tot}$	***GJ/ton***	***F41***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from own pulp stock and to that of non-integrated paper mills where the repulping of purchased pulp is excluded.

3.5. Fossil fuel consumption

For a graphical overview over the calculation procedure, see *Appendix – Allocation of fuel consumption.* The allocation is made in the same way as for total fuel consumption, which is why the same calculation scheme is used. The difference is that the index *fos* is added to each parameter.

3.5.1. Input data

Several of the input parameters used in the calculation of fossil fuel consumption are also used for total fuel consumption. For definitions of these, see section 3.4.1. Below, therefore, only the input parameters that are added for the calculation of fossil fuel consumption are described.

Fossil fuel used for the production of steam and hot water

$\eta_{fos\ ext}$ = efficiency of fossil-fired power boiler producing steam that is delivered externally or used at the mill but in processes outside the system boundaries of conventional pulp/paper production. Defaults to 90% if the efficiency of the boiler is not known. Leave blank if fossil fuel is never used to produce such heat.

$\eta_{fos\ ct}$ = efficiency of fossil-fired power boiler producing steam used for power generation in a condensing turbine. Defaults to 90% if the efficiency of the boiler is not known. Leave blank if fossil fuel is never used to produce steam for condensing power generation.

Fossil fuel used for direct heating

$fu_{dry\ dir\ fos}$ = fossil fuel used for direct heating in the *drying of market pulp*, e.g. in direct-fired flake dryers

$fu_{pa\ dir\ fos}$ = fossil fuel used for direct heating in the *actual paper production*, e.g. for drying of paper or coating

Fossil fuels used for transports and other purposes than indirect or direct heating

$fu_{stock\ oth\ fos}$ = fossil transportation fuels and other fossil fuels used in operations that can be attributed to the *production of pulp stock*, e.g. trucks in the woodyard

$fu_{dry\ oth\ fos}$ = fossil transportation fuels and other fossil fuels used in operations that can be attributed to *pulp drying* and subsequent steps, e.g. trucks for handling finished product

$fu_{repulp\ oth\ fos}$ = fossil transportation fuels and other fossil fuels used in operations that can be attributed to the *repulping of purchased pulp*, e.g. in the unloading of purchased pulp

$fu_{pa\ oth\ fos}$ = fossil transportation fuels and other fossil fuels used in operations that can be attributed to *actual paper production*, e.g. trucks for handling finished product

3.5.2. Calculations

3.5.3.1. Calculations for fossil fuel, alternative 0: total consumption of fossil fuel

$Fu_{boil\ fos}$ = Consumption of fossil fuel used in boilers to produce heat (steam, hot water)

$Fu_{boil\ gross\ fos}$	=	$fu_{oil\ fos\ boil} + fu_{gas\ fos\ boil}$	TJ	fF1
$fu_{sold\ prim\ heat\ fos}$	=	$(Fu_{boil\ gross\ fos} / Fu_{boil\ inner\ gross}) * (q_{prim\ sold} / \eta_{fos\ ext})$	TJ	fF2
$fu_{ext\ prim\ heat\ fos}$	=	$(Fu_{boil\ gross\ fos} / Fu_{boil\ inner\ gross}) * (q_{prim\ ext} / \eta_{fos\ ext})$	TJ	fF3
$fu_{ct\ fos}$	=	$(Fu_{boil\ gross\ fos} / Fu_{boil\ inner\ gross}) * (q_{prim\ ct} / \eta_{fos\ ct})$	TJ	fF4
$Fu_{boil\ net\ fos}$	=	$Fu_{boil\ gross\ fos} - fu_{sold\ prim\ heat\ fos} - fu_{ext\ prim\ heat\ fos} - fu_{ct\ fos}$	TJ	fF5

$Fu_{dir\ fos}$ = Fossil fuel used for direct heating

$Fu_{dir\ fos}$	=	$fu_{oil\ fos\ dir} + fu_{gas\ fos\ dir}$	TJ	fF6
$Fu_{dir\ fos}$	=	$fu_{dry\ dir\ fos} + fu_{pa\ dir\ fos}$	TJ	fF7

$Fu_{other\ fos}$ = Fossil fuel used for other purposes, including fuels for internal transports other purposes than indirect and direct heating

$Fu_{other\ fos}$	=	$fu_{transp\ fos} + fu_{remain\ fos}$	TJ	fF8
$Fu_{other\ fos}$	=	$fu_{stock\ oth\ fos} + fu_{dry\ oth\ fos} + fu_{repulp\ oth\ fos} + fu_{pa\ oth\ fos}$	TJ	fF9

$Fu_{tot\ fos}$= Total consumption of fossil fuels at the pulp and paper mill

$Fu_{tot\ fos}$	=	$Fu_{boil\ net\ fos} + Fu_{dir\ fos} + Fu_{other\ fos}$	TJ	fF10

Allocation of fossil fuel used in boilers for the production of steam or hot water

$fu_{stock\ boil\ fos}$	=	$Fu_{boil\ net\ fos} * (Q_{stock} - (q_{prod\ ref} - q_{ref\ sold})) / (Q_{tot\ net} - (q_{prod\ ref} - q_{ref\ sold}))$	TJ	fF11
$fu_{dry\ panna\ fos}$	=	$Fu_{boil\ net\ fos} * Q_{dry} / (Q_{tot\ net} - (q_{prod\ ref} - q_{ref\ sold})$	TJ	fF12
$fu_{repulp\ boil\ fos}$	=	$Fu_{boil\ net\ fos} * Q_{repulp} / (Q_{tot\ net} - (q_{prod\ ref} - q_{ref\ sold})$	TJ	fF13
$fu_{pa\ boil\ fos}$	=	$Fu_{boil\ net\ fos} * Q_{pa} / (Q_{tot\ net} - (q_{prod\ ref} - q_{ref\ sold})$	TJ	fF14

$fu_{stock\ boil\ fos}$ = fossil fuel used to produce heat in the form of steam or hot water allocated to the *production of pulp stock*

$fu_{dry\ boil\ fos}$ = fossil fuel used to produce heat in the form of steam or hot water allocated to the *drying of pulp stock to market pulp*

$fu_{repulp\ boil\ fos}$ = fossil fuel used to produce heat in the form of steam or hot water allocated to the *repulping of purchased pulp*

$fu_{pa\ boil\ fos}$ = fossil fuel used to produce heat in the form of steam or hot water allocated to the *actual paper production*

Fu $_{stock\ fos}$ = Fossil fuel for production of pulp stock

Fu $_{stock\ fos}$	=	fu $_{stock\ boil\ fos}$ + fu $_{stock\ oth\ fos}$	TJ	fF15

Fu $_{dry\ fos}$ = Fossil fuel for drying of market pulp

Fu $_{dry\ fos}$	=	fu $_{dry\ boil\ fos}$ + fu $_{dry\ dir\ fos}$ + fu $_{dry\ oth\ fos}$	TJ	fF16

Fu $_{repulp\ fos}$ = Fossil fuel for repulping of purchased pulp

Fu $_{repulp\ fos}$	=	fu $_{repulp\ boil\ fos}$ + fu $_{repulp\ oth\ fos}$	TJ	fF17

Fu $_{pa\ fos}$ = Fossil fuel for actual paper production

Fu $_{pa\ fos}$	=	fu $_{pa\ boil\ fos}$ + fu $_{pa\ dir\ fos}$ + fu $_{pa\ oth\ fos}$	TJ	fF18

3.5.2.2. Calculations for fossil fuel, alternative 1: excluding fuel for boilers

Fu $_{tot\ fos}$= Total consumption of fossil fuel at the mill, excluding fuel for boilers

Fu $_{tot\ fos\ alt}$	=	Fu $_{dir\ fos}$ + Fu $_{other\ fos}$	TJ	fF19

Fu $_{stock\ fos}$ = Fossil fuel for production of pulp stock, excluding fuel for boilers

Fu $_{stock\ fos\ alt}$	=	fu $_{stock\ oth\ fos}$	TJ	fF20

Fu $_{dry\ fos}$ = Fossil fuel for drying of market pulp, excluding fuel for boilers

Fu $_{tork\ fos\ alt}$	=	fu $_{dry\ dir\ fos}$ + fu $_{dry\ oth\ fos}$	TJ	fF21

Fu $_{repulp\ fos}$ = Fossil fuel for repulping of purchased pulp, excluding fuel for boilers

Fu $_{repulp\ fos\ alt}$	=	fu $_{repulp\ oth\ fos}$	TJ	fF22

Fu $_{pa\ fos}$ = Fossil fuel for actual paper production, excluding fuel for boilers

Fu $_{pa\ fos\ alt}$	=	fu $_{pa\ dir\ fos}$ + fu $_{pa\ oth\ fos}$	TJ	fF23

3.5.3. KPIs: Specific consumption of fossil fuel

3.5.3.1. KPIs for fossil fuel, alternative 0: total consumption of fossil fuel

Fossil fuel consumption, in total for the mill per ton of final product

= Fu $_{tot\ fos}$ / Final prod	***GJ/ton***	***fF24***

This KPI can only be used to follow up the performance of a given mill over time.

Consumption of fossil fuel per ton of pulp stock produced

= Fu $_{stock\ fos}$ / Pu $_{stock}$	***GJ/ADt***	***fF25***

This KPI is used to compare the consumption to that of other integrated mills' production of pulp stock and to that of non-integrated pulp mills where the drying of the market pulp is excluded.

Consumption of fossil fuel for drying, per ton of market pulp produced

= Fu $_{dry\ fos}$ / Pu $_{market}$	***GJ/ADt***	***fF26***

This KPI is used to compare the consumption for drying of market pulp to that of other integrated and non-integrated pulp mills.

Consumption of fossil fuel per ton of market pulp produced

= Fu $_{stock\ fos}$ / Pu $_{stock}$ + Fu $_{dry\ fos}$ / Pu $_{market}$	***GJ/ADt***	***fF27***

This KPI is used to compare the consumption to that of other integrated mills' production of market pulp and to that of non-integrated market pulp mills.

Consumption of fossil fuel per ton of paper produced from purchased pulp

= Fu $_{repulp\ fos}$ / Pu $_{purch}$ + Fu $_{pa\ fos}$ / Pa $_{tot}$	***GJ/ton***	***fF28***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from purchased pulp and to that of non-integrated paper mills.

Consumption of fossil fuel per ton of paper produced from pulp stock

= Fu $_{pa\ fos}$ / Pa $_{tot}$	***GJ/ton***	***fF29***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from own pulp stock and to that of non-integrated paper mills where the repulping of purchased pulp is excluded.

3.5.3.2. KPIs for fossil fuel, alternative 1: excluding fuel for boilers

Consumption of fossil fuel for direct heating and as transportation fuel, in total for the mill per ton of final product

$= Fu_{tot\ fos\ alt} / Final\ prod$	***GJ/ton***	***fF30***

This KPI can only be used to follow up the performance of a given mill over time.

Consumption of fossil fuel for direct heating and as transportation fuel per ton of pulp stock produced

$= Fu_{stock\ fos\ alt} / Pu_{stock}$	***GJ/ADt***	***fF31***

This KPI is used to compare the consumption to that of other integrated mills' production of pulp stock and to that of non-integrated pulp mills where the drying of the market pulp is excluded.

Consumption of fossil fuel for direct heating and as transportation fuel, for drying, per ton of market pulp produced

$= Fu_{dry\ fos\ alt} / Pu_{market}$	***GJ/ADt***	***fF32***

This KPI is used to compare the consumption for drying of market pulp to that of other integrated and non-integrated pulp mills.

Consumption of fossil fuel for direct heating and as transportation fuel per ton of market pulp produced

$= Fu_{stock\ fos\ alt} / Pu_{stock} + Fu_{dry\ fos\ alt} / Pu_{market}$	***GJ/ADt***	***fF33***

This KPI is used to compare the consumption to that of other integrated mills' production of market pulp and to that of non-integrated market pulp mills.

Consumption of fossil fuel for direct heating and as transportation fuel per ton of paper produced from purchased pulp

$= Fu_{repulp\ fos\ alt} / Pu_{purch} + Fu_{pa\ fos\ alt} / Pa_{tot}$	***GJ/ton***	***fF34***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from purchased pulp and to that of non-integrated paper mills.

Consumption of fossil fuel for direct heating and as transportation fuel per ton of paper produced from pulp stock

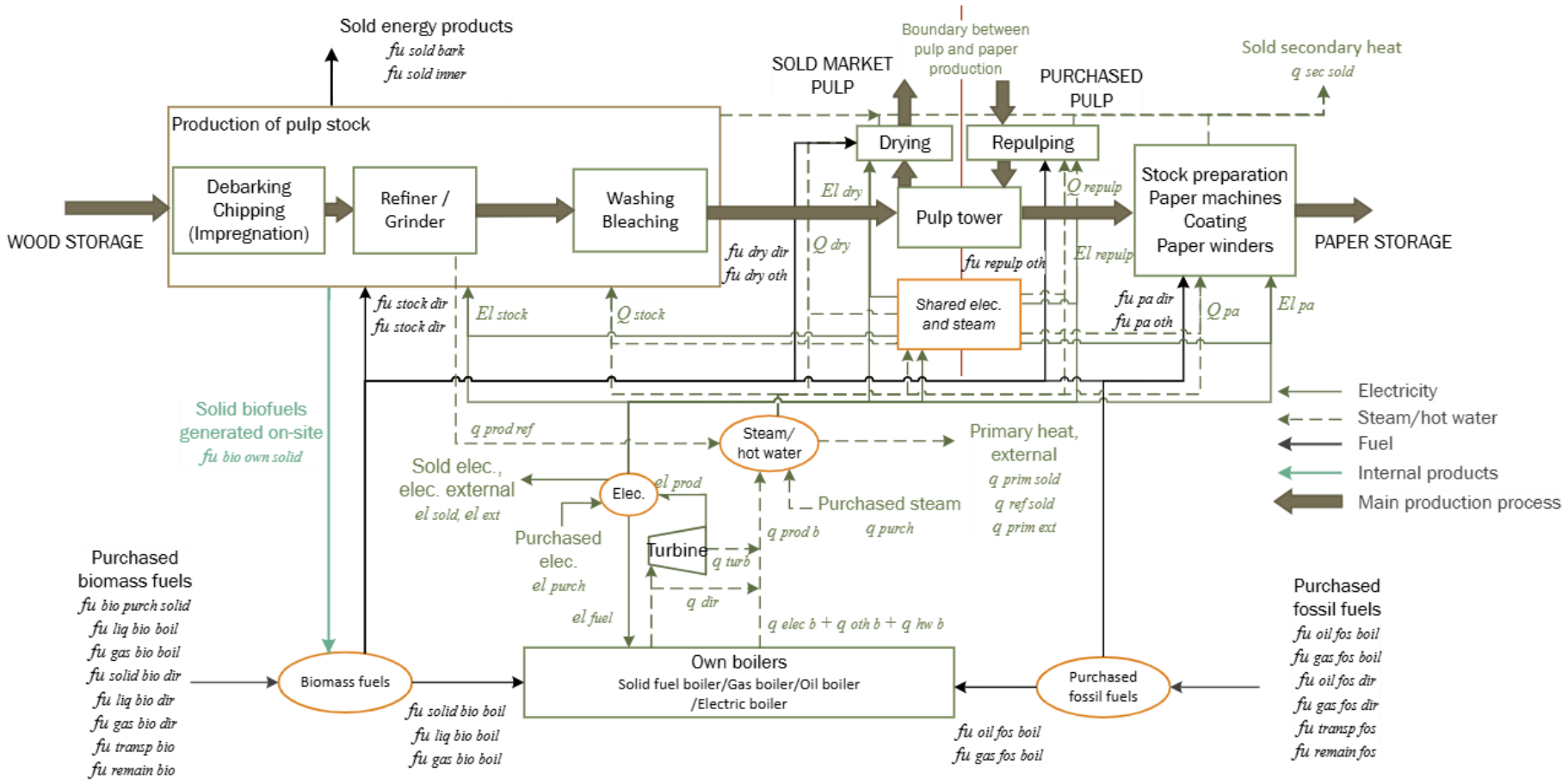
$= Fu_{pa\ fos\ alt} / Pa_{tot}$	***GJ/ton***	***fF35***

This KPI is used to compare the consumption to that of other integrated mills' production of paper from own pulp stock and to that of non-integrated paper mills where the repulping of purchased pulp is excluded.

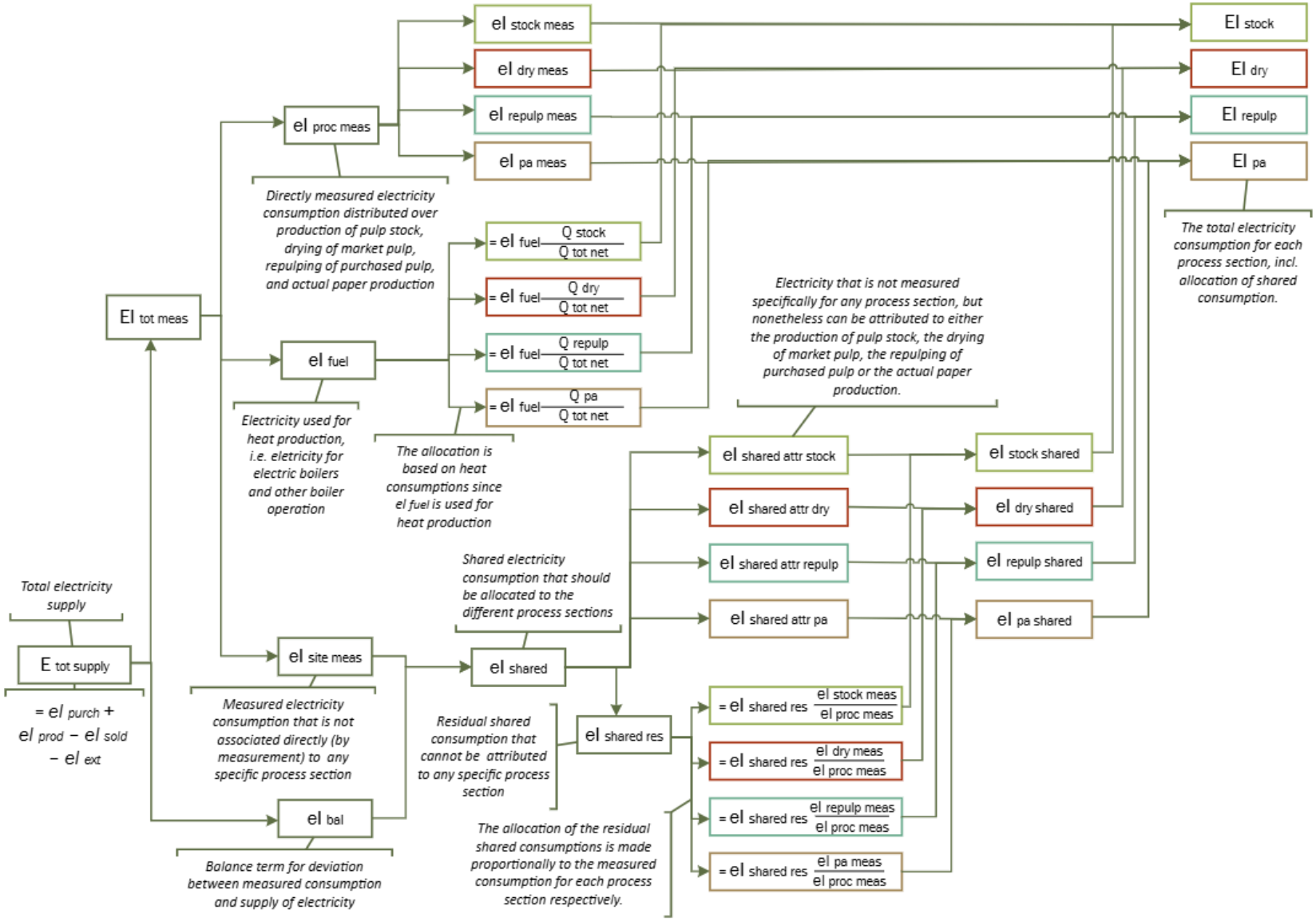
Appendix. Flow chart and graphical allocation schemes

1. Flow chart
2. Allocation electricity
3. Allocation heat
4. Allocation fuel
5. Balance for solid biofuels

Flowchart

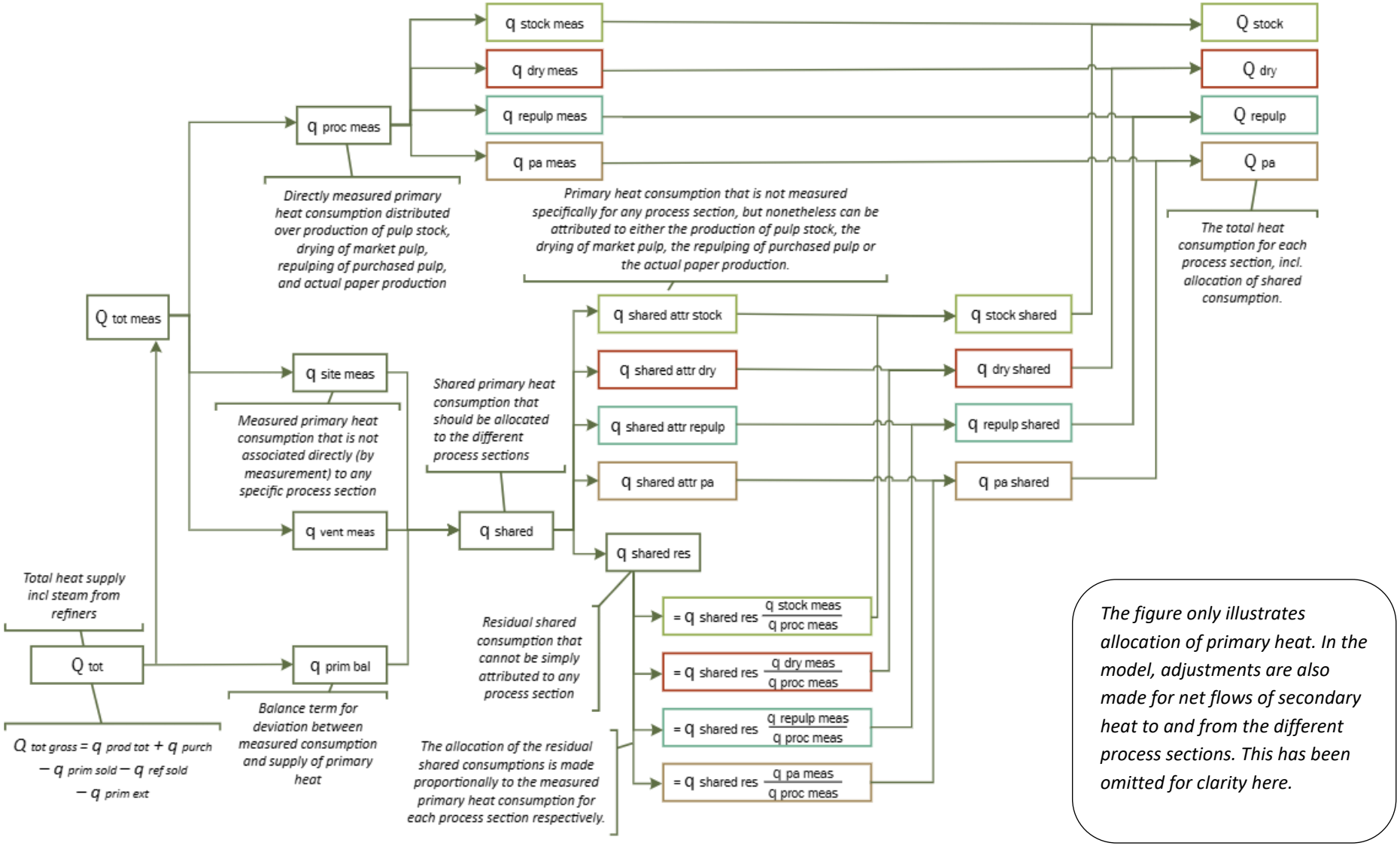

Sold energy products
fu sold bark
fu sold inner
Boundary between pulp and paper production
SOLD MARKET PULP
PURCHASED PULP
Sold secondary heat
q sec sold
Production of pulp stock
Debarking Chipping (Impregnation)
Refiner / Grinder
Washing Bleaching
Drying
Repulping
Stock preparation Paper machines Coating Paper winders
WOOD STORAGE
PAPER STORAGE
El dry
Q repulp
Pulp tower
fu dry dir
fu dry oth
Q dry
fu repulp oth
El repulp
Shared elec. and steam
fu stock dir
fu stock dir
El stock
Q stock
fu pa dir
fu pa oth
Q pa
El pa
Solid biofuels generated on-site
fu bio own solid
q prod ref
Steam/ hot water
Primary heat, external
q prim sold
q ref sold
q prim ext
Sold elec., elec. external
el sold, el ext
Elec.
el prod
Purchased steam
q purch
q prod b
Purchased elec.
el purch
Turbine
q turb
q dir
el fuel
q elec b + q oth b + q hw b
Purchased biomass fuels
fu bio purch solid
fu liq bio boil
fu gas bio boil
fu solid bio dir
fu liq bio dir
fu gas bio dir
fu transp bio
fu remain bio
Biomass fuels
Own boilers
Solid fuel boiler/Gas boiler/Oil boiler /Electric boiler
Purchased fossil fuels
fu solid bio boil
fu liq bio boil
fu gas bio boil
fu oil fos boil
fu gas fos boil
Purchased fossil fuels
fu oil fos boil
fu gas fos boil
fu oil fos dir
fu gas fos dir
fu transp fos
fu remain fos
Electricity
Steam/hot water
Fuel
Internal products
Main production process

Allocation of electricity consumption



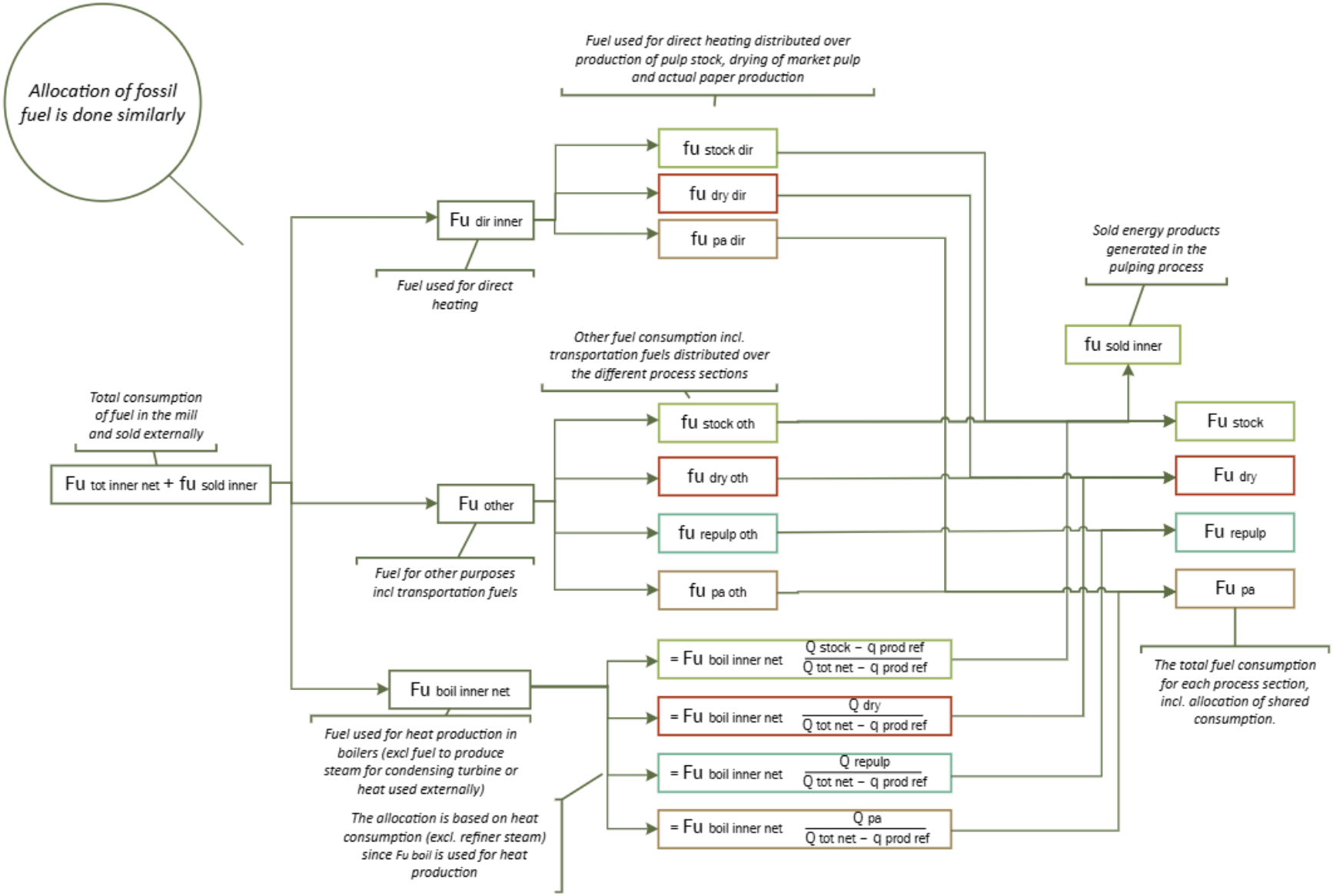
Allocation of heat consumption

When allocating heat consumption, the mill's own consumption of refiner steam is considered as primary heat



The figure only illustrates allocation of primary heat. In the model, adjustments are also made for net flows of secondary heat to and from the different process sections. This has been omitted for clarity here.

Allocation of fuel consumption, inner system boundary



Balance for solid biofuels