Biomass streams in Austria: Drawing a complete picture of biogenic material flows within the national economy

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Keywords: biomass, material flows, MFA, Austria, bioenergy, Sankey diagram

Published as:
Kalt Gerald, 2015. Biomass streams in Austria: Drawing a complete picture of biogenic material flows within the national economy. Resources, Conservation and Recycling 95, 100–111. doi:10.1016/j.resconrec.2014.12.006

Abstract:

In order to achieve the targets defined in the European Union's "Low Carbon Roadmap", the "Energy Roadmap 2050" and the "Bioeconomy Strategy", an enhanced use of biomass is required; not only for energy but also for material uses. In this context and to facilitate targeted resource and energy policy measures, profound knowledge of the status quo of biomass utilization is of crucial importance.

The core objective of this paper is to provide complete flow diagrams of the biomass streams within the Austrian economic system from a meso-scale perspective, taking into account all types of uses. Contrary to material flow accounts (MFA), internal streams (e.g. due to biomass processing and transformation, recycling and reuse of residues and by-products, stock changes of end-consumer products) are explicitly taken into consideration and quantified. This approach reveals gaps and inconsistencies in statistical data and facilitates conclusions about quantities not recorded in statistics. Furthermore, the structure of biomass use is visualized and the extent of biogenic material reuse and recycling is revealed.

The results show that biomass imports to Austria surpassed exports by about 15 % in 2011 (based on dry mass). The distribution of biomass among the different uses depends on whether direct consumption or final uses are considered. In the latter case, which is considered more appropriate, inland biomass consumption was distributed as follows: 7 % human food, 18 % raw material, 38 % energy and 37 % animal feed. Exports are primarily composed of wood products.

Contrary to common assumption, energy recovery is still usually the ultimate step of cascadic biomass use rather than primary purpose, or based on by-products. Judging from wood quantities being processed and consumed and foreign trade data, domestic wood supply according to felling reports (and stated as "domestic extraction used" in official MFA data) is clearly underrated. Conversely, domestic feed production according to MFA data is inconsistent with official animal feed statistics and appears to be overestimated by at least 30 %.

Highlights:

- Complete flow diagrams of the biomass streams within the Austrian economic system
- Gaps and inconsistencies in statistical data and material flow accounts are revealed
- The most relevant sinks of domestic biomass streams are energy and animal husbandry
- Judging from consumption and trade, domestic wood supply is underrated in MFA data
- Largest part of biomass for energy is made up by wastes, residues and by-products

1 Introduction

The substitution of fossil-based resources is one of the core objectives of the European Union‘s long-term policy targets. In order to achieve the ambitious targets defined in the European Union’s “Low Carbon Roadmap” (European Commission, 2011a), the “Energy Roadmap 2050” (European Commission, 2011b) and the “Bioeconomy Strategy” (European Commission, 2012), an enhanced use of biomass is required; both for material and for energy uses (see Kalt et al., 2012, for example).

Already today forestry and the wood processing industries are important elements of Austria’s economy (Statistik Austria, 2014a, Statistik Austria, 2014b). In the energy sector, biomass is the most important renewable energy source (Statistik Austria, 2014c) and is generally considered to be of high importance for the establishment of a sustainable energy system (see Streicher et al., 2010, for example). With forest resources already being utilized to a large extent (BFW, 2011) and limited agricultural land available for dedicated energy crops, the need for efficient management of biogenic resources, recycling and cascade use is becoming increasingly urgent. Profound knowledge of the status quo of biomass utilization is of crucial importance for designing targeted resource and energy policy measures.

Due to the wide range of biomass types and uses, material reuse and recycling, the structure of biomass use in a national economy is complex. Material flow accounts (MFA; see Eurostat, 2013a) provide some insight, yet they disregard crucial aspects like transformation processes, secondary uses, recycling and stock development. Therefore they are of limited use for answering many research and policy questions.

The core objective of this paper is to provide complete flow diagrams of the biomass streams within the Austrian economic system from a meso-scale perspective. These diagrams are intended as a basis for resource and energy policy decisions, long-term planning in the context of action plans and national strategies as well as scenario development. Furthermore, the methodological approach and obtained results might be of use for researchers analyzing biomass flows in other countries or regions.

The paper does not consider the biomass streams within forests, arable land and other biomass production systems. Analyses of nutrient cycles, the humus balance or other ecological aspects are not within the scope of this work.

2 Methodology, data and difficulties

In following sections, the methodological approach, data basis, uncertainties and challenges in mapping biomass streams are described.

2.1 Methodological approach

The applied methodological approach included the following steps:

(1) Literature research: The research focussed on international studies exploring biomass flows within an economy and existing publications and data for Austria. A study from Switzerland (Baier and Baum, 2008) proved to be of high value. Official

MFA data for Austria are described in Eisenmenger et al. (2011) and are available for download at Eurostat (2013b).

(2) Reviewing statistical data and selecting primary data sources: The main data sources were identified (see section 2.2) and online database queries were conducted. Data from industry associations were used for cross-checking, e.g. Austropapier (2014), Holzindustrie (2014), Agrana (2014), ARGE Biokraft (2014).

(3) Definition of a preliminary structure of the flow diagram: Based on the previous steps, a preliminary set of nodes and streams, intended to represent all relevant flows within the economic system as well as international trade, was defined.

(4) Devising a common and consistent level of aggregation for biomass flows: The levels of aggregation in statistics and databases often vary widely. For further processing, data were aggregated to a common level (which is considered relatively high yet sufficiently detailed for this research question). This also included converting statistics to other statistical codes, as the product codes used in national economic (production) statistics (Statistik Austria, 2013a) are not consistent with "HS-codes" used in foreign trade statistics (Eurostat, 2013c). This was done using correspondence tables provided by Statistik Austria.

(5) Identification of redundant data and resolving of contradicting data: In this step some of the main difficulties in drawing a complete picture were resolved (see section 2.3). To avoid double counting, data redundancy resulting from the use of sources with partly overlapping ranges were eliminated (e.g. the Eurostat foreign trade database and the FAO forestry database both contain data on international wood trade, but different units of measurement are used).

(6) Definition of conversion factors and creation of a complete data base: Based on literature and values stated in statistics, conversion factors were determined (e.g. tonnes per m^3 for wood, representative water contents of all biomass types and products). These factors were used to derive a complete representation of relevant biomass streams in tonnes (wet and dry mass basis).

(7) Validation, identification and filling of data gaps: Next, the ultimate structure of the diagram was decided. Compared to the preliminary structure (step 3), some nodes representing different industry sectors were merged due to insufficient data availability and/or uncertainties with respect to the origin or destination of flows. Data gaps were identified and filled based on plausibility and mass balance considerations.

(8) Graphic representation: Two versions of the flow diagrams were prepared; one based on the reported quantities including water ("wet mass basis diagram") and one showing quantities converted to tonnes of dry mass ("dry mass basis diagram").

(9) Interpretation, discussion and conclusions: The final step of the work was to interpret and discuss the results and draw conclusions.

2.2 Data

Primarily data from official statistics were used. If no official or scientifically published data were available, other publications and reports (such as annual business reports) were used. In some few cases, where no official or otherwise published data could be found, own assessments were made in consultation with national experts.

The main sources were:

National supply balance sheets (Statistik Austria, 2013b): These statistics provide data on production, foreign trade and consumption by type of use (food, feed, industrial uses) at an appropriate level of aggregation.

Forestry statistics provided by FAOSTAT (FAO, 2013): They include all relevant statistical items like production, domestic supply and foreign trade for all types of wood, paper, pulp and wood based panel and consistent units of measurement are used for all items.

Foreign trade statistics (Eurostat, 2013c): Following the "Combined Nomenclature" (CN, see European Commission, 2013), foreign trade data are available at different levels of aggregation. Four-digit codes (HS4) were generally found to be sufficiently detailed for this work. First, the complete set of HS4-data was obtained from the Eurostat database. Second, all product codes containing materials or products of biogenic origin were identified (more than 500 HS4-codes included in 47 different HS2-codes). Third, to avoid double counting all products covered by other statistics (primarily agricultural products covered in supply balances and wood included in FAO-data) were eliminated.

National economic (production) statistics (Statistik Austria, 2013b): In this statistic, the national classification system "ÖPRODCOM" is used. After the data had been converted to the HS4 classification system, the same approach as for foreign trade data was applied to avoid double counting.

National energy balance (Statistik Austria, 2014c): Data are provided for 13 types of biogenic fuels. Energy data were cross-checked with other statistics (waste statistics, forestry data and biofuel statistics).

National Waste Management Plan (UBA, 2012): The most recent waste data are provided in the "Status Report 2012" (see BMLFUW, 2013a). All available data referring to biogenic wastes were analysed and cross-checked with other statistics.

In addition to these main sources, the following sources were used to fill data gaps and/or gain further insight:

In addition to the national energy balance, **annual biofuel reports** published by the Federal Environmental Agency (Winter, 2012) provided further information about biofuel supply and consumption.

Data on non-marketable animal feed published in the **"Green Report" of the Ministry of Agriculture, Forestry, Environment and Water Management** (BMLFUW, 2013b) were used.

The supply balance sheets mentioned above are available for the following agricultural commodities: grain cereals, pulses, potatoes, plant oil, sugar beet, fruit and vegetables. Data on further crops were taken from the **Eurostat database** (Eurostat, 2013d).

Data on streams not (or only partly) covered in the above-mentioned sources were taken or derived from other publications, for example: The assessment of the total amount of manure is based on Zethner and Süßenbacher (2012). The share of straw used as bedding material was taken from (Eisenmenger et al., 2011). The input to biogas plants was calculated on the basis of the annual Green Electricity Report published by the Austrian energy regulator (E-Control, 2011). The amount of fermentation residues from biogas plants was estimated based on data from KTBL (2013).

2.3 Uncertainties and methodological challenges

Despite the wealth of statistics available, there are considerable uncertainties in mapping biomass flows. In addition to general inaccuracies of statistics, the following sources of uncertainties have been identified:

(a) The definition of representative conversion factors is one of the main difficulties, especially if inhomogeneous aggregates are involved and/or there is no detailed information available on material compositions (e.g. in the case of biogenic waste or diverse products recorded under one trade code).

(b) For some sectors production in economic statistics (Statistik Austria, 2013a) is expressed in number of units rather than weight or volume units. In such cases, only rough estimates can be derived.

(c) As mentioned above, redundant data are available in several areas. In such cases, units of measurement often differ and it is sometimes not possible to determine universally valid conversion factors. Furthermore, nomenclatures and classification systems are often not consistent, which makes it difficult to identify and quantify overlapping ranges of different datasets. This is especially true for waste data (e.g. in the field of wood wastes/wood processing residues). However, by combining all available supply, consumption and waste data, plausible solutions could be found in all such cases.

(d) Foreign trade and production statistics are based on surveys with cut-off thresholds, which implies some inaccuracy. However, compared to most other sources of uncertainties, the relevance of cut-off thresholds is very limited due to relatively high levels of coverage (e.g. 95 to 97% in the case of foreign trade statistics; Statistik Austria, 2013c).

(e) Moreover, certain data are not available due to confidentiality (e.g. material flows related to the starch industry). Estimates have been derived from available information on plant capacities and capacity utilization.

For *substance* flow analyses, the law of mass conservation expressed as a continuity equation is one of the core principles and may be used to calculate unknown flows. For this *material* flow analysis, however, applying the continuity equation is partly considered problematic for the following reasons: (1) Generally, it can only be applied for dry mass flows or if considerable changes in water contents (and other changes in material composition) in the according node are negligible. (2) Material losses and stock changes are usually not known. (3) Considering the wide range of uncertainties, assumptions about average water contents and other potential error sources described above, the continuity equation cannot be expected to be satisfied for all nodes.

Hence, the continuity equation was only applied to calculate unknown dry mass flows if there was good reason to suspect that certain flows are significantly underrated or generally not covered by any statistics. For example:

(a) There is no data on the domestic use of wood based panels, sawnwood etc. in the construction sector. Building construction is certainly included in economic statistics, but only expressed in monetary values and numbers of buildings. Therefore, the according flows were calculated on the basis of domestic supply and foreign trade.

(b) Previous studies have shown that domestic supply of industrial roundwood and fuelwood is clearly higher than official felling reports indicate (Strimitzer and Nemestothy, 2014; Kalt and Kranzl, 2012). Consumption and foreign trade data were used to calculate these quantities.

(c) Human food consumption was calculated on the basis of supply balances, economic (production) statistics (Statistik Austria, 2013), foreign trade and waste data. Considering the diversity of food products, insufficient data on food being disposed of (amounts and compositions of material ending up in private composting can only be estimated), and the level of aggregation applied here, the results in this field should be regarded as rough estimates.

3 Results

The following figures show the main results of this work: the biomass flows in Austria’s national economy in 2011 in tonnes of dry mass (Fig. 1) and tonnes of wet mass (Fig. 2).

3.1 Explanations and clarifications

The biomass streams are depicted as Sankey diagrams, consisting of nodes and streams. Nodes represent sources (e.g. forestry or arable land), sinks (e.g. combustion), and transformation processes (e.g. processing of roundwood to sawlogs and residues in the sawmill industry). The width of streams is proportional to the quantity (weight in tonnes of wet/dry mass).

To avoid misinterpretations, the following aspects need to be mentioned:

Streams generally consist of various biomass types and/or products (“components”). Despite a relatively high level of aggregation applied, the number of different components amounts to more than 50, meaning that individual representations or labelling of all components in the diagrams is not practicable. A data table summarizing all flow data and assumed water contents is included in the Annex.

Water contents usually change during conversion processes. Hence, input and output streams of nodes containing such processes sometimes show significant differences in the "wet mass basis diagram".

In both the dry and the wet mass basis diagram, input and output quantities of some nodes show small differences for the following reasons: (1) Stockkeeping and losses are not shown. (2) Due to a minimum stream width, lines representing flow quantities below a certain threshold are not proportional to the actual quantities.

The water contents of biomass types/products vary widely, causing significant differences between the two diagrams. The scaling factors of the diagrams differ by a factor of 2 (i.e. a flow of, for example, 1 million tonnes is shown twice as broad in the dry mass basis diagram as in the wet mass basis diagram).

Quantities ending up in sinks are considered to be of special interest for various reasons. In order to have these quantities explicitly represented in the diagrams, they are shown as streams to arrow-shaped nodes pointing upwards.

Nodes summing up streams from different sources (usually imports and domestic supply) were introduced for purposes of improved clarity. They are represented by arrow-shaped nodes labelled "Total [component name]".

Some nodes have loops or "backward flows"; they represent recycling, material reuse and utilization of residues and by-products (e.g. utilization of sawmill residues in the paper, pulp and wood panel industry; crop production used as seed; land application of manure; use of residues as animal feed).

Due to their magnitude and economic importance, wood flows between the different wood-processing industries (essentially the sawmill industry, the paper, pulp and panel industry), are of special interest in Austria. However, as there are already separate *wood flow diagrams* available (see Strimitzer and Nemestothy, 2014), there is no need for reproducing these material flows here. The wood-processing industries are therefore - highly simplified - shown as one single node here.

Building construction is included in "Miscellaneous industry sectors", and buildings (or rather their biogenic components) are considered as "products". Stock increases of wood products can largely be attributed to building construction.

3.2 Biomass streams in Austria in 2011

On a dry-matter basis, the most relevant biomass streams are made up by wood flows related to the wood processing industries. Roundwood flows to the sawmill industry represent the largest streams, followed by the paper and pulp and the wood panel industry. Energy uses directly or indirectly related to the wood processing industries (i.e. heat and power generation in autoproduction plants, waste liquor utilization in the paper industry, pellet production from sawmill residues and wood residues sold for energy generation) together account for 45 % of all biomass used for energy (dry mass basis). Therefore, the wood processing industries are highly important elements of biomass supply and consumption in Austria. More specifically, the sawmill industry supplies large quantities of wood chips and other residues to the paper, pulp and panel industry. In the figures, this is represented by the recycling loop of the wood processing industries. A more detailed analysis of the wood flows in Austria with a focus on the interrelations between then different branches is provided in Strimitzer and Nemestothy (2014) and Kalt and Kranzl (2012).

The most obvious difference between the figures 1 (dry mass basis) and 2 (wet mass basis) is the magnitude of the agricultural material cycle, comprising production on arable land and grassland, animal husbandry and the application of manure on agricultural land. With an assumed average dry mass content of 10 %, the total flows of manure are estimated 33 million tons (Mt), representing the largest material flow on a wet mass basis. Due to insufficient statistical data on manure application, the distribution between arable land, extensive and cultivated grassland should be seen as a rough estimate.[1]

Due to comparatively low water contents of biomass used for energy, energy generation appears to be less significant in the wet mass basis diagram than on a dry mass basis. The streams to “Energy uses”, which are associated to practically all biomass utilization chains, illustrate the diversity of bioenergy and the fact that the Austrian bioenergy sector is largely based on by-products and wastes. Apart from the by-product and waste streams originating from production and consumption nodes, the direct stream from “Forestry” to “Energy uses” can also partly be considered as by-product utilization for the following reason: Log wood and forest wood chips are usually by-products of stemwood harvesting for material uses.

Agricultural biomass consumption is dominated by animal husbandry. On a dry mass basis, animal husbandry is the second largest and on a wet matter basis by far the largest node in the flow diagram. Biomass from grassland, accounting for 4.7 million tons dry mass (Mt_{dry}), was almost as important as fodder crops from arable land (5.2 Mt_{dry}) in 2011.

Human food consumption is significantly lower than the flows of animal feed. Liquid biofuel supply (primarily biodiesel and ethanol, accounting for 6.75 % of all road transport fuels), is of relatively little importance in the overall picture. Still, in the market segment of plant oil the additional resource demand for biodiesel production had a strong impact on the supply balance: The self-sufficiency decreased from about 60 % around the year 2000 to about 30 % in recent years (Statistik Austria, 2013b).

The figures illustrate the high significance of international biomass trade. Apart from wood, large quantities of agricultural commodities and paper are both imported and exported. Austria is a net exporter of paper products (net exports of paper and paperboard accounted for 2.4 Mt_{dry}) and a net importer of recovered paper (0.9 Mt_{dry}). Cross-border trade with refined wood fuels (primarily wood pellets) has increased significantly during the last ten years and amounted to about 0.7 Mt_{dry} being both imported (primarily from the Northern neighbouring countries) and exported (primarily to Italy) in 2011 (see Kalt and Kranzl, 2012).

[1] The data shown in the figures are based on the assumption that the distribution corresponds to the shares of feed (dry mass basis) originating from the according land use type.

The illustration on dry mass basis facilitates a direct and more substantial comparison between flows of different material than the wet mass basis diagram. Moreover, identifying data gaps and quantifying unknown streams is only possible if a consistent reference unit is used. The wet mass basis diagram, on the other hand, yields information on *actual* material flows and provides insight into the extent of transport needs in different fields of biomass production and use. Most notable, the feed-manure-cycle is related to vast material transports, albeit over typically short distances in comparison to the forest industry, for example.

As hardly any commodities with high water contents are included in cross-border streams, international trade appears clearly less significant if wet mass flows are considered. The average water content in both import and export streams is approximately 25 %. In contrast, biomass from agricultural land has an average water content of 75 %; primarily due to a high share of field forage and the quantity of biomass from grassland.

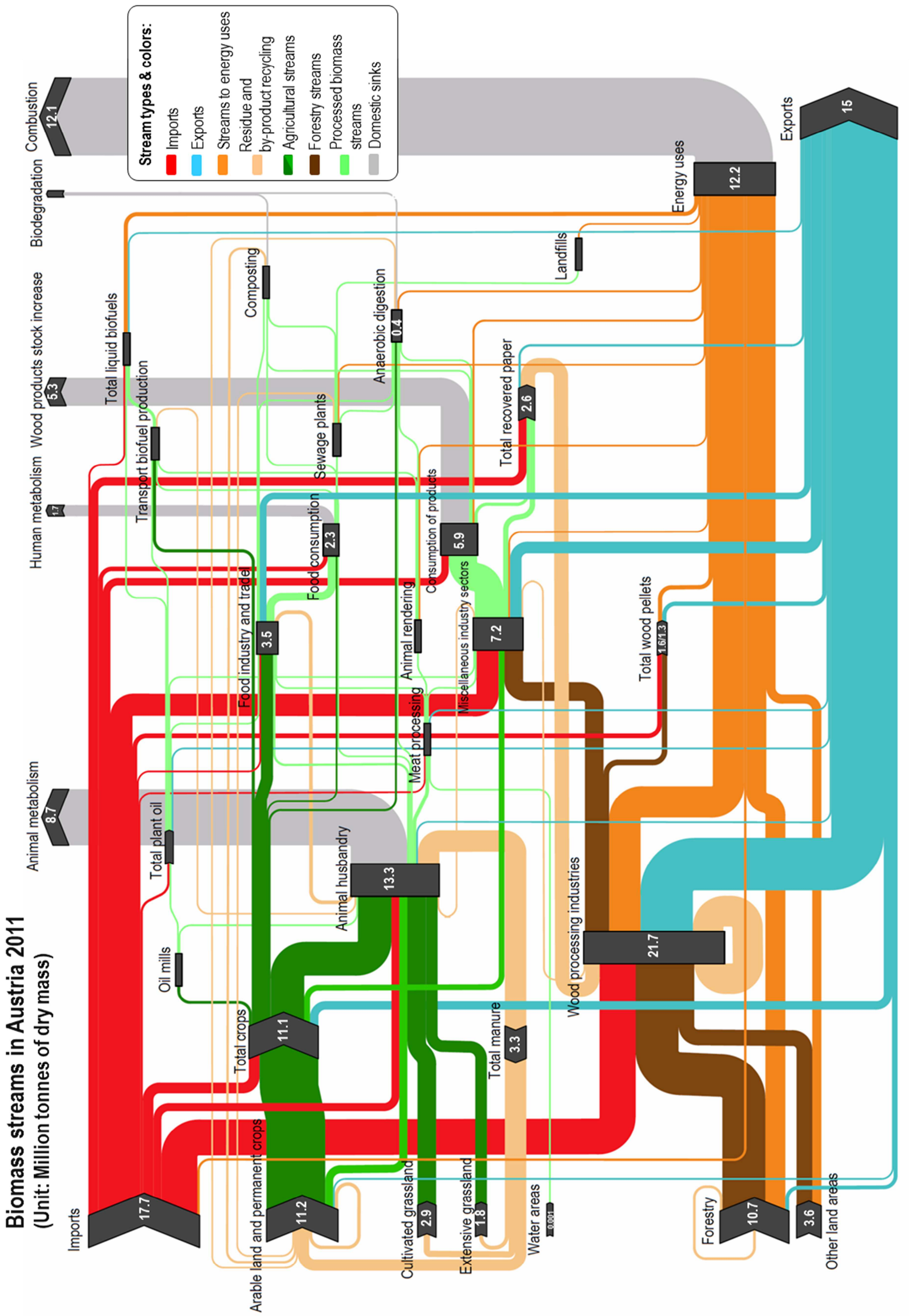

Fig. 1: Dry biomass streams in Austria in the year 2011 (“dry mass basis diagram”)
Sources: see section 2.2.

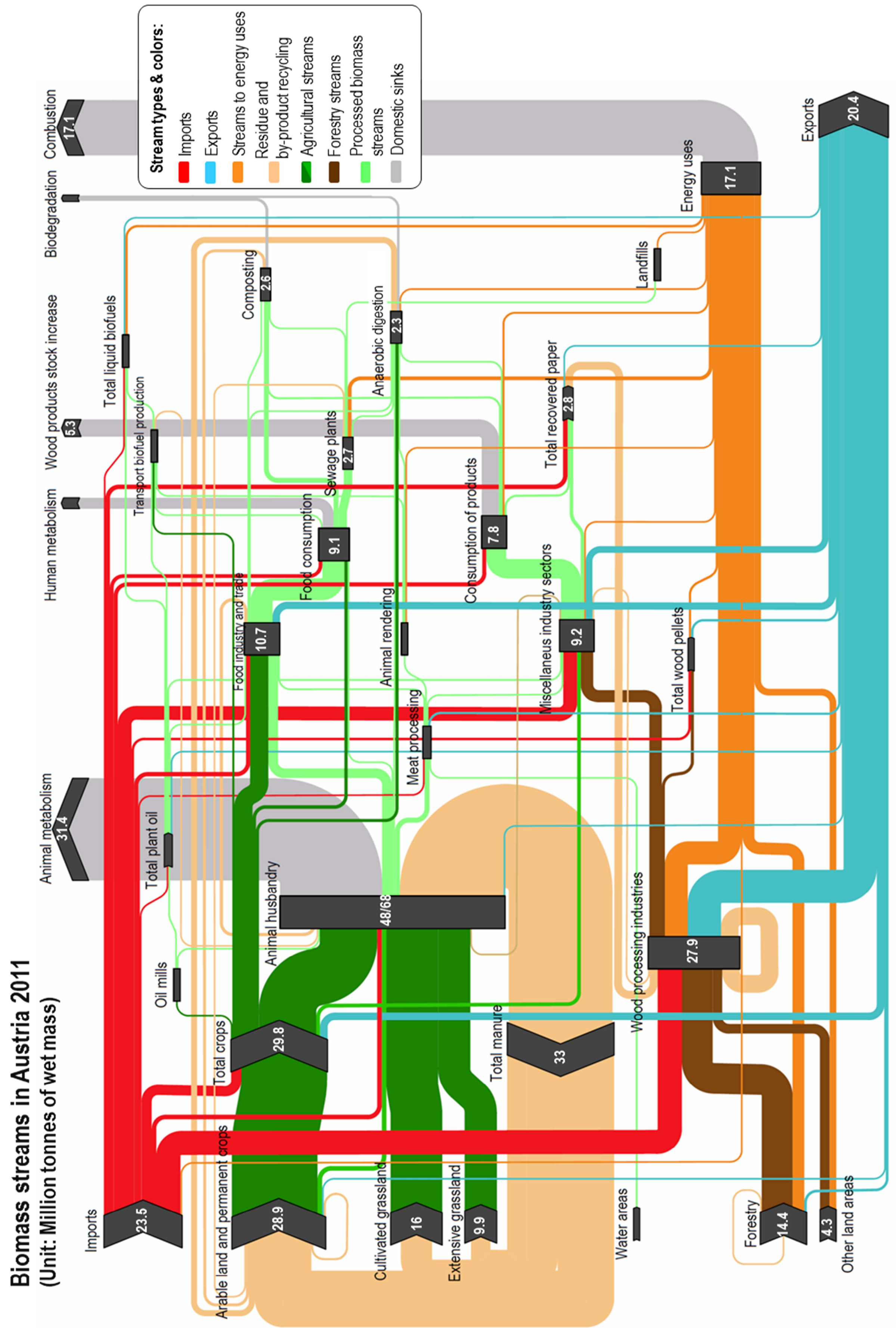

Fig. 2: Wet biomass streams in Austria in the year 2011 ("wet mass basis diagram"). Sources: see section 2.2.

4 Discussion and conclusions

4.1 Key conclusions from the material flow analysis

The total supply of biomass for Austria's economy in 2011 was composed as follows (dry mass basis): The largest share came from imports (approx. 40 %), domestic agricultural biomass accounted for about one third and about 20 % was forest biomass recorded in official felling reports. The rest is considered to be forest wood not recorded in statistics and biomass from miscellaneous areas (e.g. roadside verges, orchards, vineyards).

Exports were about 15 % lower than imports in 2011. More than 50 % of biomass exports can be attributed to the sawmill, the paper and pulp and the panel industry.

The most relevant biomass sinks on dry mass basis in Austria are energy generation and animal husbandry. 12.2 Mt_{dry} (17.1 Mt_{wet}) were combusted for energy generation in 2011 and approximately 12 Mt_{dry} (46 Mt_{wet}) of biomass were consumed as feed (including grazed biomass, all kinds of fodder crops and other feedstuffs). Hence, on wet mass basis, animal husbandry is by far the most significant biomass sink. By comparison, human food consumption is estimated 2.3 Mt_{dry} (8 Mt_{wet})[2].

The main inconsistencies in statistical data about biomass supply and consumption refer to wood and feedstuff supply. Domestic wood supply according to felling reports (and stated as "domestic extraction used" in MFA) is clearly underrated. This data gap is not addressed in any official statistics, but it has already been analysed and discussed in previous studies (Kalt and Kranzl, 2012; Strimitzer and Nemestothy, 2014). For future MFA it is recommended that unregistered domestic wood supply is estimated based on consumption figures.

Conversely, domestic feed production according to MFA is inconsistent with official animal feed statistics and appears to be overestimated by at least 30 %. In contrast to the inconsistency in wood supply, this was not found out through mass balance considerations but by comparing different official statistics; namely MFA data (Eurostat, 2013b) and data on agricultural production (BMLFUW, 2013b), supply balances (Statistik Austria, 2013b) and foreign trade (Eurostat, 2013c). This inconsistency, which may partly be explained by material losses in feed supply chains, should be removed or at least addressed in future MFA.

Contrary to common assumption, energy recovery is usually the ultimate step of cascadic biomass use rather than primary purpose. Hence, recent developments (renewable energy targets and associated support schemes resulting in increasing bioenergy use) have not changed the fact that bioenergy in Austria is mostly based on by-products, residues and wastes.

Only in the case of liquid biofuels and biogas originating from energy crops, fairly insignificant segments which have been stagnant in recent years, energy generation is definitely the primary purpose of biomass production. In the case of energy wood

[2] According to Krausmann et al. (2008) 2 Mt_{dry} of biomass directly served as human food in Austria in 2000. If animal-based food is taken into consideration, this is highly consistent with the results of the present study.

(wood logs and forest wood chips) there are usually other primary purposes than the provision of biomass for energy, such as industrial roundwood production, forest thinning, orchard pruning etc.

4.2 Implications of enhanced cascadic biomass use

Still, options for increasing resource efficiency through enhanced cascadic utilization chains should be explored. This can be achieved by promoting the separate collection and sorting of biogenic wastes or adding further stages of material uses for by-products before combustion. Wood processing residues, for example, could in principle be used for producing advanced biomaterials before being ultimately used for energy generation in waste incineration or dedicated biomass plants.

Currently, more than 3 Mt_{dry} of residues from wood processing (approximately 1.7 Mt_{dry} of black liquor not included) are directly used for energy. If for example 10 % of this residue flow were used for manufacturing cellulose acetate polymers, the output would correspond approximately to one fourth of Austria's total consumption of plastics (cp. IfBB, 2014; Kalt et al., 2014). From a resource efficiency perspective and to minimize logistics and transport expenses, an optimal strategy would probably involve existing wood industry facilities being converted to integrated biorefineries.

To provide a scientific decision basis for potential state intervention, resource efficiency gains and other benefits achieved through enhanced cascadic biomass use must be weighted against economic aspects as well as possible negative spillover effects. If, for example, wood residues are increasingly used as raw material for biopolymers, the wood processing sector will likely become more dependent on external fuel and energy supply. In such cases, resource efficiency gains and the amount of overall greenhouse gas savings depend on various factors: efficiencies and energy requirements of biomass transformation processes compared to conventional ones, logistics and transport requirements compared to a business-as-usual scenario, and the energy sources used to substitute residue-based autoproduction, to name just a few. Depending on policy priorities, it might or might not be beneficial to promote further cascadic biomass uses through support schemes or regulatory measures. Science-based recommendations concerning optimization of biomass flows with regard to cascade use should therefore be based on scenario analysis.

4.3 Austria, the EU, Switzerland and the rest of the world

Biomass supply and utilization patterns in Austria are characterized by the country's high percentage of forested land, its large wood processing industries, a traditionally great importance of bioenergy and its landlocked location in the centre of Europe. Especially with regard to the magnitude of roundwood imports and wood products exports in relation to the domestic production, the situation in Austria is quite specific. As discussed in Kalt and Kranzl (2012), there are only three more EU countries which are importing large quantities of roundwood while being a net exporter of wood products: Sweden, Finland and Germany. For the EU as a whole this is also true (FAO, 2013).

Biomass stream in Switzerland in the year 2006 are analysed and shown as detailed flow diagrams in Baier and Baum (2008). Just like Austria, Switzerland is a mountainous country located in Central Europe with slightly more than 8 million inhabitants, and the GDP in purchasing power parity terms is very similar (OECD/IEA, 2014); hence, a direct comparison between the two countries is considered reasonable and suitable for revealing particularities in the countries' biomass flows. The most apparent difference is significantly lower wood flows in Switzerland. Roundwood production in Austria was around three times higher in recent years and the relative differences in foreign trade flows and industrial wood processing were even greater (see FAO, 2013). Also, biomass is of clearly less significance for energy generation in Switzerland: The share in total primary energy supply is below 6 % (OECD/IEA, 2014; SFOE, 2014), whereas in Austria it is close to 20 % (Statistik Austria, 2014c). However, a comparison with the diagrams in Baier and Baum (2008) reveals that agricultural production and consumption patterns are quite similar in Austria and Switzerland: In both countries, slightly more than 80 % of agricultural production are used as feed, and the share of green fodder is between 50 and 60 % (dry mass basis).

Krausmann et al. (2008) provide ratios for biomass production and utilization patterns on a global scale and data for 179 countries including Austria. Considering the indicators for biomass extraction used in this study, Austria is clearly above average. On a per hectare basis, Austria ranked 22nd and on a per capita basis 32nd in the year 2000. According to the results of the present study, the indicator values have increased by 16 % (per hectare) and 11 % (per capita) until 2011.

With regard to the four main categories of biomass consumption used by Krausmann et al., the global consumption in 2000 was distributed as follows: 12 % of the used extraction directly served as human food, 58 % as feed, 20 % as raw material and 10 % as fuel. For Austria in 2011, the following *direct* consumption ratios have been determined in the present study: 4 % human food, 20 % feed, 34 % raw material, 11 % energy and 31 % exports. Hence, the shares of human food and feed consumption are significantly lower in Austria than on a global scale, whereas raw material consumption is clearly higher.

However, the distribution looks entirely different if final uses are considered instead of direct consumption: 5 % human food, 25 % feed, 13 % raw material, 25 % energy and 31 % exports (see also Fig.3, where inland use is scaled to 100 %). The main reasons for the higher shares of energy and feed in this case are by-products ending up in energy generation or as animal feed, respectively. Animal products like meat and dairy products, which are secondary products and therefore not counted towards food in a "direct consumption approach", increase the share of human food. Also, if final uses are considered the category "raw material" only refers to biomass included in final products (rather than total input flows to industrial processes).

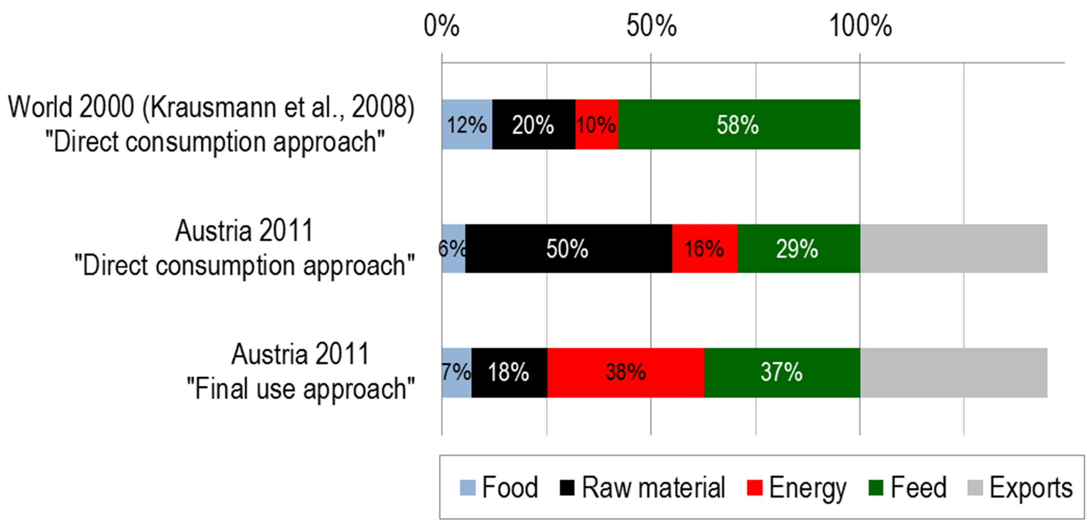

Figure 3: Comparison of the structure of biomass use in Austria in 2011 (based on two different approaches) and globally in 2000. (For better comparability with data according to Krausmann et al. (2008), the inland use in Austria was scaled to 100 %.)

The differing results from the two approaches ("direct consumption" vs. "final use") can be used to derive indicators for the extent of cascadic biomass use: For Austria it is concluded that close to 60 % of biomass used for energy was originally intended for other purposes, and that by-products accounted for more than 20 % of feed consumed in 2011. Such indicators could be of some value for monitoring resource efficiency and progress towards future "biobased economy targets". To facilitate cross-country comparisons, harmonized definitions and approaches still need to be developed.

4.4 Further remarks regarding future research

Considering the current and expected future importance of biomass for the Austrian national economy, a detailed analysis of the material flows as presented in this paper is considered to be of great value. The flow diagrams illustrate the magnitudes and interrelations of different biomass uses. They can help to identify options for increasing resource efficiency and to reliably estimate the extent of cascade biomass use.

Despite the above-mentioned inconsistencies and considerable uncertainties in some areas, largely consistent and satisfyingly detailed overall pictures could be derived from existing statistics, data in literature and (in some rare cases) own estimates. More detailed statistical data would primarily be desirable in the following fields: Industrial processing and material uses of agricultural commodities (e.g. detailed statistical data on the starch industry are subject to confidentiality), domestic supply and consumption of end-consumer products (like sawnwood and wood based panel being used in the construction sector, in the furniture industry etc.), manure and waste management (Several biomass-related data are based on non-representative surveys or estimates in the Federal Waste Management Plan; UBA, 2012). Such data would be especially useful for estimates on carbon stock developments, which are relevant in the context of national obligations to reduce greenhouse gas emissions, and for conceiving policy strategies to increase resource efficiency.

5 Literature

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Acknowledgements

This paper was prepared as part of the project “BioTransform.at – Using domestic land and biomass resources to facilitate a trans-formation towards a low-carbon society in Austria”, supported by the Austrian Climate and Energy Fund within the Austrian Climate Research Programme. The work presented was partly carried out

within the Austrian Climate Initiative “klima:aktiv nawaro markt". The author gratefully acknowledges the valuable comments and suggestions of two anonymous reviewers.

Annex

Table 1: Flow data, water contents and reliability of data

Source of flow	Sink of flow	Commodity/Biomass type	Flow quantity		Water content	Reliability of data[a]
			Mt_{dry}	Mt_{wet}		
Arable land and permanent crops	Total crops	Cereal grains	5	5.7	13%	++
Arable land and permanent crops	Total crops	Pulses	< 0.1	< 0.1	75%	++
Arable land and permanent crops	Total crops	Potatos	0.2	0.8	78%	++
Arable land and permanent crops	Total crops	Vegetables	< 0.1	0.8	90%	++
Arable land and permanent crops	Total crops	Oilseeds	0.3	0.4	10%	++
Arable land and permanent crops	Total crops	Sugar beet	0.8	3.5	78%	++
Arable land and permanent crops	Total crops	Fruit	< 0.1	0.5	85%	++
Arable land and permanent crops	Total crops	Field forage	2.6	14.7	82%	++
Arable land and permanent crops	Total crops	Miscellaneous plant products	0.4	0.4	15%	++
Arable land and permanent crops	Arable land and permanent crops	Cereal grains	< 0.1	0.1	13%	++
Arable land and permanent crops	Arable land and permanent crops	Pulses	< 0.01	< 0.01	75%	++
Arable land and permanent crops	Arable land and permanent crops	Potatos	< 0.1	< 0.1	78%	++
Arable land and permanent crops	Arable land and permanent crops	Straw	0.4	0.5	14%	+
Arable land and permanent crops	Exports	Straw	< 0.1	< 0.1	14%	++
Arable land and permanent crops	Animal husbandry	Straw	1.2	1.4	14%	+
Imports	Total crops	Cereal grains	1.5	1.7	13%	++
Imports	Total crops	Pulses	< 0.01	< 0.01	75%	++
Imports	Total crops	Potatos	< 0.1	0.2	78%	++
Imports	Total crops	Vegetables	< 0.1	0.7	90%	++
Imports	Total crops	Oilseeds	< 0.01	< 0.01	10%	++
Imports	Total crops	Sugar beet	< 0.01	< 0.01	78%	++
Imports	Total crops	Fruit	< 0.1	0.6	85%	++
Total crops	Food industry and trade	Cereal grains	0.9	1	13%	++
Total crops	Food industry and trade	Pulses	< 0.01	< 0.01	75%	++
Total crops	Food industry and trade	Potatos	< 0.1	< 0.1	78%	++
Total crops	Food industry and trade	Vegetables	< 0.1	0.9	90%	++
Total crops	Food industry and trade	Sugar beet	0.7	3.2	78%	++
Total crops	Food industry and trade	Fruit	< 0.1	0.2	85%	++
Total crops	Food industry and trade	Miscellaneous plant products	0.2	0.2	15%	o
Total crops	Miscellaneous industry sectors	Cereal grains	0.8	1	13%	+
Total crops	Transport biofuel production	Cereal grains	0.5	0.6	13%	+
Total crops	Miscellaneous industry sectors	Potatos	< 0.1	0.2	78%	++
Total crops	Oil mills	Plant oil	0.4	0.4	0%	++
Total crops	Food consumption	Potatos	< 0.1	0.4	78%	++
Total crops	Food consumption	Fruit	< 0.1	0.6	85%	++
Total crops	Exports	Cereal grains	1	1.1	13%	++
Total crops	Exports	Pulses	< 0.01	< 0.01	75%	++
Total crops	Exports	Potatos	< 0.1	0.2	78%	++
Total crops	Exports	Vegetables	< 0.1	0.3	90%	++
Total crops	Exports	Sugar beet	< 0.1	0.2	78%	++
Total crops	Exports	Fruit	< 0.1	0.2	85%	++
Total crops	Exports	Miscellaneous plant products	0.2	0.3	15%	+
Total crops	Animal husbandry	Cereal grains	2.5	2.9	13%	++
Total crops	Animal husbandry	Pulses	< 0.1	< 0.1	75%	++
Total crops	Animal husbandry	Potatos	< 0.01	< 0.1	78%	++
Total crops	Animal husbandry	Field forage	2.6	14.7	82%	++
Cultivated grassland	Animal husbandry	Grass and grass silage	2.9	16	82%	++
Extensive grassland	Animal husbandry	Grass and grass silage	1.8	9.9	82%	++
Food industry and trade	Animal husbandry	Plant residues and by-products	0.6	1	43%	+
Miscellaneous industry sectors	Animal husbandry	Plant residues and by-products	< 0.1	0.1	50%	+
Animal husbandry	Food consumption	Raw milk	< 0.01	< 0.1	88%	++
Animal husbandry	Food industry and trade	Raw milk	0.4	3	88%	++
Animal husbandry	Meat processing	Live animals	0.6	1.5	75%	o
Animal husbandry	Total manure	Manure	3.3	33	90%	+
Total manure	Arable land and permanent crops	Manure	1.7	17.4	90%	o
Total manure	Cultivated grassland	Manure	1	9.6	90%	o
Total manure	Extensive grassland	Manure	0.6	6	90%	o
Meat processing	Animal rendering	Slaughterhouse waste	0.1	0.3	70%	++

Meat processing	Food industry and trade	Meat	0.1	0.5	75%	++
Meat processing	Food industry and trade	Fish	< 0.1	< 0.1	75%	++
Meat processing	Food industry and trade	Animal fats	< 0.1	< 0.1	1%	++
Meat processing	Miscellaneous industry sectors	Miscellaneous animal products	< 0.01	< 0.01	13%	+
Water areas	Meat processing	Fish	< 0.01	< 0.01	75%	++
Imports	Animal husbandry	Straw	< 0.1	< 0.1	14%	++
Imports	Animal husbandry	Press residues	0.9	1	10%	+
Imports	Animal husbandry	Miscellaneous animal feedstuff	0.3	0.3	19%	+
Imports	Meat processing	Live animals	< 0.1	< 0.1	75%	++
Imports	Meat processing	Animal fats	< 0.1	< 0.1	0%	++
Imports	Food industry and trade	Meat	< 0.1	0.4	75%	++
Imports	Food industry and trade	Fish	< 0.1	< 0.1	75%	++
Animal husbandry	Exports	Live animals	< 0.01	< 0.1	75%	++
Animal husbandry	Exports	Miscellaneous animal products	0.1	0.1	5%	++
Meat processing	Exports	Meat	0.1	0.5	75%	++
Meat processing	Exports	Animal fats	< 0.1	< 0.1	0%	++
Meat processing	Exports	Miscellaneous animal products	< 0.1	< 0.1	19%	+
Oil mills	Total plant oil	Plant oil	0.2	0.2	0%	++
Imports	Total plant oil	Plant oil	0.4	0.4	0%	++
Total plant oil	Food industry and trade	Plant oil	0.2	0.2	0%	++
Total plant oil	Transport biofuel production	Plant oil	0.2	0.2	0%	++
Total plant oil	Total liquid biofuels	Plant oil	< 0.1	< 0.1	0%	+
Total plant oil	Miscellaneous industry sectors	Plant oil	< 0.1	< 0.1	0%	++
Total plant oil	Exports	Plant oil	0.1	0.1	0%	++
Oil mills	Animal husbandry	Plant oil	< 0.1	< 0.1	0%	++
Oil mills	Animal husbandry	Press residues	0.2	0.2	10%	++
Food consumption	Transport biofuel production	Waste edible oil	< 0.1	< 0.1	0%	++
Meat processing	Transport biofuel production	Animal fats	< 0.1	< 0.1	0%	++
Transport biofuel production	Total liquid biofuels	Biodiesel	0.3	0.3	0%	++
Transport biofuel production	Total liquid biofuels	Bioethanol	0.2	0.2	0%	++
Transport biofuel production	Animal husbandry	DDGS	0.2	0.2	12%	++
Imports	Total liquid biofuels	Biodiesel	0.3	0.3	0%	++
Imports	Total liquid biofuels	Bioethanol	< 0.1	< 0.1	0%	++
Total liquid biofuels	Energy uses	Plant oil	< 0.1	< 0.1	0%	+
Total liquid biofuels	Energy uses	Biodiesel	0.5	0.5	0%	++
Total liquid biofuels	Energy uses	Bioethanol	0.1	0.1	0%	++
Total liquid biofuels	Exports	Biodiesel	< 0.1	< 0.1	0%	++
Total liquid biofuels	Exports	Bioethanol	< 0.1	< 0.1	0%	++
Animal husbandry	Anaerobic digestion	Manure	< 0.1	0.5	90%	+
Total crops	Anaerobic digestion	Biogas crops	0.3	0.9	65%	+
Consumption of products	Anaerobic digestion	Biogenic waste	0.1	0.3	64%	+
Food industry and trade	Anaerobic digestion	Plant residues and by-products	< 0.1	< 0.1	60%	+
Animal rendering	Anaerobic digestion	Slaughterhouse waste	< 0.1	< 0.1	70%	+
Sewage plants	Anaerobic digestion	Sewage sludge	< 0.1	0.4	90%	+
Anaerobic digestion	Arable land and permanent crops	Fermentation residues	0.1	1.8	94%	o
Anaerobic digestion	Energy uses	Biogas	0.3	0.3	5%	++
Forestry	Wood processing industries	Sawlogs	4.9	6.9	30%	++
Forestry	Wood processing industries	Industrial roundwood	1.8	2.5	30%	++
Forestry	Energy uses	Fuelwood (logs)	1.7	2	15%	++
Forestry	Energy uses	Forest wood chips	1.4	1.7	15%	++
Forestry	Forestry	Felling residues	0.4	0.5	15%	+
Wood processing industries	Energy uses	Wood processing residues	3.2	3.7	15%	++
Wood processing industries	Energy uses	Black liquor	1.7	3.3	50%	++
Wood processing industries	Miscellaneous industry sectors	Sawnwood	1.8	2.6	30%	++
Wood processing industries	Miscellaneous industry sectors	Paper and paperboard	0.8	0.9	10%	++
Wood processing industries	Miscellaneous industry sectors	Wood panels	0.3	0.4	30%	++
Wood processing industries	Total wood pellets and briquettes	Wood pellets and briquettes	0.9	0.9	8%	+
Wood processing industries	Consumption of products	Miscellaneous consumer products	0.4	0.4	10%	o
Wood processing industries	Wood processing industries	Pulp	2	2.2	10%	++
Wood processing industries	Wood processing industries	Wood processing residues	2.7	3.1	15%	+
Consumption of products	Total waste paper	Waste paper	0.5	0.5	9%	+
Miscellaneous industry sectors	Total waste paper	Waste paper	0.8	0.9	9%	+
Total wood pellets and briquettes	Energy uses	Wood pellets and briquettes	0.6	0.7	8%	++
Total waste paper	Wood processing industries	Waste paper	2.2	2.4	9%	++
Total waste paper	Exports	Waste paper	0.4	0.4	9%	++
Miscellaneous industry sectors	Wood processing industries	Miscellaneous plant products	< 0.1	0.1	10%	o
Imports	Wood processing industries	Sawlogs	2.4	3.4	30%	++

Imports	Wood processing industries	Industrial roundwood	1.6	2.2	30%	++
Imports	Energy uses	Fuelwood (logs)	0.5	0.6	15%	++
Imports	Wood processing industries	Wood processing residues	1.1	1.3	15%	++
Imports	Wood processing industries	Pulp	0.6	0.6	10%	++
Imports	Total waste paper	Waste paper	1.3	1.4	9%	++
Imports	Miscellaneous industry sectors	Sawnwood	0.9	1.3	30%	++
Imports	Miscellaneous industry sectors	Paper and paperboard	1.2	1.4	10%	++
Imports	Miscellaneous industry sectors	Wood panels	1.1	1.3	15%	++
Imports	Total wood pellets and briquettes	Wood pellets and briquettes	0.7	0.8	8%	++
Forestry	Exports	Sawlogs	0.4	0.5	30%	++
Forestry	Exports	Industrial roundwood	0.2	0.3	30%	++
Forestry	Exports	Fuelwood (logs)	< 0.1	< 0.1	15%	++
Wood processing industries	Exports	Sawnwood	2.6	3.7	30%	++
Wood processing industries	Exports	Wood panels	1.3	1.8	30%	++
Wood processing industries	Exports	Paper and paperboard	3.6	4	10%	++
Wood processing industries	Exports	Wood processing residues	0.3	0.3	15%	++
Wood processing industries	Exports	Pulp	0.4	0.4	10%	++
Total wood pellets and briquettes	Exports	Wood pellets and briquettes	0.7	0.7	8%	++
Food industry and trade	Food consumption	Sugar and sugary products	0.3	0.3	0%	+
Food industry and trade	Food consumption	Milk and dairy products	0.2	1	75%	+
Food industry and trade	Food consumption	Miscellaneous food	0.7	5.5	34%	o
Miscellaneous industry sectors	Consumption of products	Miscellaneous consumer products	4.4	6.1	9%	o
Food industry and trade	Exports	Fish	< 0.01	< 0.01	75%	++
Imports	Food industry and trade	Sugar and sugary products	0.4	0.4	0%	++
Imports	Food industry and trade	Milk and dairy products	< 0.1	0.2	75%	++
Imports	Food industry and trade	Miscellaneous food	0.2	0.2	10%	++
Imports	Food industry and trade	Miscellaneous plant products	< 0.1	< 0.1	8%	+
Imports	Food consumption	Miscellaneous food	0.5	1	45%	+
Imports	Food consumption	Miscellaneous plant products	0.2	0.2	8%	+
Imports	Consumption of products	Miscellaneous consumer products	1.1	1.3	9%	+
Imports	Miscellaneous industry sectors	Miscellaneous animal products	0.2	0.2	9%	+
Imports	Miscellaneous industry sectors	Miscellaneous plant products	< 0.1	< 0.1	8%	+
Food industry and trade	Exports	Miscellaneous food	0.8	1.2	34%	+
Food industry and trade	Exports	Miscellaneous plant products	< 0.1	< 0.1	8%	+
Miscellaneous industry sectors	Exports	Miscellaneous consumer products	1.7	1.9	8%	+
Food industry and trade	Exports	Sugar and sugary products	0.5	0.5	0%	++
Miscellaneous industry sectors	Exports	Miscellaneous plant products	< 0.1	0.2	57%	+
Food industry and trade	Exports	Plant residues and by-products	< 0.1	0.4	94%	+
Food industry and trade	Exports	Milk and dairy products	0.2	0.6	75%	++
Food industry and trade	Composting	Biogenic waste	< 0.1	0.1	60%	o
Consumption of products	Composting	Biogenic waste	0.2	0.6	64%	o
Food consumption	Composting	Biogenic waste	0.2	1.5	86%	o
Consumption of products	Energy uses	Biogenic waste	0.3	0.6	46%	++
Miscellaneous industry sectors	Energy uses	Biogenic waste	0.2	0.2	11%	++
Animal rendering	Energy uses	Slaughterhouse waste	0.1	0.1	6%	++
Food consumption	Sewage plants	Sewage sludge	0.3	2.6	90%	++
Sewage plants	Arable land and permanent crops	Sewage sludge	< 0.1	0.4	90%	o
Sewage plants	Energy uses	Sewage sludge	0.1	1.2	90%	++
Sewage plants	Energy uses	Sewage gas	< 0.1	< 0.1	5%	++
Sewage plants	Landfills	Sewage sludge	< 0.1	0.2	90%	o
Sewage plants	Composting	Sewage sludge	< 0.1	0.4	90%	o
Composting	Arable land and permanent crops	Compost	0.4	0.9	60%	o
Landfills	Energy uses	Landfill gas	< 0.1	< 0.1	5%	++
Other land areas	Energy uses	Biogenic waste	0.3	0.8	60%	o
Other land areas	Energy uses	Fuelwood (logs)	1.1	1.3	15%	o
Other land areas	Wood processing industries	Sawlogs	2.5	3	30%	o
Animal husbandry	Animal metabolism	Miscellaneous animal feedstuff	8.7	31.4	72%	o
Consumption of products	Wood products stock increase	Miscellaneous consumer products	4.5	5.3	16%	o
Composting	Biodegredation	Plant residues and by-products	0.2	0.9	80%	o
Anaerobic digestion	Biodegredation	Plant residues and by-products	0.2	0.7	75%	o
Energy uses	Combustion	Plant oil	< 0.1	< 0.1	0%	++
Energy uses	Combustion	Biodiesel	0.5	0.5	0%	++
Energy uses	Combustion	Bioethanol	0.1	0.1	0%	++
Energy uses	Combustion	Biogas	0.3	0.3	5%	++
Energy uses	Combustion	Fuelwood (logs)	3.3	3.9	15%	++
Energy uses	Combustion	Forest wood chips	1.4	1.7	15%	++
Energy uses	Combustion	Wood processing residues	3.2	3.7	15%	++

Energy uses	Combustion	Black liquor	1.7	3.3	50%	++
Energy uses	Combustion	Wood pellets and briquettes	0.6	0.7	8%	++
Energy uses	Combustion	Biogenic waste	0.9	1.7	45%	++
Energy uses	Combustion	Sewage sludge	0.1	1.2	90%	++
Energy uses	Combustion	Sewage gas	< 0.1	< 0.1	5%	++
Energy uses	Combustion	Landfill gas	< 0.1	< 0.1	5%	++

a) *"++": Data are directly based on official statistics or publications with high reliability;*
"+": Data from sound publications/statistics; due to high aggregation, estimated parameters or known sources of uncertainties, data are considered less reliable;
"o": Data calculated by author based on continuity equation or estimated due to lack of data;