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An assessment of international trade related to bioenergy use in Austria—Methodological aspects, recent developments and the relevance of indirect trade

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ABSTRACT

Increasing international biomass trade for energy and concerns about sustainability of globally traded biomass have raised interest in assessments of cross-border trade related to bioenergy. Within this paper, approaches to overcome methodological difficulties related to biomass trade are proposed and applied for the case of Austria.

Biomass currently has a share of 15.5% in Austria's primary energy consumption of 1354 PJ (2009). According to energy statistics, the rate of self-sufficiency with biomass for energy (defined as the ratio of domestic production to inland consumption, with both imports and exports taken into account) is 91%. However, feedstock imports for transport fuel production and indirect imports of wood-based fuels (wood processing residues and waste liquor of the paper industry originating from imported wood) are not taken into account in energy statistics, but prove to be of some significance. Imports of agricultural commodities to the amount of 9.7 PJ can be attributed to domestic biofuel production, and indirect imports of wood-based fuels, account for 31 PJ. With these import streams taken into account, the share of domestic fuels in bioenergy use is only 67%, rather than 84%, as official energy statistics suggest. On the other hand, Austria is exporting more than 50% of its production of sawnwood, panelboard and paper products.

1. Introduction and rationale

With a share of about 15% in the primary energy consumption (PEC) in 2009 (Statistik Austria, 2012), biomass is of major importance for the Austrian energy supply. According to energy statistics, 84% of the biomass used for energy production in Austria originates from domestic sources. With biomass exports (primarily wood pellets) taken into account, the rate of self-sufficiency with biomass is 91%. Biomass accounts for 40% of the total primary energy supply of domestic origin. Therefore, biomass is considered to make a significant contribution to energy security and reducing dependence on energy imports, both of which are core objectives of Austria's energy policy (BMWFJ and BMLFUW, 2010).

However, in fact cross-border trade of biomass used for energy generation is often not fully captured in statistics. In energy statistics only biomass fuels which are traded directly for the purpose of energy recovery is taken into account. Some other trade streams which are just as, or even more important than direct biomass trade are not included. Hence, there is evidence that biomass imports are in fact clearly more significant than energy statistics suggest. Previous studies on international biomass trade highlight the importance of the concept of "indirect" biomass trade (e.g., Heinimö and Junginger, 2009). This concept refers to biomass being traded for material uses, but ultimately ending up in energy generation, for example imported wood products ending up in waste utilization plants or large shares of industrial roundwood ending up as wood-processing residues. According to Heinimö and Junginger (2009), indirect trade of biomass through trading of industrial roundwood and material byproducts comprises the largest proportion of international biomass trade for energy, accounting for approximately two thirds of the total global trade volumes in 2006. Despite a rapid growth in direct biomass trade for energy in recent years, direct trade volumes are clearly less significant: direct trade with ethanol accounted for about 13% of bioenergy-related trade in 2006, wood pellets for 6.5%, fuel wood for 4.3% and biodiesel for 1.6%.

Due to the high importance of international trade for the mobilization of global biomass potentials on the one hand, and rising concerns about sustainability issues of globally traded

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biomass on the other, profound knowledge of developments in international biomass trade are considered an essential basis for policy making in the field of bioenergy.

The objective of this study is threefold: First, to contribute to a clarification of methodological challenges of assessing international trade streams. Second, to document recent trends in bioenergy-related trade and interconnections with the wood-processing industries in Austria. And third, to propose methodologies for assessing biomass trade streams not captured in energy statistics, in order to provide insight into the actual import dependence of the Austrian bioenergy sector. This includes indirect imports of wood-based fuels and feedstock imports for the production of biofuels. The latter are of particular interest, as the increasing global demand for energy crops for biofuel production is found to have an impact on food prices (e.g., Schmidhuber, 2007; Mitchell, 2008; Baffes and Haniotis, 2010) and land-use change (Fonseca et al., 2010), which is likely to offset the greenhouse gas savings achieved through substituting fossil fuels (e.g., Searchinger et al., 2008; Havlík et al., 2010). Finally, the results of the assessments are used to derive detailed flow diagrams of the wood streams (including wood for material and energy uses) as well as of the Austrian bioenergy sector, taking into account the above-mentioned trade streams, different biomass types and end uses.

The issue of international biomass trade is considered to be of high interest for policy makers for the following reasons: First, with regard to supply security and import dependence, it is of crucial importance to have a clear picture of energy commodities trade not captured in energy statistics. And second, monitoring global carbon flows has a political dimension in the context of carbon mitigation policies.

The paper is structured as follows: Section 2 gives an introduction into the methodological challenges addressed within this work, as well as an overview of the approaches applied and the data used. In Section 3, a brief summary of the historic development of bioenergy use in Austria is presented. Section 4 is dedicated to direct biomass trade[2]: Imports and exports according to energy statistics are discussed (Section 4.1), trade streams according to trade statistics are mapped (4.2), and trade quantities related to biogenic transport fuels are analyzed (4.3). The topic of Section 5 is indirect trade with wood-based fuels. After an overview of the methodological approach (5.1), the current wood flows in Austria are described (5.2) and the quantities of indirect trade streams are assessed (5.3). In Section 5.4, the concept of indirect trade is extended to wood products. Section 6 includes a synthesis, discussion and conclusions. Explanations of terms and definitions used in this work are provided in Appendix A.

2. Methodological challenges and data

There are numerous challenges related to measurement of internationally traded quantities of biomass for energy generation. The following methodological challenges need to be addressed (cp. Heinimö and Junginger, 2009):

Most biomass types are produced and traded for several applications, including energy purposes as well as material uses. Biomass for energy is often aggregated together with biomass for other purposes in production statistics (e.g., wood chips and residues, which are used for energy generation as well as for the production of paper and panelboard). This is also true for trade statistics, as trade codes according to the Combined Nomenclature (CN codes) (European Commission, 2010) usually aggregate streams intended for different purposes.

- Biomass is often traded for material uses, but ultimately ends up in energy production. Due to large international trade streams of raw wood and (semi-)finished wood products, this is especially relevant for residues from wood processing (sawmill by-products), waste liquor of the paper and pulp industry and other wood wastes which originate from imported material and are ultimately used for energy recovery. These trade streams are referred to as "indirect trade".
  In order to identify the most relevant indirect trade streams, a detailed assessment of the foreign trade with raw wood and wood products, as well as wood flows within Austria is carried out.
- Liquid transport fuels are traded as pure biofuels as well as different blends with fossil fuels. Depending on the form in which they are traded, biofuels are recorded under different trade codes. For example, ethanol can be imported under the CN code 2207 01, 2207 02 and 3824 9099, as well as further codes in the case of low-blend ethanol, together with other types of denaturated or undenaturated ethyl alcohol (Akkerhuis, 2010). Therefore, a complete assessment of international biofuel trade on the basis of trade statistics is considered infeasible (at least with the current set of CN codes).
- An increasing energetic use of a certain commodity may result in displacement effects to other, non-energetic uses. If increasing shares of domestically produced biomass are used for energy generation, larger quantities of the same biomass required for other purposes have to be imported. Due to methodological difficulties in the assessment of such "induced imports", we propose an approach on the basis of self-sufficiency rates (see Section 4.3).
- As physical properties of most biomass types and especially wood vary widely, the conversion of quantities stated in mass units (e.g., in trade statistics) or volume units (solid cubic meters, SCM; e.g., in forestry statistics) to energy quantities is associated with substantial uncertainties. Furthermore, natural and forced drying of wood results in a loss of weight and volume, causing inaccuracies in investigations of wood flows. Disregarding these sources of uncertainty, the conversion factors stated in Table 1 are assumed.

To sum up, investigations of biomass trade streams related to bioenergy are not straightforward, and specific methodologies need to be developed, in order to gain insight into the import dependence of the bioenergy sector or the effect of an increasing bioenergy use on trade flows.

The official national energy statistics according to Statistik Austria (2012) form the starting point of this assessment. With regard to biofuels for transport, the official report pursuant to Directive 2003/30/EC (Winter, 2010) is also used, as it provides more detailed data on the utilization of biogenic transport fuels. This report also contains data on domestic production, imports and exports of liquid biofuels, but it does not provide any information on the origin of feedstock used for biofuel production. National supply statistics for agricultural commodities are used to fill in this data gap (Statistik Austria, 2011).

As there are no data on supply balances and cross-border streams of biogas substrates available (primarily maize is used in Austria; see Kalt et al., 2010), the assessment of import streams of the biogas sector is based on a bottom-up estimate by the umbrella organization of the composting and biogas plants in Austria, "ARGE Kompost & Biogas" (Kirchmeyr, 2011). Data from trade statistics (Eurostat, 2011a) are used to map direct trade streams of the following wood fuels: wood-processing residues,

[2] The quantities referred to as "direct trade" in this study include biomass streams stated in energy statistics as well as feedstock used for the production of biogenic fuels (such as oilseeds and plant oil for the production of biodiesel).

Table 1
Conversion factors for biomass.

	GJ[a]/kg	GJ[a]/SCM[b]
Log wood	14.31[c]	7.20[d]
Wood chips, wood-processing residues, other wood waste	9.69[c]	–
Wood pellets	18.00[c]	–
Biodiesel	36.60[c]	–
Ethanol	26.68[c]	–
Vegetable oil	37.60[c]	
Black liquor	8.47[c]	–
Charcoal	31.00[c]	–
Raw wood	–	7.20[d]

[a] Lower heating value.
[b] SCM: solid cubic meters under bark (i.e., excluding bark).
[c] Based on Statistik Austria (2012).
[d] Assumption corresponding to coniferous wood at 20% moisture content on a wet weight basis.

wood log, wood waste and pellets. Other streams are not mapped due to insufficient differentiation and/or fragmentary data in trade statistics.[3] Table 2 provides an overview of most relevant biomass types used for energy in Austria, their definitions and CN codes. However, it is stressed that biomass for energy is traded under numerous other codes (e.g., agricultural commodities like oilseeds), and that most codes listed here also include material used for non-energy uses. It also needs to be stressed that there are substantial uncertainties related to trade statistics, as frequent discrepancies between data according to the exporting country and corresponding data of the importing country indicate (Kalt et al., 2011a).

In order to assess indirect trade quantities of wood-based fuels (Section 5), it is necessary to have a detailed picture of the different utilization paths of the various wood fractions, as well as the flows between the wood processing industries. The required data are obtained from production and consumption statistics of the wood-processing industries (sawmill industry: FAO, 2011a; paper and pulp industry: Austropapier, 2011; panelboard industry: Schmied, 2011) and Pellet@las (2011), statistical data on wood consumption and trade (FAO, 2011a; FAO, 2011b), previous assessments of the Austrian wood flows (Hagauer et al., 2007; Hagauer, 2008) as well as reports on timber felling (Prem, 2009). These data are used to draw a flow diagram of the main wood streams in Austria. Based on this, the quantities of indirectly traded biomass used for energy generation are assessed.

More detailed descriptions of the methodological approaches have been included in the respective sections for better readability.

3. Bioenergy use in Austria

This section gives a brief overview of the historic development and structure of biomass use in Austria. Fig. 1 shows the development of biomass primary energy consumption broken down by biomass types. From 1970 to 2004, biomass statistics differentiated only between the categories "wood log", "municipal solid wastes" and "other biomass and biofuels". The latter include all types of liquid biofuels, biogas and wood fuels like wood chips, residues, pellets etc. The data for the biogenic fraction of municipal solid wastes during this period are estimates based on an assumed biogenic share in municipal waste of 20%. More detailed data are available for the years 2005–2009. The biogenic share of wastes was in the range of 17–24% during this period. In Fig. 1, all liquid biofuels have been summarized to one category, as the original differentiation in energy statistics is considered to be misleading.[4]

Fig. 1 also shows the share of biomass in the total PEC, which increased from less than 6% (less than 50 PJ/a) during the 1970s to 15% (210 PJ) in 2009. The main increase in biomass use took place during the periods 1980–1985 and 2004–2009. Until the year 1999 the use of wood log for domestic heating accounted for more than 50% of the total biomass use for energy. The rest was primarily wood wastes and sawmill by-products as well as waste liquor of the paper and pulp industry. Especially during the last five years, the different fractions of wood biomass, including forest wood chips, sawmill by-products and other wood wastes as well as liquid and gaseous biomass have become increasingly important, whereas wood log remained relatively constant at about 60 PJ/a. As a result, wood log accounted for only 30% of the total biomass use in 2009.

The final energy consumption of biomass-derived energy is structured as follows (2009): Wood log and other biogenic fuels used for heat generation account for 65.6%, district heat for 13.5%, electrical energy from biomass power plants, including combined heat and power (CHP) plants, for 8.5%, and transport fuels for 12.4% (Statistik Austria, 2012).

The importance of biomass for Austria's energy security is emphasized by its share in the primary energy supply of domestic origin: According to the official data by Statistik Austria (2012), biomass accounted for 40% in 2009, which is more than the share of all other renewable energy sources (33%), as well as of fossil fuels (27%). To what extent this picture changes when it is considered that "domestic production" according to energy statistics actually includes indirectly imported biomass and biofuels produced from imported feedstock is one of the core objectives of this work.

The increasing use of biofuels for transport was one of the most dynamic developments in the Austrian bioenergy sector in the last decades. In order to provide a more detailed insight into this development, which is of special significance with regard to cross-border trade (as will be shown in Section 4.3), Fig. 2 shows the use of biogenic transport fuels broken down by types of biofuels as well as the share in the total fuel consumption in road transport. The figure illustrates that this share increased from about 1% in 2005 to 7% in 2009. The figure also illustrates that the largest contribution comes from biodiesel in blends (66% in 2009), followed by pure biodiesel (19%), ethanol in blends (12%) and vegetable oil (3%). The current use of E85 (a blend that contains 85% ethanol and 15% gasoline) and biomethane (cleaned and conditioned biogas), is negligible (Winter, 2010).

With regard to the 2020-scenario described in Austria's official Renewable Energy Action Plan (Karner et al., 2010), it is not expected that bioenergy use in Austria will continue to grow at the same pace as in recent years. In fact, only very slight increases are projected for energy from biomass until 2020 (see Kalt et al., 2011b), which could (under the assumption of rising efficiency) be achieved without mobilizing or importing additional biomass resources.

4. Direct biomass trade

In this section, direct trade streams related to bioenergy use are analyzed. This includes biomass imports and exports according to

[3] For example, biodiesel trade captured in CN code 3824 9091, which has been established in 2008 (Freshfields Bruckhaus Deringer, 2008), only includes pure biodiesel as well as B99 (a diesel blend that contains 99% biodiesel and 1% fossil diesel), and therefore only an unrepresentatively small fraction of the actual trade streams.

[4] In Statistik Austria (2012) pure liquid biofuels (biodiesel, ethanol and vegetable oil) are included in the category "other liquid biofuels", whereas the categories "biodiesel" and "ethanol" only comprises quantities blended with fossil fuels.

Table 2
CN codes of biomass types used for energy and their definitions according to the nomenclature of trade goods.
Sources: Heinimö (2008), Akkerhuis (2010), European Commission (2010), Alakangas et al. (2011), Eurostat (2011a).

Product (term used in this study)	CN code(s)	Definition(s) according to European Commission (2010)
Wood fuels		
Wood log	4401 1000	Fuel wood, in logs, in billets, in twigs, in faggots or in similar forms
Wood chips	4401 2100 (coniferous); 4401 2200 (non-coniferous)	Wood in chips or particles
Wood-processing residues, refined wood fuels and other wood waste	4401 3000	Sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms
Wood pellets	4401 3020	Sawdust and wood waste and scrap, agglomerated in pellets
Sawdust	4401 3040	Sawdust of wood, whether or not agglomerated in logs, briquettes or similar forms (excl. pellets)
Wood waste	4401 3080	Wood waste and scrap, whether or not agglomerated in logs, briquettes or similar forms (excl. sawdust and pellets)
Charcoal	4402 0000	Wood charcoal, incl. shell or nut charcoal, whether or not agglomerated
Liquid biomass		
Rapeseed oil/ sunflower oil	1514/1512	Rape, colza or mustard oil and fractions thereof/sunflower-seed, safflower or cotton-seed oil and fractions thereof, whether or not refined, but not chemically modified
Ethanol	2207 1000; 2207 2000; 3824 9099	Undenatured ethyl alcohol, of actual alcoholic strength of 80%; denatured ethyl alcohol and other spirits of any strength; chemical products and preparations of the chemical or allied industries
Biodiesel	3824 9091	Fatty acid mono-alkyl esters, containing by volume 96.5% or more of esters
Black liquor	3804 0000	Residual lyes from the manufacture of wood pulp, whether or not concentrated, desugared or chemically treated, including lignin sulphonates

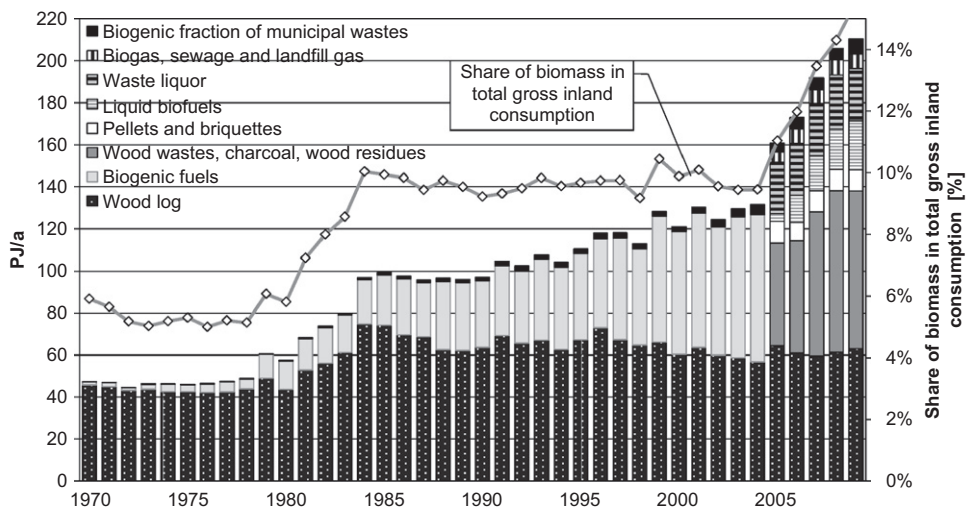

Fig. 1. Biomass primary energy consumption in Austria from 1970 to 2009 and biomass share in total primary energy consumption.
Source: Statistik Austria (2012), own calculations.

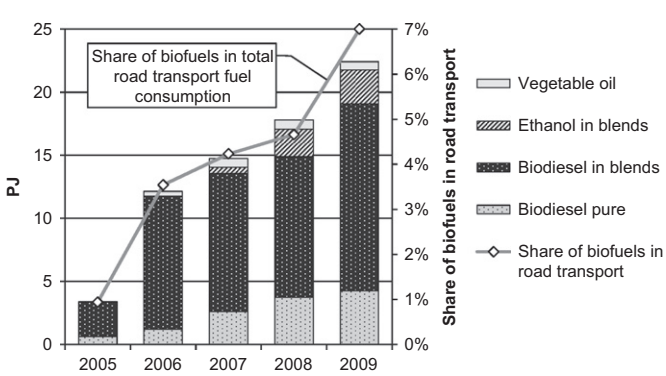

Fig. 2. Development of the consumption of biofuels for transport in Austria from 2005 to 2009.
Source: Winter (2010).

energy statistics, streams of wood fuels according to trade statistics as well as biofuel and feedstock trade related to the use of biofuels in the transport sector.

4.1. Biomass trade according to energy statistics

Fig. 3 shows the imports and exports of biomass used for energy production in Austria according to energy statistics. For the period 2005–2009, the data are broken down by different types of biofuels, pellets and briquettes, wood log and charcoal. International trade of other biomass types (like wood chips, biogenic municipal solid wastes, etc.) is indicated as zero for all years (which is, according to trade statistics, in fact not true for wood chips).

Being a land-locked country with the Alps as a natural barrier, imports to one region and exports from another are often the case in Austria. For some biomass types (e.g. "pure liquid biofuels" and "pellets and briquettes"), these imports and exports are closely matched in most years.

The figure illustrates that according to energy statistics, Austria was a net exporter of biomass fuels until 2005. From 2000 to 2004, both imports and exports increased about 2.5-fold, resulting in net exports of 5.6% of the total biomass PEC. In the following years, which were characterized by a rapid increase of

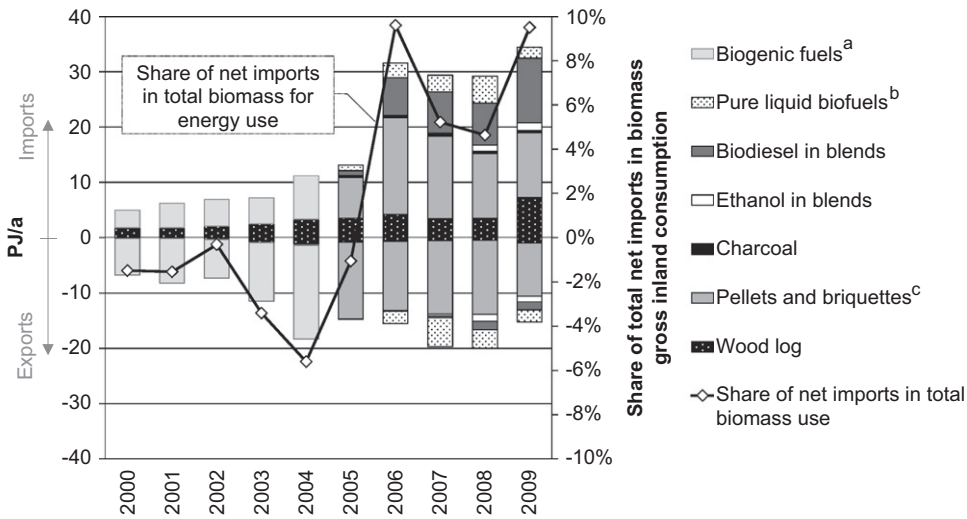

Fig. 3. Imports and exports of biogenic energy carriers according to energy statistics of the national statistical authority. (a) Includes all types of biomass except wood log. (b) Includes vegetable oil, pure biodiesel and E85. (c) A comparison with other trade statistics indicates that the category "pellets and briquettes" also includes unrefined wood fuels (wood chips, wood-processing residues, etc.).
Source: Statistik Austria (2012).

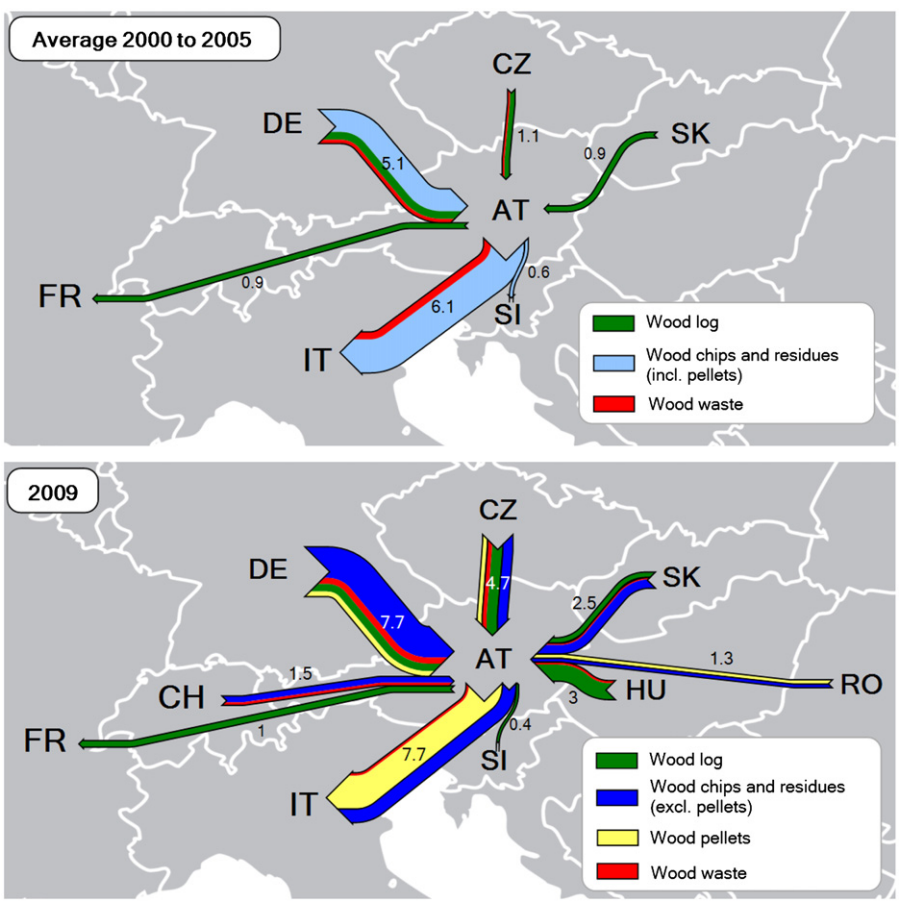

Fig. 4. Comparison of the net trade streams of wood log, wood chips and residues, pellets and wood waste in 2009 (bottom) with the annual average during 2000–2005 (top) (values in PJ; only streams above 0.3 PJ are shown).
Source: Eurostat (2011a), own calculations and illustration.

biomass use (see Fig. 1), the imports rose to around 30 PJ/a. As a result, the net imports accounted for up to 10% of the total biomass consumption (2006 and 2009). Both increasing imports of liquid biofuels and wood fuels contributed to this trend.

4.2. Wood streams by trade partners

Trade statistics provide data on biomass streams broken down by trade partners. Fig. 4 shows an illustration of the net trade

streams of the following commodities according to Eurostat (2011a): log wood, wood chips, residues, pellets and wood waste.

In order to illustrate the dynamics in recent years, the average annual trade volumes during 2000–2005 are compared to the streams in 2009. For the year 2009, separate data on wood pellet trade are available under CN code 4401 3020. In the preceding years, pellets have been recorded together with sawdust, briquettes and other agglomerated forms of sawdust under CN code 4401 3010 (cf. Table 2).

As mentioned above, it is important to note that trade statistics do not differentiate between end purposes. Therefore, based on trade statistics, it is not possible to determine the trade volumes which are actually related to bioenergy use. However, it is assumed that wood log, wood pellets and wood waste are almost exclusively used for energy generation. With regard to wood chips and residues, statistics of the wood processing industries indicate that notable quantities are related to material uses. In 2009, the imports of sawmill by-products of the paper, pulp and wood board industries accounted for an equivalent of 11 PJ (Austropapier, 2011; Schmied, 2011). This corresponds to the total imports according to trade statistics. Hence, it is concluded that at least in 2009, wood residues were only imported for material uses.

Fig. 4 illustrates that especially the net imports from the northern and eastern neighboring countries have risen significantly in recent years. The total net imports from Czech Republic, Slovakia and Hungary accounted for approximately 2 PJ per year during the period 2000–2005. In 2009 they amounted to more than 10 PJ, and an additional 1.3 PJ were imported from Romania. Together, this is equivalent to 5% of the total biomass PEC in Austria in 2009. However, Germany and Italy are still Austria's main trade partners. The net imports from Germany accounted for 7.7 PJ in 2009, compared to an average of 5.1 PJ during 2000–2005, and the net exports to Italy increased from 6.1 to 7.7 PJ. With an export quantity of more than 5 PJ in 2009, pellet exports to Italy are by far the most important pellet trade stream and also Austria's main export stream of wood fuels.

Another notable aspect is that Austria's trade streams with neighboring countries and other European countries shown in the figure comprise more than 90% of the total international trade volumes of wood fuels relevant for Austria. Hence, despite rapidly increasing import activities, Austria's wood fuel trade with more distant countries is still rather negligible.

4.3. Cross-border trade related to biofuels

The increasing use of the transport fuels biodiesel, ethanol and vegetable oil resulted in a significant rise of related cross-border trade. Apart from trade with refined biofuels, which is documented in the national biofuel report (Winter, 2010), cross-border trade of feedstock used for biofuel production needs to be considered. As there are no data available on the actual import share of the Austrian biofuel industry, the following methodology for calculating "virtual" feedstock imports on the basis of the self-sufficiency of agricultural products is applied: If the self-sufficiency in the respective biofuel feedstock $\sigma_{feedstock}$ is found to be less than 100% ($\sigma_{feedstock} < 1$), the total domestic biofuel production $P_{biofuel}$ is split into production based on domestic feedstock (P_{dom}), and such based on imports (P_{imp}) according to the following formulas:

$$P_{imp} = P_{biofuel}\,(1-\sigma_{feedstock})$$

$$P_{dom} = P_{biofuel} \cdot \sigma_{feedstock}$$

Hence, with this approach it is implicitly assumed that imports and domestic supply of the respective commodity are distributed in equal shares among all end purposes.[5] Next, the virtual feedstock imports together with data on trade streams of refined biofuels are combined to supply balances for biofuels and an according flow diagram.

Biodiesel, being the most important biofuel in Austria, is related to the most significant trade streams. According to Winter (2010), biodiesel imports accounted for approximately 50% of the inland consumption in the period 2005–2009. On the other hand, close to one quarter of the domestic production of biodiesel, which increased from 70,000 t (2005) to more than 320,000 t (2009) during this period, was exported. The self-sufficiency with vegetable oil (calculated on the basis of oilseed production in Austria) has decreased from about 60% around the year 2000 to less than 23% in the marketing year[6] 2007/08 and 27% in 2008/09 and 2009/10 (Statistik Austria, 2011). Fig. 5 shows the supply balance for vegetable oil since 1998/99. With the quantities used in the industry (which is dominated by biodiesel production) increasing by a factor of 7 from 2000/01 to 2009/10, it is apparent that the rapid growth of the Austrian biodiesel industry was the main reason for the increasing import dependence.

Fig. 6 shows the biodiesel supply balance based on Winter (2010) and the methodology described above. While the domestic biodiesel consumption increased from 5500 t in 2005 to 520,000 t in 2009, the production based on domestically produced feedstock only increased from 21,000 t to 87,000 t during the same period, and accounted for no more than 17% of the consumption in 2009. Domestic production based on imported feedstock, on the other hand, accounted for an average of 41% of the consumption during the last five years.

With regard to vegetable oil used for transportation, data are highly uncertain, due to largely regional distribution channels. According to Winter (2010), approximately 17,000–18,000 t (0.6–0.67 PJ) of vegetable oil were used for transportation annually during 2007–2009. It is assumed that at least the quantities which are used in agriculture (approximately 2700 t or 0.1 PJ in the year 2009) originate from domestic production. Based on the self-sufficiency with vegetable oil, the virtual feedstock imports in the years 2007–2009 are calculated to close to 13,000 t (0.5 PJ).

The Austrian production of bioethanol used for transportation is limited to one large-scale plant. The plant became fully operational in mid-2008 and has a capacity of approximately 190,000 t/a (5.1 PJ/a). The annual feedstock demand at full capacity is reported to account for 620,000 t (75% wheat and triticale, 15% maize and 10% sugar juice). According to the operator's financial report for the business year 2009/10, Agrana (2010), "most" of the feedstock used originated from domestic production. However, as the Austrian self-sufficiency with feedstock used for ethanol production was above 100% during the relevant period (Statistik Austria, 2011), the virtual feedstock imports related to ethanol production are zero. The trade streams with ethanol according to Winter (2010) indicate that while Austria was a net importer in 2007 and 2008, the situation changed in 2009, with net exports amounting to 28% of the inland production.

Fig. 7 shows the flow diagram for biofuels used in the transport sector in 2009. Together, biofuel net imports and virtual feedstock imports accounted for 70% of the total biofuel consumption.

5. Indirect trade of wood-based fuels

Apart from wood chips, bark and other wood fuels, "wood-based fuels" comprise waste liquor of the paper and pulp industry

[5] Note that this approach is only applicable if reliable supply balance sheets are available, as it is the case for agricultural commodities but not forest products.

[6] A "marketing year" is a 12-month period, usually starting from a new harvest.

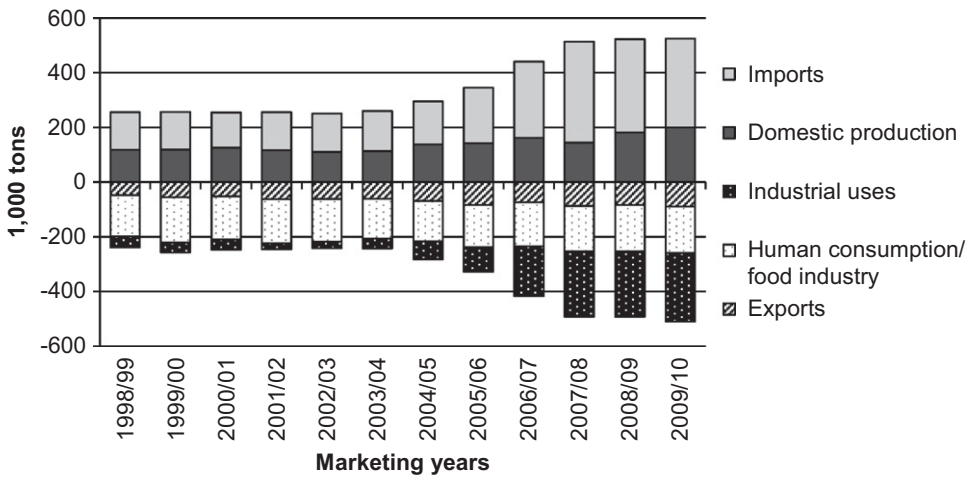

Fig. 5. Supply balance for vegetable oil (Stockkeeping, consumption for animal feed and losses are not shown due to negligible quantities, "Domestic production" also includes imported oilseeds crushed in Austria, whereas the self-sufficiency mentioned in the text is calculated on the basis of oilseed production in Austria.)
Source: Statistik Austria (2011).

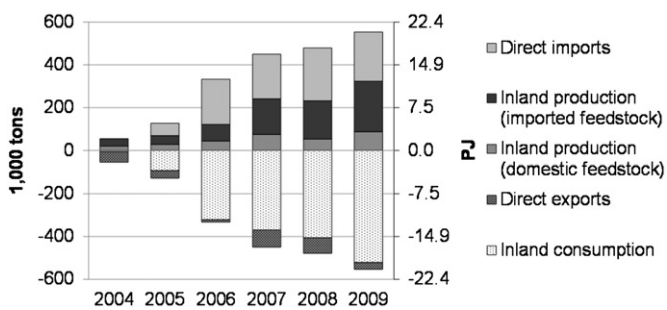

Fig. 6. Supply balance for biodiesel in Austria.
Sources: Winter (2010), Statistik Austria (2011), Statistik Austria (2012), own calculations and illustration.

which is usually used for process energy generation. In this section, the quantities of these fuels, which are traded indirectly through sawlogs, industrial roundwood and wood products are assessed. Due to the fact that wood streams are quite complex, not all relevant streams are captured in statistics and statistical data are sometimes inconsistent, it is stressed that the results are associated with some uncertainties and are considered to be best possible estimates.

5.1. Methodological approach

The methodological approach is based on the following steps: First, fundamental data on cross-border trade as well as production and consumption data are obtained from statistical databases. This data basis is enhanced with data from the wood processing industries (see Section 2), and used to derive a picture of the main wood streams. This includes international trade streams as well as flows between the industry sectors and toward different end uses.

Next, the consistency of the picture is checked, data gaps are filled on the basis of mass balance calculations and estimates in literature (primarily Hagauer et al., 2007), and streams of wood fractions not stated separately in production, consumption and trade statistics (such as bark and off-cuts) are added to the picture, based on typical percentages stated in literature. The biomass consumption according to energy statistics is also taken into account in this step. The final dataset, representing a complete picture of the Austrian wood flows, is displayed graphically as a flow diagram for the most recent year 2009. This diagram is presented and interpreted in the next section.

Next, the historical data are evaluated on the basis of two approaches: Within the first approach (Section 5.3) the main biomass streams, representing indirect imports of wood-based fuels are identified and the according quantities determined on the basis of conversion factors derived from empirical data. This approach is to illustrate the importance of indirectly imported wood-based fuels for the Austrian bioenergy sector. The second approach (Section 5.4) is based on the consideration that it can be assumed that all types of wood products (including panelboard, sawnwood and all types of paper products) ultimately end up in energy generation after their intended uses.[7] All trade streams of wood products can therefore be considered as indirect biomass streams for energy. Within the second approach, the main trade streams of wood products available in statistics are aggregated, in order to quantify the total net imports/exports of wood material.

5.2. Wood streams in Austria

Fig. 8 shows the wood flow diagram for the year 2009. The figure illustrates that the bulk of raw wood is processed to sawnwood by the sawmill industry. The average share of imports in the consumption of the sawmill industry accounted for 43% during the period 2001–2009 (between 35 and 52%). Apart from industrial roundwood, the wood supply of the paper and pulp industry and the panelboard industry is based on residues of the sawmill industry ("sawmill by-products"). Therefore, the sawmill industry acts as an important raw material supplier for the other industry segments. The increasing production of the Austrian sawmill industry in the last years and decades provided favorable framework conditions for the growth of the paper and pulp and the wood board industry. However, the import quantities of these industries have also amounted to notable trade streams, as the utilization of wood residues for pellet production and energy generation (and therefore also the competition between material and energy uses) has been growing in recent years.

[7] According to the Austrian Landfill Ordinance, biogenic wastes may not be landfilled. Therefore, thermal utilization is the usual way of disposing waste wood. In the case of paper and other wood products, one or more recycling loops may occur before the material is used energetically. Still, the final use can be assumed to be for energy generation.

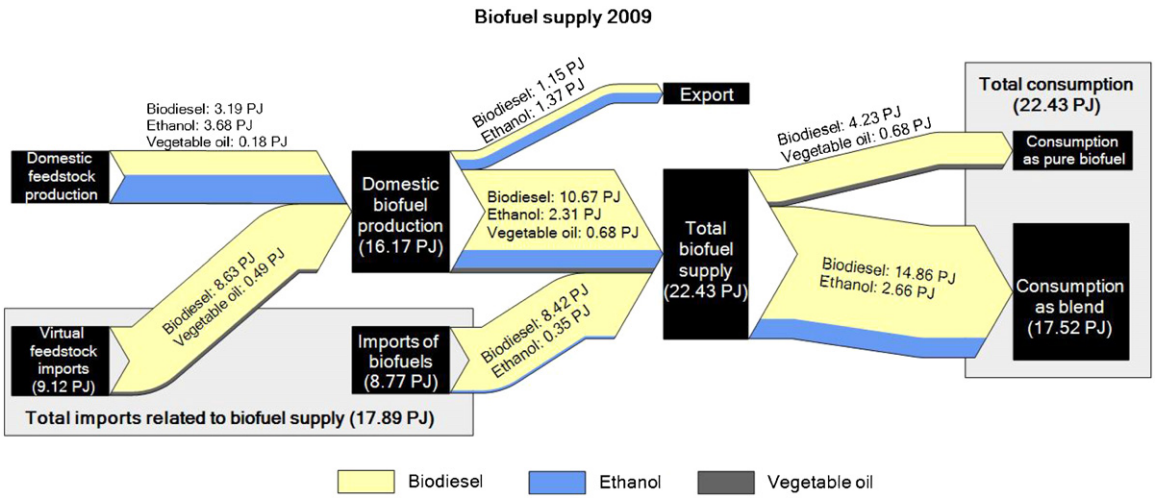

Fig. 7. Flow diagram of the Austrian biofuel sector in 2009. (Feedstock imports are stated as equivalents of the refined biofuel rather than calorific values of the feedstock used.)
Sources: Winter (2010), Statistik Austria (2011), Statistik Austria (2012), own calculations and illustration.

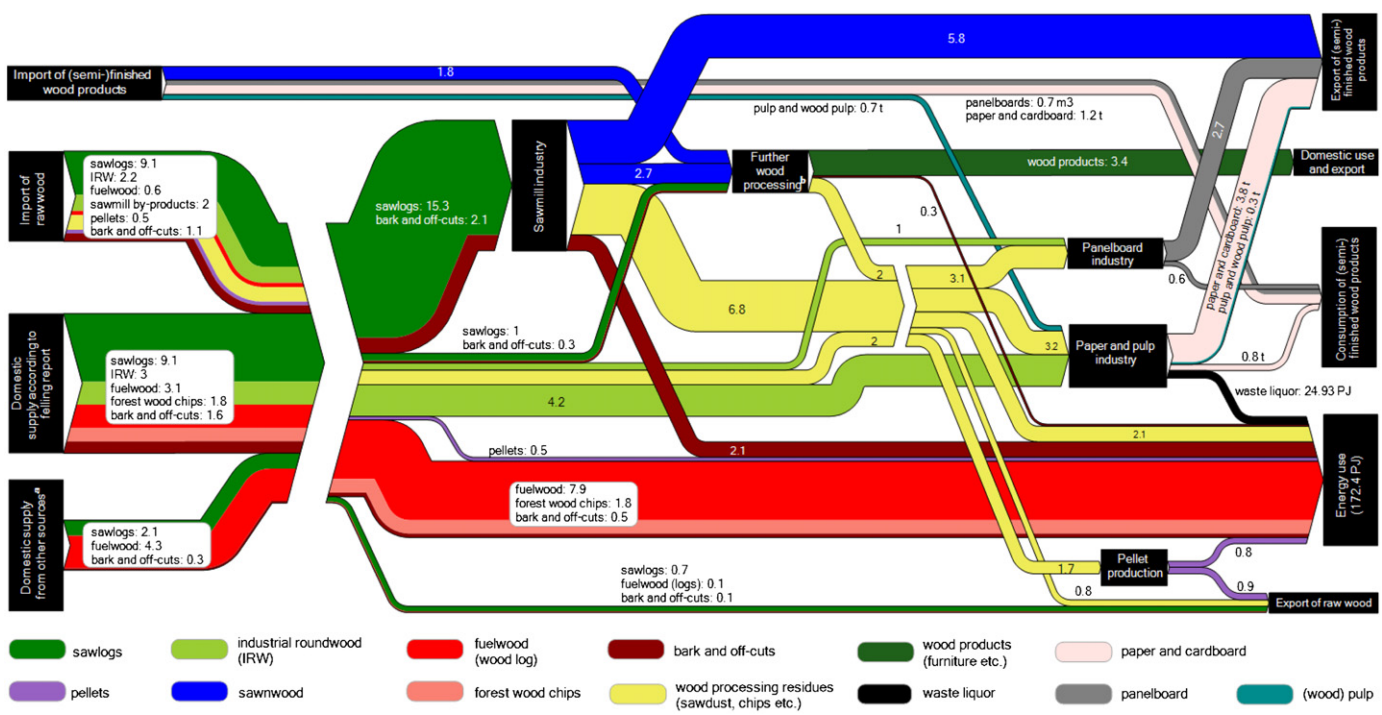

Fig. 8. Wood flow diagram for Austria in the year 2009 (values in millions of solid cubic meters, if not stated otherwise; see Appendix A for further definitions). (a) Domestic supply from other sources: All domestic sources of raw wood not included in the official felling report; primarily fuelwood from privately owned forests and wood from non-forest areas. (b) Further wood processing: carpentries, furniture plants and veneer plants, etc.
Sources: Prem (2009) (domestic supply according to wood felling report), FAO (2011a) (foreign trade of raw wood and (semi-)finished wood products), Austropapier (2011) (consumption statistics and foreign trade of the paper and pulp industry), Schmied (2011) (consumption statistics of the panelboard industry), Statistik Austria (2012) (biomass consumption for energy), Eurostat (2011a) (foreign trade of pellets), Hagauer et al. (2007) (general structure of the diagram, estimated values for roundwood consumption and production of by-products in "further wood processing"), own assessments and illustration.

The flow diagram shows that about one third of the Austrian raw wood supply in 2009 was based on imports. Therefore, a significant share of sawmill by-products, bark and off-cuts being used for energy production in Austria actually originate from foreign countries. On the other hand, large quantities of finished and semi-finished wood products are being exported (sawnwood, paper products and panelboard). Austria's exports of panelboard and paper products are about twice as high as the inland consumption, and the net exports of sawnwood are in a similar range as the quantity which is consumed domestically (i.e., processed to furniture, construction wood and other end-products).

5.3. Indirect imports of wood-based fuels

Based on the wood flow chart in Fig. 8, the following wood streams have been identified as the most significant indirect import streams of biomass for energy:

- Wood-processing residues being imported as sawlogs.

- Bark and off-cuts being imported together with sawlogs and industrial roundwood.
- Industrial roundwood and sawmill by-products being imported by the paper and pulp industry, and ending up as waste liquor used for energy generation.

Hence, the total indirect imports of wood-based fuels (WBF_{indir}) are calculated as the sum of indirectly imported wood-processing residues (WPR_{indir}), bark and off-cuts (BOC_{indir}) and waste liquor (WL_{indir}):

$$WBF_{indir} = WPR_{indir} + BOC_{indir} + WL_{indir}$$

Indirectly imported wood processing residues are calculated according to the following equation, where $\sum_j (WPR_{prod,j})$ denotes the total production of wood processing residues over all relevant industries j (sawmill industry and further wood processing), $\sigma_{import,j}$ the share of imports in the according raw wood supply and α_{energy} the share of wood processing residues which is used energetically in Austria.

$$WPR_{indir} = \alpha_{energy} \sum_j (WPR_{prod,j} \cdot \sigma_{import,j})$$

The indirectly imported quantity of bark and off-cuts is calculated on the basis of the total raw wood imports to Austria RW_{import} and estimated shares of bark p_{bark} and material which ends up as off-cuts $p_{off\text{-}cuts}$ according to the following equation, as bark and off-cuts are not included in wood quantities measured in volume units (Sandler, 2001).

$$BOC_{indir} = RW_{import} \left(\frac{p_{bark} + p_{off\text{-}cuts}}{1 - p_{bark} - p_{off\text{-}cuts}} \right)$$

Based on Hagauer et al. (2007) and Sandler (2001), p_{bark} is generally assumed 10% and $p_{off\text{-}cuts}$ 2.5%.

Indirect imports of waste liquor WL_{indir} are calculated on the basis of the total waste liquor production WL_{prod} and the shares of directly and indirectly imported raw wood (σ_{import} and σ_{indir}) consumed by the paper and pulp industry:

$$WL_{indir} = WL_{prod}(\sigma_{import} + \sigma_{indir})$$

The results of this assessment are summarized in Fig. 9. The indirect import streams accounted for an annual average of 27 PJ and between 14 and 20% of the total annual biomass consumption during the considered period. Wood-processing residues accounted for close to 50% of the total quantity (about 13 PJ), and bark and off-cuts for an average of more than 8 PJ per year. With regard to waste liquor, it was found that between 18 and 32% of the total quantity used for energy generation in Austria can be traced back to directly or indirectly imported wood. Hence, the average quantities of indirectly imported waste liquor amounted to about 6 PJ per year during 2001–2009.

Compared to direct imports of the bioenergy sector, indirect imports of wood-based fuels were clearly more significant until 2005: Direct imports of wood fuels accounted for about 10 PJ and exports for about 15 PJ in 2005, as Fig. 3 shows. Only since 2006, direct imports considered in energy statistics are in a similar range. The main reasons for the relatively high fluctuations in indirect and direct imports of wood-based biomass (Fig. 3 and Fig. 9) are seen in the weather conditions and storms, which had a significant impact on the wood supply in recent years. Due to large quantities of fallen timber in 2007 and 2008 (caused by the storms "Kyrill" and "Paula"), the total domestic wood supply (including sawlogs, industrial roundwood and fuelwood) was about 25% higher than the average value of 2005, 2006 and 2009 (Prem, 2009). This explains the comparatively low imports in 2007 and 2008, compared to 2006 and 2009.

5.4. Cross-border trade with wood products

The results of the previous approach indicate that large quantities of wood-based fuels which are used for energy generation in Austria actually originate from imported biomass. On the other hand, it needs to be taken into account that Austria is a net exporter of (semi-)finished wood products. Assuming that wood products and raw wood intended for material uses are usually used for energy generation after their primary uses (either in dedicated bioenergy plants or as biogenic waste in waste treatment plants), these trade flows can also be considered as indirect biomass trade for energy. Due to insufficient data on foreign trade with wood products, as well as methodological difficulties related to recycling rates and time lags between border-crossing and energetic uses, it is considered not feasible to derive time series of indirect trade related to these streams. However, by aggregating all trade streams related to material wood uses, it is possible to roughly determine whether Austria actually depends on imports, or is in fact a net exporter of wood material.

Fig. 10 shows the aggregated trade streams with wood products and raw wood intended for material uses (in SCM and energy equivalents), and Fig. 11 the aggregated trade streams of the paper and pulp industries (in tons). Apparently, the aggregated wood imports and exports shown in Fig. 10 are in a similar

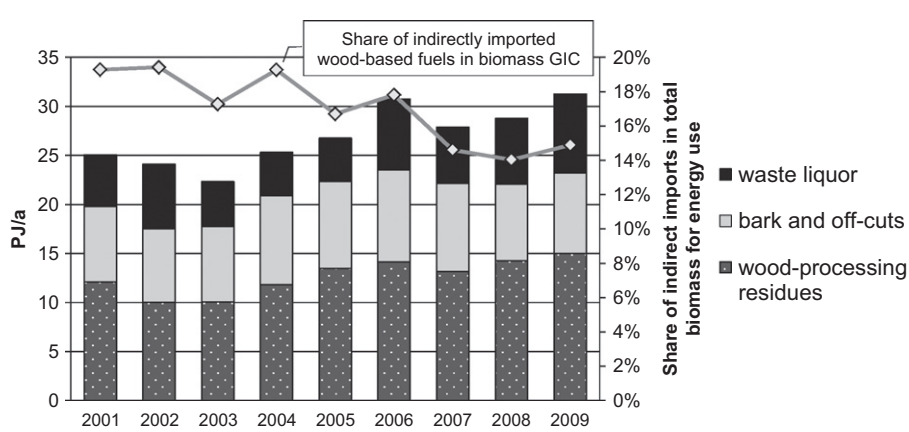

Fig. 9. Development of the main indirect import streams for energy use, and the according share in the total biomass consumption.
Sources: Hagauer et al. (2007), BMWFJ and BMLFUW (2010), Austropapier (2011), FAO (2011a), FAO (2011b), Schmied (2011), Statistik Austria (2012), own calculations and illustration.

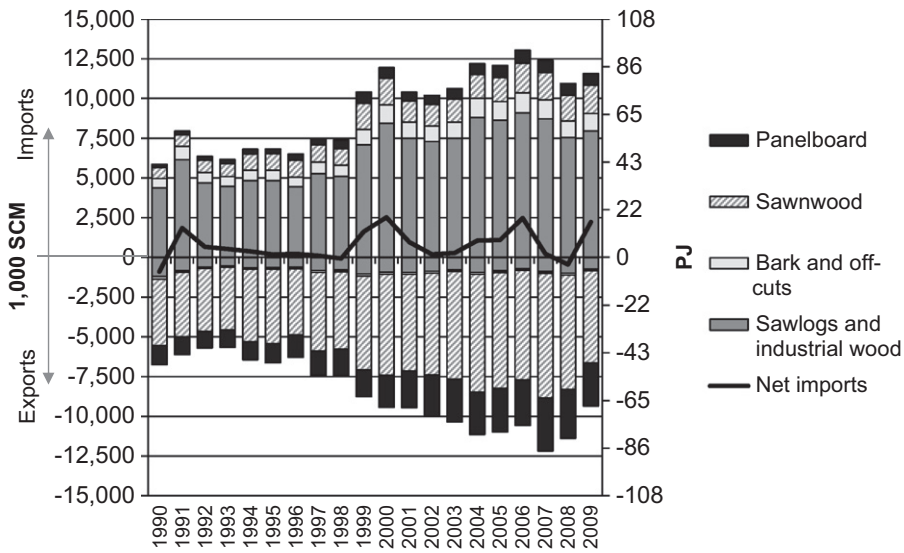

Fig. 10. Aggregated trade streams with wood products and raw wood intended for material uses.
Sources: FAO (2011b), own calculations and illustration.

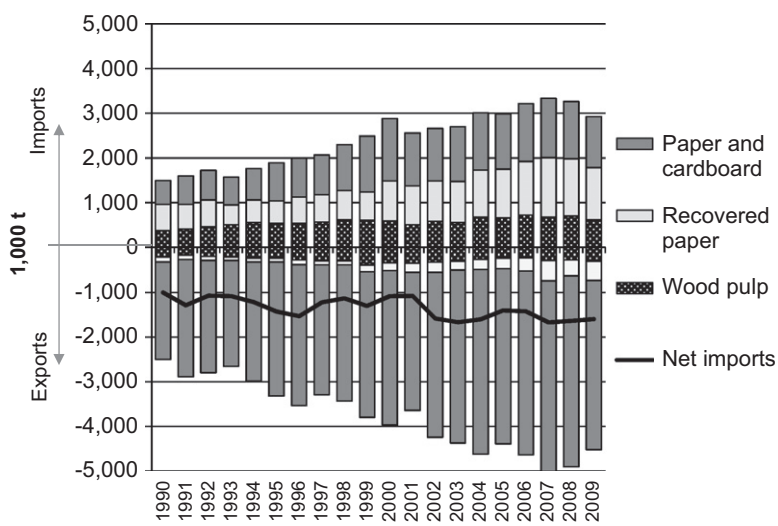

Fig. 11. Aggregated trade streams of paper, cardboard, recovered paper and wood pulp.
Sources: Austropapier (2011), FAO (2011b), own calculations and illustration.

range. The total net imports varied from about −0.9–2.5 million SCM during 1990–2009, but in most years the imports and exports were quite balanced. In contrast, the total net imports of the commodities paper, cardboard, pulp and recovered paper have been clearly negative during the last 20 years. Considering the quantity of wood required to produce this surplus, it is concluded that these net exports are a highly relevant indirect biomass stream. According to statistical data (Austropapier, 2011), an average of more than 1.5 SCM of wood are required to produce 1 t of paper/pulp.

To sum up, this approach indicates that the high imports of raw wood (which are the reason for the significant indirect imports of wood-based fuels determined in the previous section) are largely balanced by exports of sawnwood and panelboard. Furthermore, with the main trade streams of raw wood and wood products taken into account, the available data indicate that Austria has definitely been a net exporter of wood-based material in several years of the considered period (e.g., 2008 and 2007).

6. Synthesis, discussion and conclusions

As a result of the increasing use of bioenergy, global cross-border trade of biomass has grown strongly during the last decade (Junginger et al., 2011). On a global scale, indirect trade through roundwood and wood chips accounts for the most significant trade streams (630 PJ in 2006 according to Heinimö and Junginger (2009)), but direct trade with refined biomass fuels has increased from practically zero in 2000 to an estimated 200 PJ in 2009 (liquid biofuels: 120 to 130 PJ, pellets: 75 PJ according to Junginger et al. (2011)).

Due to several reasons explained in this work, getting insight into international biomass trade related to energy generation is not straightforward. Additional trade codes for specific biomass types can help to facilitate the monitoring of direct trade streams, as experience with recently introduced CN codes (for wood pellets and biodiesel) shows. But in order to quantify displacement effects of an increasing use of bioenergy and to track

indirect trade streams, specific methodologies (such as the ones proposed in this work) need to be applied.

6.1. The Austrian bioenergy sector

The official energy statistics for Austria also indicate that biomass trade for energy has recently been increasing significantly: Imports have surged from about 5 PJ in 2000 to 34.5 PJ in 2009, and exports from 6.7 to 15.2 PJ during the same period. Whereas imports are dominated by biodiesel and unrefined wood fuels, wood pellets account for the main proportion of biomass exports. According to energy statistics, 84% of the biomass used for energy originates from domestic production. The self-sufficiency in biomass for energy, defined as the ratio of production to consumption, was 91% in 2009. However, the results of this work indicate that with feedstock for biofuel production and indirect trade of wood-based fuels taken into account, cross-border trade related to bioenergy is clearly more significant than energy statistics suggest. Imports of agricultural commodities which can be attributed to biofuel production (according to the approach proposed in this work, where imports are distributed proportionally between the different end uses) accounted for close to 10 PJ in 2009, which corresponds to about 40% of the total biomass consumption in the transport sector. Assuming that vegetable oil from domestic production is primarily used for human consumption (as it was the case before the rapid growth in biodiesel production in recent years), feedstock imports related to biofuel production might actually be even higher. However, with a self-sufficiency rate of about 30% (according to our approach), the Austrian biofuel sector is highly dependent on imports, and its overall environmental impact highly depends on sustainability issues like agricultural practices and land-use change in exporting countries, or global indirect land-use change, respectively. The far-reaching policy implications of this issue are currently neglected to a large extent.

Despite the rapid growth of the biofuel sector in recent years, it is still of minor importance compared to residential heating and industrial heat/CHP generation, as Fig. 12 illustrates. The figure shows a flow diagram of the Austrian bioenergy sector. It is based on the official energy statistics (Winter, 2010; Statistik Austria, 2012), as well as the results of this work, i.e., data on indirect imports and (virtual) feedstock imports for biofuel production. Furthermore, feedstock imports for biogas production (primarily maize and small quantities of beet), accounting for approximately 1% of the total biogas feedstock used according to an estimate of the ARGE Kompost & Biogas (Kirchmeyr, 2011), are also depicted.

Undoubtedly, a main reason for the relatively high share of biomass in the Austrian energy supply (15.5% in 2009) is the size of the wood processing industry, as it acts as a supplier of cheap wood residues for energy use and covers a large share of its process energy demand with biomass. Apart from that, the high import streams of raw wood for material uses represent significant indirect import streams of wood-processing residues, bark, waste liquor etc. Based on the main fractions, it was found that these import streams were in a range of 30 PJ or 15% of the total biomass primary energy consumption in the last four years. This result emphasizes that there are strong interconnections between the wood processing industry and the bioenergy sector, and that the supply security of the Austrian bioenergy sector highly depends on the import and export activities of this industry branch. As Fig. 12 shows, indirect imports of wood-based fuels are primarily relevant for the supply of CHP, district heat and

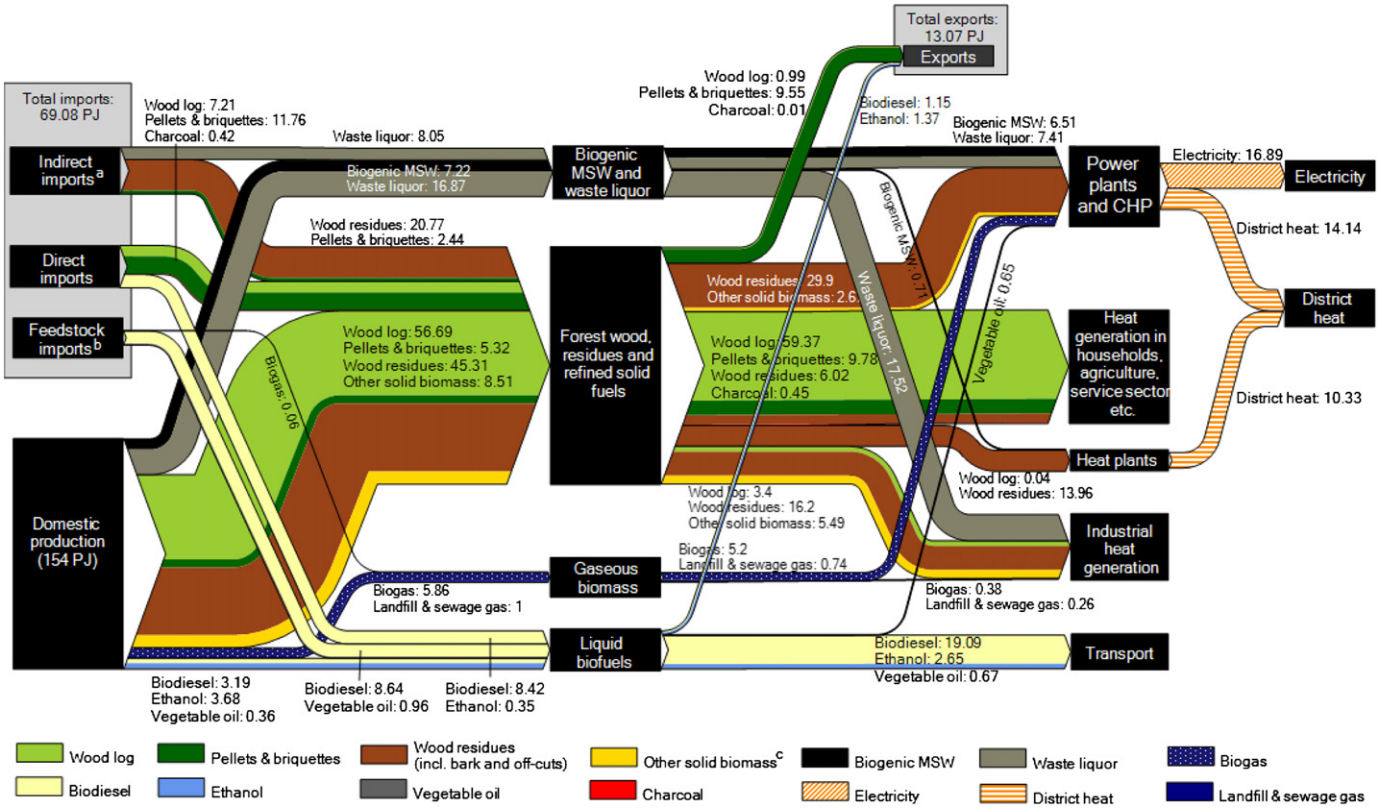

Fig. 12. Flow diagram of the Austrian bioenergy sector (values in PJ; feedstock imports are stated as equivalents of the refined biofuel; flows of less than 0.5 PJ are partly not displayed for better readability). (a) Indirect imports of wood-based fuels (see Section 5.3). (b) Feedstock imports according to the approach described in Section 4.3. (c) "Other solid biomass" comprises wood waste and small quantities of straw.
Sources: Winter (2010), Kirchmeyr (2011), Statistik Austria (2012) (estimate of feedstock imports for biogas production), own assessments and illustration.

industrial heat generation, whereas small-scale heat generation is almost exclusively based on domestic and (to a very limited extent) directly imported biomass.

In total, about one-third of the biomass used for energy in Austria in 2009 can be traced back to imports. Together, indirect imports of wood-based fuels and feedstock imports are clearly more significant than direct imports stated in energy statistics. However, it needs to be stressed that while Austria is importing large amounts of raw wood, it is a net exporter of the wood products sawnwood, panelboard and paper products. Extending the concept of indirect trade to these products is connected with substantial methodological difficulties, and data on trade with finished wood products prove to be insufficient for a full assessment. Our rough approach, which is based on the most significant streams of wood products mentioned above, indicates that Austria's raw wood imports are largely balanced by exports of sawnwood and panelboard. Furthermore, with paper products taken into account, Austria has at least in some years of the last decade been a net exporter of wood-based material. Nonetheless, it is considered noteworthy that a significant fraction of wood-based fuels stated under domestic production in energy statistics actually originates from imports.

6.2. The European perspective

Considering the increasing use of bioenergy in the EU and the importance of bioenergy for achieving the "2020 targets" (Szabó et al., 2011), it is considered crucial to monitor developments in biomass trade on a European level, possibly based on the approaches proposed in this work. Based on a rough investigation, it was found that some developments on the European level are somewhat similar to the situation in Austria: According to energy statistics, the EU is becoming increasingly dependent on biomass imports for energy: From 2006 to 2010, the net biomass imports increased from 0 to 4.5% of the total biomass PEC and accounted for more than 200 PJ in 2010 (Eurostat, 2011b). Increasing imports of both wood fuels and liquid biofuels contributed to this development. Furthermore, the total net imports of vegetable oil used for food, energy and other uses (including oil contained in net imports of oilseeds) have more than doubled during the last 10 years and are now approximately equal to the quantity produced in the EU (FAO, 2012).

Based on a rough investigation of the current state of wood trade in EU countries, it was found that in the following countries the situation is similar to Austria, as they have large imports of roundwood and large exports of sawnwood: Sweden, Finland and Germany (FAO, 2011b). Other countries are net importers (e.g., Italy, the Netherlands, UK) or net exporters of all wood types (e.g., Latvia, Czech Republic, Slovakia). Despite a significant decrease in roundwood imports from Russia since 2007, the EU as a whole is (just like Austria) net importer of roundwood and net exporter of sawnwood, and importing increasing amounts of wood chips, particles, etc.

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Appendix A. Explanation of terms and definitions used in this study

Biomass: All kinds of biogenic material used for energy or other purposes; biomass used for energy generation is denoted as "biomass for energy" or "biomass fuels".

Biofuels: Biogenic transport fuels (e.g., biodiesel, ethanol).

Raw wood: Includes sawlogs, industrial roundwood, fuelwood, off-cuts and bark.

Sawnwood: Planks, beams and other wood products that have been produced from roundwood.

Sawlogs: Raw wood for sawnwood production.

Industrial roundwood: Includes roundwood consumed by the paper and pulp industry (pulpwood) and such consumed by the panelboard industry.

Panelboard: All kinds of particle board and fiberboard.

Wood-processing residues: Sawmill by-products like sawdust, wood chips and other residues from wood processing (bark and off-cuts not included, if not stated otherwise).

Wood-based fuels: Comprises all types of wood fuels (fuelwood, wood chips, sawdust etc.) as well as waste liquor of the paper and pulp industry (black liquor).

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