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Kurt Kratena, Ina Meyer

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This study quantifies the CO_2 emissions embodied in Austrian exports and imports, using a two region-input output approach (Austria and the rest of the world). The approach considers differences in production technologies between Austria and the rest of the world, concerning the CO_2 coefficients (per unit of output) and the input-output structure (both are taken from data for EU 27). The CO_2 emissions embodied in Austrian imports are considerably higher than CO_2 emissions embodied in exports, i.e., CO_2 for Austrian demand is leaking to the rest of the world. From 1995 to 2005 this negative balance of CO_2 in trade has diminished in absolute terms, from 11 million tons (1995) to 6.4 million tons (2005), as CO_2 embodied in exports has grown more rapidly than CO_2 embodied in imports, thereby creating a huge potential for future carbon leakage.

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1. Introduction

As studies dealing with the analysis of embodied carbon in imported and exported goods suggests, considerable amounts of carbon are embodied in international trade of manufactured goods around the world. Peters and Hertwich (2008), for instance, calculate that 5.3 Giga tons (Gt) (21.5%) of global CO_2 emissions are embodied in internationally traded goods. The acceleration of the global integration via international outsourcing and fragmentation of production processes has contributed to this development. Embodied carbon emissions in imports are, however, not considered in the legal reporting requirement under the United Nations Framework Convention on Climate Change (UNFCCC) because this scheme follows a territorial principle where only emissions produced from domestic sources are accounted for. Due to the lack of accounting for emissions embodied in imports, this approach to greenhouse gas (GHG) emissions inventory can generate misleading emissions profiles, e.g. emissions per unit of GDP or per capita of a country depending on the significance of embodied emissions in the respective national trade balance. It has been suggested to account for emissions embodied in trade because this gives a more adequate description of countries emissions profiles. It would as well broaden the scope for mitigation policies with respect to traded goods and related foreign production processes (Peters – Hertwich, 2008a).

A correlated issue of concern is related to climate protection agreements that have a limited geographic scope such as the Kyoto Protocol. Industries in countries with binding emission reduction targets have to compete with exports from countries without mandatory emission reductions. Due to the lower costs involved (through lower carbon prices due to absent pricing mechanisms), there is an incentive to shift carbon-intensive production to non-participant countries, an effect known as carbon leakage. Production relocations improve the competitiveness position of the relevant industry, and, at the same time, reduce the countries' emission budget if carbon embodied in trade is not accounted for. Carbon leakage, however, could imply a rise in the international emission budget if production shifts address countries with less carbon efficient installations and, in particular, less stringent environmental legislation. This could put climate protection policies at risk. The effective scope of carbon leakage is not generally clear and depends on the case and, particularly, on the fuel mix to which the industry relocates. Knowledge on the energy intensity of technologies over the various countries is, however, lacking (Bosch – Kuenen, 2009). In addition, the extent of carbon leakage is dependent on the stringency of the climate policy, i.e. the price of carbon imposed by taxes or cap and trade mechanisms. Studies suggest that a price of 20 €/tone of CO_2 until 2012 could induce a rate of carbon leakage of between 0.5% and 25% in the iron and steel sector, and between 40% and 70% in the cement sector (Reinaud, 2009). The problem of carbon leakage has also led to an assessment by the

European Commission of sectors deemed to be exposed to a significant risk of carbon leakage with respect to the implementation of the revised EU Emissions Trading System (EU ETS). Under the revised EU ETS which will apply from 2013, installations in such sectors will receive a higher share of greenhouse gas emission allowances free of charge than other industrial sectors. Evidence for a relocation-oriented kind of leakage, i.e. longer-term estimates of carbon leakage such as changes in investment, is said to be poor, however (Peters – Hertwich, 2008a). Little is known about the ongoing structural change especially regarding the current economic slow-down and the degree of mobility of manufacturing industries.

But there is evidence for a second type of leakage, namely an increased consumption of products containing carbon in a participating country on the account of an increased production in a non-participating country due to imports. Most EU countries have a larger increase in emissions with consumption, in particular the smaller countries as they are highly dependent on trade. Some authors thus argue in favor of a shift from production-based emission reporting (including exports) to a consumption-based system of emission accounting that includes imported CO_2 emissions (Peters – Hertwich, 2008b). In this case, the responsibility for GHG emissions would be attributed to consumers of the relevant product no matter if produced inland or abraod. A GHG inventory based on consumption is compiled by taking the production-based GHG inventory, adding the emissions embodied in imports and subtracting emissions embodied in exports. Emissions associated with production are considered lower than emissions associated with consumption with respect to industrialized countries, while for developing countries it is the other way round, more emissions are released from production than from consumption. This holds, e.g. for Germany, France, Italy, Japan, the United States and China (Ahmad – Wykoff, 2003; Nakano et al., 2009). Emissions of Annex B parties[1] are 5.6% higher based on consumption compared to production, while for non-Annex B countries the consumption-based emissions are -8.1% lower compared to production (Peters – Hertwich, 2008a). In sum, a third of the global increase in production-based emissions took place within the non-OECD economies in the late 1990s (about 860 Mt CO_2) but more than half of the consumption-based emission (1550 Mt CO_2) is attributable to OECD consumption (Nakano et al., 2009).

The problem of carbon leakage, i.e. carbon embodied in traded goods with non-participating countries, suggests the need to assess carbon emissions embodied in trade. This is, on the one hand, to judge about the effectiveness of efforts to reduce GHG emissions, and, on the other hand, to assess countries' emission profile and scope of responsibility more clearly. It does not seem likely that negotiations in December 2009 in Copenhagen will lead to a shift in the underlying emission reporting scheme, namely the GHG inventory employed by the UNFCCC, however. Methods for estimating a country's GHG emissions have not been the subject of debate with respect to post-Kyoto agreements (Peters – Hertwich, 2008b). But

[1] Annex B Parties include all Annex I countries but Turkey and Belarus and are listed in Annex B of the Kyoto Protocol. Annex I parties are included in Annex I to the UNFCCC, United Nations Framework Convention on Climate Change.

more stringent mitigation policies by countries and regions will likely drive issues such as border-tax adjustments or international sectoral approaches to mitigation (IEA, 2009) more important if stringent abatement regimes continue to be of limited geographic scope.

2. Aim of the project

The aim of the project is to quantify Austria's emissions embodied in international trade in order to calculate net imports (positive or negative) of carbon emissions. The calculation draws on trade balances and is equivalent to a consumption-based approach of GHG accounting. This stands in contrast with the GHG inventory applied by the UNFCCC, which assigns emissions to the producer of the pollution, following a territorial principle. The main reason to apply a consumption-based approach to carbon emissions is to gain additional insight into possible causes of changes in emissions, i.e. to assess whether changes are the result of changes in the composition of final consumption, production or indeed changes in international trade. Deriving a picture of the emission performance of Austria taking into account emissions embodied in trade, we compare the development of CO_2 emissions at three different points in time: 1995, 2000 and 2005. The change in the net imports of CO_2 emissions in this period reveals, if the burden of emission reduction in Austria has been shifted to other countries (carbon leakage) or if Austria has attracted emissions due to consumption growth in other regions.

3. GHG inventories and the concept of embodied carbon

GHG inventories are required no matter of the design of a potential post-Kyoto climate policy agreement because commitments and performance in terms of emissions are evaluated on their basis. Peters and Hertwich (2008b) argue that there has been little debate on using different system boundaries when constructing GHG inventories, i.e. the territorial or the consumer-oriented boundary. In particular, countries may have different mitigation options using different system boundaries in GHG inventories. Currently, national GHG inventories comprise GHG emissions and removals from sinks taking place within national territories over which the country has jurisdiction (Intergovernmental Panel on Climate Change; IPCC, 1996). This system boundary is essentially the same as used in international energy statistics (IEA, 2005) but differs from the system boundary of the 'resident principle' used in national accounts. This implies that GHG inventories are not directly comparable to economic activities as aggregated in the NAMEA (National Accounting Matrix including Environmental Accounts) data. The rationale of the Systems of National Accounts (SNA) is the concept of gross domestic product, i.e. the total gross values added that is produced by all units resident in the economy. The difference between the territorial and the economic system boundary gives rise to problems in allocating emissions from international activities that are not bound to the national territory, e.g. international transportation. Therefore, emissions from international transportation (bunker fuels) have not yet been allocated to national GHG inventories. Using the SNA definitions for ownership of productive activity would resolve issues such as the allocation for international transportation. These activities would be treated as exports and emissions were allocated in the same way as economic activity in the National Accounting Matrices including Environmental Accounting (NAMEA; Statistik Austria, 2006).

In addition, the system boundary of the current UNFCCC GHG inventory defined by the territorial principle is based on a country's production omitting international trade and resource endowments, i.e. it accounts for domestically produced products for households and governmental final demand and investment, including changes in business inventories as well as emissions associated with the production of products destined for export (see Table 1). It omits imports of manufactured goods that play a major role in globalized economic activities. Therefore, several studies have stressed consumption-based approaches to GHG calculations that consider imports of goods (e.g. Wyckoff – Roop, 1994; Munksgaard – Pedersen, 2001; Ahmad – Wyckoff, 2003; Shui – Harriss, 2006; Peters, 2008; Peters – Hertwich, 2008b). Ahmad and Wyckoff (2003), for instance, use an indicator that estimates emissions associated with the domestic consumption that captures total domestic final demand. It calculates emissions from households and government final consumption and investment, including changes in business inventories regardless of the fact that the goods being consumed were imported or produced domestically. A GHG inventory based on a country's consumption is thus derived by excluding emissions embodied in exports and including emissions embodied in imports (Table 1). Consequently, emissions required producing a country's exports are allocated to the country that consumes the exports. Each country is hence responsible for the emissions caused by the production of its imports (Ahmad – Wyckoff, 2003). Calculations suggest that emissions associated with domestic consumption of products are higher than the domestic production of emissions for the OECD as a whole as well as for some countries (Ahmad – Wyckoff, 2003).

A key to account for carbon leakage within an emissions binding Post-Kyoto agreement could, in principle, be to use consumption-based GHG inventories instead of territorial production-based inventories. Consumption-based emission inventories account for carbon leakage associated with imports of intermediate or final products needed to meet final consumer demand. This means, parties that have agreed internationally binding emissions reduction would – under a consumption-based GHG inventory – be prevented from reducing domestic emissions just by importing the necessary carbon emitting goods without adjusting final demand patterns or finding more carbon efficient production methods. Further, by using consumption-based GHG inventories, developed countries would be assigned a greater share of global GHG emissions, thus, emission commitments for developing countries could be much weaker. Consumption-based GHG inventories create an incentive to trade products from countries with lowest emissions, highest technological efficiency standards and a highly decarbonised energy system. This would shift production to where it is environmentally preferable. International trade could hence increase the ability to reduce

GHG emissions in the same way that international trade has been exploited to reduce production costs.

Table 1: Production vs. consumption-based approach to GHG inventories

UNFCCC GHG-inventory	Literature
production approach	**consumption approach**
= GHG emissions according to territorial principle (incl. exports)	= production approach - exports + imports

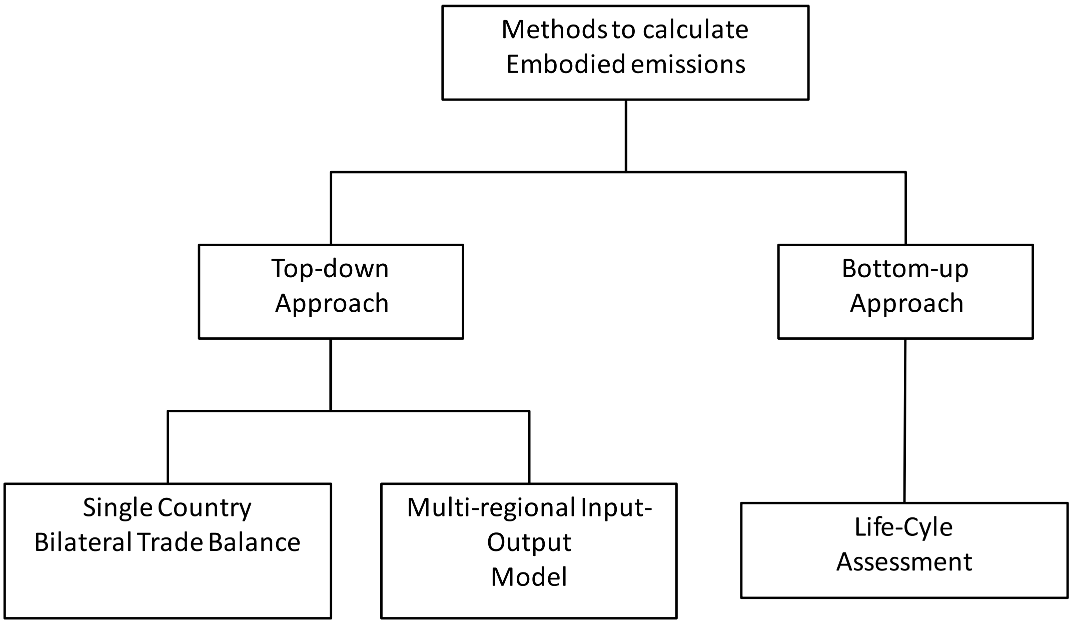
S: Own illustration.

A crucial question refers to obstacles to implementation of consumption-based accounts, in particular, practical issues associated with data availability and data construction need to be addressed (see section 6). The quality of data finally depends, among others, on the data quality of the main trading partners and the complexity of the international production network for relevant economic sectors. National GHG inventories would thereby become internally linked through trading partner and be influenced by their respective emission profile. This would drive the process of emissions accounting and mitigation more international.

4 Measuring embodied emissions

The term carbon (emissions) embodied in a product is defined as all the emissions required to produce the product (Peters – Hertwich, 2008b). This includes all stages of the production process from raw material extraction through to final assembly and ultimately the final sale of the product. These emissions can be calculated using different methodological approaches. Methods to calculate embodied emissions can be distinguished into bottom-up or top-down methods (see Figure 1). Bottom-up methods calculate embodied carbon emissions by analyzing the production process of a specific product, for instance, by life-cycle analysis. A prominent example for this kind of analysis is the assessment of the primary energy required to provide apples from New Zealand transported by air to the Rhein-Ruhr area in Germany, compared with home-grown apples harvested in mid-October and stored and cooled until mid March (Blanke, 2006). The system boundaries within LCA are flexible, e.g. the increased energy required to import apples from overseas was partially offset by the energy needed for cold storage of domestic apples but could be fully offset if home-grown apples were stored for up to 18 month. The measurement of embodied emissions by LCA can as well be complex when considering not only the inputs to the related product, but, additionally, the inputs to those inputs up the whole value chain.

Figure 1: Methods to calculate embodied carbon emissions



S: Own illustration.

For the analysis of carbon embedded in imports and exports of a country, input-output analysis is applied (top-down approach). Input-output tables comprise the technology of each industry in terms of input requirements per unit of gross output, with each industry embracing a range of different specific products. Each of the products has different emissions coefficients (carbon to value coefficients). For each industry a sectoral carbon coefficient is estimated using averages. Hence this approach is not particularly useful in the calculation of embodied carbon in a single product.

For global climate policy the emissions embodied in trade between countries are of interest. Using Input-Output analysis two main approaches to modeling carbon embodied in trade at national level can be distinguished: (i) the single country approach and (ii) the multi-regional approach. The single country approach determines the domestic carbon emissions in each country necessary to produce the bilateral trade balances with another country. This approach is the most transparent but usually does not consider the imports required to produce the bilateral trade. A more complex approach for constructing consumption-based GHG inventories uses a multiregional input-output model that calculates emissions involved in intermediate goods trade. The full multiregional input-output model distinguishes between trade in intermediate goods and trade in final goods, as well as by trading partners (Peters, 2008).

During the last decade, the single country approach has been applied widely in the literature, as Wiedmann et al. (2007) show in their complete extensive survey. Most of these studies deal with one country in their analysis, like for example Sanchez-Choliz and Duarte (2004) for Spain and Mongelli et al. (2006) for Italy. Antweiler (1996) calculated net embodied emissions for a large number of countries and derived 'pollution terms of trade' from that. The simplest application for a single country consists of multiplying a vector of net-exports with a Leontief inverse and a matrix of emission coefficients. Some of the single country studies apply a multi-regional approach to quantify the emissions embodied in the trade of one country, as Weber and Matthews (2007) for the US and Turner et al. (2007) and Wiedmann, et al. (2007) for the UK. The crucial point for the differences between single country and multi-regional approaches is the technology in the rest of the world compared to the technology in the home country. The simple single country approach starts from the assumption that both regions use the same technology. This assumption has been discussed in the literature and the high data demands are often seen as the main impediment for introducing differences in technologies. It must be noted here that the notion of technology refers to two aspects: (i) the CO_2 coefficient per unit of output and (ii) the intermediate input requirements expressed in the input-output matrix. The main reason for advocating the multi-regional approach for the calculation of trade-embodied carbon emissions is that both CO_2 coefficients and input-output matrices of all trading partners are known.

Although the multi-regional approach might therefore be seen as superior to the single country approach, the discussion about the technology assumption seems to be slightly misleading. This assumption is usually made at a very aggregate level in terms of inputs per unit of output of industries. At this level of aggregation the term 'technology' is not appropriate, because a useful definition of technology of production can only be given at a much more disaggregated level, i.e. at the level of processes. As the output of each industry comprises a set of different commodities and corresponding processes, product-mix effects might lead to significant differences in input per output requirements of industries, though the underlying process technologies are identical. The key to relaxing the assumption of identical technologies at home and abroad therefore lies in applying a more diaggregate classification of industries than most of the literature. In this paper we closely follow the methodology lined out in Serrano and Dietzenbacher (2008) of a multi-regional framework, adapted for single country-analysis.

5 Quantifying embodied emissions in Austrian external trade - the methodology

A single country approach is applied here to quantify the CO_2 emissions embodied in Austria's external trade. The starting point for the analysis is a two region (region *1*, *2*) input-output framework with full information about flows from any industry in each region to the corresponding user (intermediate or final demand) in each region (see: Serrano and

Dietzenbacher, 2008). In the single country approach we simply assume that region 1 is the home country and region 2 represents the rest of the world. Flows from region 1 to region 2 therefore are exports of the home country and flows from region 2 to region 1 are imports of the home country. The other flows are domestic flows within each region. The input-output model is represented in terms of the technical coefficient matrices **A**, representing the input requirements per unit of output, calculated from the flow matrices in absolute values. The technical coefficient matrices $\mathbf{A_{11}}$, $\mathbf{A_{12}}$, $\mathbf{A_{21}}$ and $\mathbf{A_{22}}$, are given by the input of intermediates from region 1 or 2 divided by the gross output **x**, of region 1 or 2. The corresponding final demand vectors are $\mathbf{y_{11}}$, $\mathbf{y_{12}}$, $\mathbf{y_{21}}$ and $\mathbf{y_{22}}$.

$$\left[\frac{x_1}{x_2}\right] = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \left[\frac{x_1}{x_2}\right] + \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \qquad (1)$$

The matrices $\mathbf{A_{11}}$ and $\mathbf{A_{22}}$ are the domestic input coefficient-matrices in both regions, $\mathbf{A_{12}}$ is the imported input coefficient-matrix in region 2 and $\mathbf{A_{21}}$ is the imported input coefficient-matrix in region 1. In a similar manner $\mathbf{y_{11}}$ and $\mathbf{y_{22}}$ represent the domestic final demand vector in both regions, and $\mathbf{y_{21}}$ is the imported final demand in region 1 and $\mathbf{y_{12}}$ the imported final demand in region 2. In this simple framework, emissions of CO_2 are linked via diagonal matrices of CO_2 emission coefficients per unit of gross output, $\hat{E}$, to the gross output vector, **x**:

$$\left[\frac{em_1}{em_2}\right] = \begin{bmatrix} \hat{E}_1 L_{11} & \hat{E}_1 L_{12} \\ \hat{E}_2 L_{21} & \hat{E}_2 L_{22} \end{bmatrix} \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \qquad (2)$$

This framework shall then be applied to the case of accounting for the trade embodied-emissions of Austria (region 1), vis-à-vis the rest of the world (ROW, region 2) as in Serrano and Dietzenbacher (2008). The exports of the small open economy would, in principle, be given by $\mathbf{A_{12}}\,\mathbf{x_2} + \mathbf{y_{12}}$. If we assume that the deliveries of a small open economy are very small in relation to the gross output of the rest of the world, we can set $\mathbf{A_{12}} = 0$ and assume that total exports are given by $\mathbf{y_{12}}$. We further assume that the matrix of total technical coefficient of the rest of the world $\mathbf{A_{22}}$ is known or can be approximated by input-output structures of a large aggregate of countries (e.g. EU 27). In that case the approach comes closer to a multi-regional input output framework, though, without taking into account the country multiplier effects of a full multi-regional framework.

We can write the domestic input matrix of the small open economy $\mathbf{A_{11}}$ as the domestic input matrix $\mathbf{A^d}$ and the import matrix $\mathbf{A_{21}}$ as $\mathbf{A^m}$. In a similar manner the vector $\mathbf{y_{11}}$ is given as domestic final demand without exports, i.e. $\mathbf{f^d} - \mathbf{ex}$, and the vector $\mathbf{y_{21}}$ as imported final demand, $\mathbf{f^m}$ of the small open economy. These assumptions yield the following partitioned system:

$$\left[\frac{x_1}{x_2}\right] = \begin{bmatrix} A^d & 0 \\ A^m & A_{22} \end{bmatrix} \left[\frac{x_1}{x_2}\right] + \begin{bmatrix} f^d - ex & ex \\ f^m & y_{22} \end{bmatrix} \qquad (3)$$

The solution of the system is given by:

$$\begin{bmatrix} x_1 \\ \hline x_2 \end{bmatrix} = \begin{bmatrix} (I-A^d)^{-1} & 0 \\ A^m(I-A^d)^{-1}(I-A_{22})^{-1} & (I-A_{22})^{-1} \end{bmatrix} \begin{bmatrix} f^d - ex & ex \\ f^m & y_{22} \end{bmatrix} \tag{4}$$

As above in (2), emissions can be calculated by pre-multiplying the single parts of the new Leontief inverse in (4) by the diagonal matrices of CO_2 emission coefficients per unit of gross output:

$$\begin{bmatrix} em_1 \\ \hline em_2 \end{bmatrix} = \begin{bmatrix} \hat{E}_1(I-A^d)^{-1} & 0 \\ \hat{E}_2 A^m(I-A^d)^{-1}(I-A_{22})^{-1} & \hat{E}_2(I-A_{22})^{-1} \end{bmatrix} \begin{bmatrix} f^d - ex & ex \\ f^m & y_{22} \end{bmatrix} \tag{5}$$

The terms comprising the new Leontief inverse can be interpreted in the following way:

The term $\hat{E}_1(I-A^d)^{-1}$ represents cumulative emissions of domestic production, the term $\hat{E}_2 A^m(I-A^d)^{-1}(I-A_{22})^{-1}$ stands for cumulative emissions of imports taking into account the import requirements for domestic output ($A^m(I-A^d)^{-1}$) as well as the production in the ROW induced by this import demand ($(I-A_{22})^{-1}$). Finally, the term $\hat{E}_2(I-A_{22})^{-1}$ comprises the cumulative emissions of the ROW.

As Ahmad and Wyckoff (2003) and Serrano and Dietzenbacher (2008) have shown, the balance of emissions between producer and consumer responsibility is identical to the trade balance of embodied emissions (exports minus imports). Therefore, we concentrate on the trade balance in this study.

The cumulative emissions in the exports of the small open economy are given as:

$$em_{\exp 1} = \hat{E}_1(I-A^d)^{-1}ex + \hat{E}_2 A^m(I-A^d)^{-1}(I-A_{22})^{-1}ex \tag{6}$$

That comprises (i) cumulative domestic emissions from domestic production of exports, and (ii) cumulative emissions in the rest of the world due to the production of intermediate imports for domestic production of exports. Similarly, the cumulative emissions in the imports of the small open economy are given as:

$$em_{imp1} = \hat{E}_2(I-A_{22})^{-1}f^m + \hat{E}_2 A^m(I-A^d)^{-1}(I-A_{22})^{-1}f^d \tag{7}$$

That comprises (i) cumulative emissions in the rest of the world due to the production of final imports, and (ii) cumulative emissions in the rest of the world due to the production of intermediate imports for domestic final demand, including exports.

The column vector of the trade balance of cumulative emissions, $\mathbf{em_{net1}}$, therefore becomes:

$$em_{net1} = \hat{E}_1(I-A^d)^{-1}ex - \hat{E}_2(I-A_{22})^{-1}f^m - \hat{E}_2 A^m(I-A^d)^{-1}(I-A_{22})^{-1}f^d \tag{8}$$

Serrano and Dietzenbacher (2008) have shown that the trade balance can also be derived as the balance between emissions induced by production (i.e. domestic emissions as measured in emission inventories) and cumulative emissions of final demand of residents.

Though this approach is only a single country approach, it allows for different technologies, both for the structure of intermediate demand as well as for emission coefficients. The multi-regional approach is often advocated by arguing that it contains a potential maximum of information about technology differences between countries. The scientific as well as political debate has very much focused on the question of process technology and carbon leakage. The standard argument is that the process technology for a certain commodity might be more emission intensive in a developing country, where production is outsourced to, than in the domestic economy, thereby creating an excessive carbon leakage effect.

Though this is fully correct from a formal point of view, it is mainly a matter of the level of aggregation, if a certain input-output model is a correct representation of 'technology'. It shall be argued here, that a number of studies with multi-regional input-output models work at a highly aggregated level of industries, where the notion of 'technology' might be misleading. Nakano et al. (2009) and Ahmad and Wyckoff (2003), for example, apply a classification of 17 industries, where some emission intensive industries are isolated (iron and steel, non-metallic mineral products), but others are aggregated with non-emission intensive activities (production of pulp and paper with printing & publishing). Note that an element of the diagonal matrix $\hat{E}$ is determined by the underlying process technologies and their respective emission intensity, as well as the output weights of these processes in total industry output. This corresponds to the well established phenomenon in the input-output literature about the impact of product mix-effects on the technology in input-output tables (see: Bezdek and Durham, 1976). Another relevant level of aggregation that determines the degree of superiority of the multi-regional approach over the single country approach is the grouping of countries. The full working out of country multipliers in international trade directly depends on the dimension of the category 'rest of the world' (ROW), which is a necessary residual in all multi-regional approaches.

The philosophy in this study was to improve the single country approach by some additional information about the economies of the trading partners. The emphasis is on maximum disaggregation for the level of industries, using the 2 digit- NACE classification of about 60 industries. It must be noted, that the notion of 'technology' at this level of industries is still misleading, as it does not allow for identifying industrial processes. It allows for separating all emission intensive industries and differentiates between 25 service sectors with a detailed representation of different modes of transport services. At this level of industry aggregation, technology differences between Austria and the ROW are taken into account. The ROW technology is approximated by the technology of EU 27. This broad multi-regional approach therefore does not account for country multipliers in international trade, but focuses on technology differences at a disaggregated level of industries.

6 Data

The main data requirement for single country or multi-regional input-output approaches for quantifying trade embodied-emissions comprises IO tables, bilateral trade data and data on CO_2 emissions. Multi-regional approaches are generally more data-intensive than single country approaches and, in addition, require more assumptions, for instance relating to input-output tables, market exchange rate conversions. These factors limit the reliability of consumption-based measures (Ahmad – Wyckoff, 2003).

The Austrian part of the input-output model applied is based on the symmetric IO tables for Austria in current prices for 1995, 2000 and 2005, as published from EUROSTAT. In between these base years, supply-use tables are available (except for 1996 and 1998), so that the total IO matrix **A** could have been interpolated with this information. The limiting factor of information, though, is the import matrix $\mathbf{A}^m$, which is only available for the base years (1995, 2000 and 2005). Though there has been some work on interpolation of import matrices for Austria in order to derive information for *total* imported intermediates by industry (Kratena, 2010), we do not want to use these interpolated matrices as a representation of the full structure of imported intermediates in a correct manner. External trade is directly taken from these IO tables and covers industries as well as services in the 2 digit-NACE classification (see the Table A1 in the Annex). Between 1995 and 2005 important changes took place in Austrian trade by industries (commodities) with large increases in net exports in some emission intensive industries such as pulp and paper as well as iron and steel.

The ROW part of the input-output model applied is based on the symmetric IO table 2000 for the EU 27, as described in Rueda-Cantuche et al. (2009). For describing the matrix $\mathbf{A}_{22}$ the full (domestic plus imported commodities) intermediate matrix of this IO table has been used.

The data for CO_2 emissions by industries in Austria have been calculated by using the new energy NAMEA dataset for Austria from Statistics Austria. This dataset contains energy data according to the (National Accounts) residential principle for 1999 to 2007 in Austria for 2 digit-NACE industries plus households, differentiating about 30 energy carriers. This has in a first step been aggregated to 23 energy carriers and for the year 2000 bridge matrices for each energy carrier have been calculated between these energy NAMEA data and the data in the IEA energy balance for Austria. Important issues in these bridge matrices are: (i) the distribution of energy input of industrial autoproducers of electricity and heat among industrial sectors, (ii) the shift between residential and territorial principle for gasoline, diesel and jet fuel, (iii) the distribution of the energy input in the institutional sector 'road transport' in the IEA energy balance among 2 digit-NACE industries and households. The application of these bridge matrices enables us to cast back the series of NAMEA energy inputs to 1995.

These energy data then are the starting point for the calculation of CO_2 emissions by 2 digit-NACE industries and households from 1995 to 2007. This is done by applying CO_2 emission factors from UNFCCC on the NAMEA energy data set. Process emissions are also included and distributed among the industries 'Other non-metallic mineral products' (NACE 26) and

'Basic metals' (NACE 27) according to their output weights. The total emission figures from these calculations only show small deviations from the total CO_2 emissions in the Austrian GHG emission inventory according to UNFCCC. These deviations might be due to the differences between the territorial and the resident principle. Large deviations are found between these calculated CO_2 emissions by industries and the CO_2 emissions in the most recent Austrian NAMEA air emission data set. This is due to the fact, that in the Austrian NAMEA air emission data set CO_2 emissions from biomass are considered, whereas the CO_2 emission factor for biomass is zero in UNFCCC. The CO_2 emission factors of the matrix $\hat{E}$ are then calculated by dividing emissions by the gross output in the IO table.

The data for CO_2 emissions by industries in the ROW are approximated by the CO_2 emissions of the EU 27 from the IEA database on energy related CO_2 emissions. These data are converted from the IEA industry classification to the 2 digit NACE classification by using output weights from the EU 27 IO table and some bridge matrices between NAMEA energy and IEA energy balances of Austria (especially for the distribution of transport emissions). Again, CO_2 emission coefficients by industry for the year 2000 are derived by dividing emissions by the gross output in the IO table for the EU 27. Between 1995 and 2000 as well as between 2000 and 2005 the same development of emission factors in the EU 27 is assumed as in Austria.

In Table 2 the CO_2 emission factors from both data sets are compared for the year 2000. In general, there are only small differences between the two vectors of emission coefficients in manufacturing. For some emission intensive industries the emission factors are higher in Austria than in the EU 27. For electricity generation the CO_2 emission factor is much higher in the EU 27 than in Austria. This result is also found in Nakano et al. (2009), which show very huge differences in emission factors across countries. The electricity sector is the most prominent example for product or process-mix effects within one industry. The process-mix between renewable electricity generation, nuclear generation and different fossil generation technologies with very different CO_2 impacts (CO_2 per unit of kWh of electricity produced) varies considerably across countries. These differences in turn bring about the huge differences in CO_2 emission coefficients per monetary unit of output in the electricity sector.

Table 2: CO_2 emissions coefficients (in kg CO_2 per unit of € output), 2000, Austria and EU 27

NACE		EU 27	Austria
15	Food products and beverages	0.085	0.088
16	Tobacco products	0.266	0.024
17	Textiles	0.078	0.070
18	Wearing apparel; furs	0.078	0.013
19	Leather and leather products	0.083	0.033
20	Wood and products of wood and cork	0.098	0.052
21	Pulp, paper and paper products	0.502	0.452
22	Printed matter and recorded media	0.012	0.009
23	Coke, refined petroleum products and nuclear fuels	1.393	1.315
24	Chemicals, chemical products and man-made fibres	0.145	0.237
25	Rubber and plastic products	0.234	0.028
26	Other non-metallic mineral products	0.690	0.882
27	Basic metals	1.260	1.505
28	Fabricated metal products, except machinery and equipment	0.046	0.031
29	Machinery and equipment n.e.c.	0.039	0.017
30	Office machinery and computers	0.027	0.002
31	Electrical machinery and apparatus n.e.c.	0.033	0.015
32	Radio, television and communication equipment and apparatus	0.033	0.012
33	Medical, precision and optical instruments, watches and clocks	0.032	0.008
34	Motor vehicles, trailers and semi-trailers	0.026	0.015
35	Other transport equipment	0.020	0.011
36	Furniture; other manufactured goods n.e.c.	0.246	0.018
37	Secondary raw materials	0.242	0.019
40	Electrical energy, gas, steam and hot water	3.782	1.154

7 Empirical results

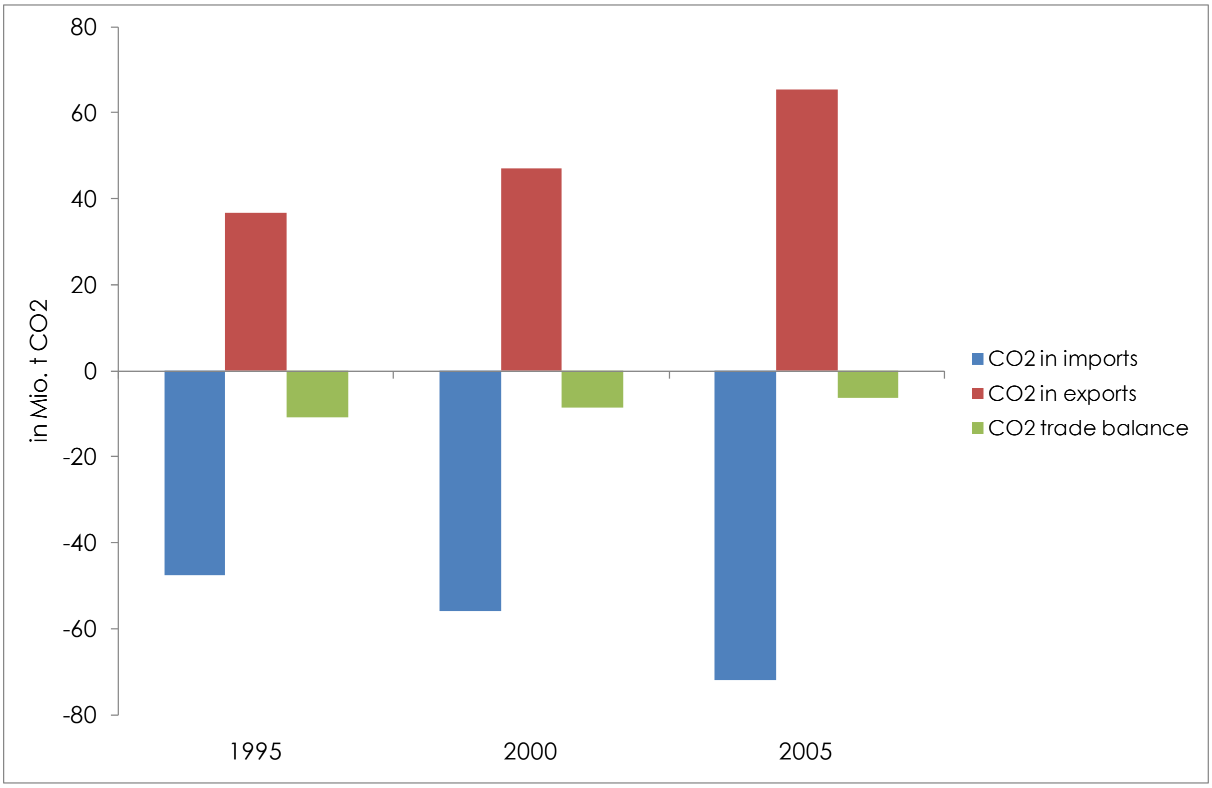
Applying the approach laid down in section 5 consists in calculating the embodied emissions as shown in equation (7) and (8) and then calculating the emission trade balance. The results for Austria show that both carbon embodied in imports and exports increased in absolute terms from 1995 to 2005 (Figure 2). Carbon embodied in Austrian international trade has therefore been growing over the years confirming the hypothesis of accelerating global integration in trade (see Table A1 in the Annex for Austrian Input-Output tables of imports and exports). In sum, the trade balance of embodied emissions has been shrinking, i.e. net imports of carbon embodied in trade were in decline. This development stands in contrast to developments that have been calculated for other countries, e.g. USA, Germany, Italy, UK and Japan, where the trade balance deficit of embodied emissions grew substantially (Nakano et al., 2009). Table 3 shows the amounts of CO_2 emissions embodied in Austrian trade flows in 1995, 2000 and 2005. According to this, imports of carbon embodied in imported goods have grown by 50% between 1995 and 2005, while carbon embodied in exports has grown by over 78%. The trade balance reduced net carbon imports by 42%. In % of total CO_2 emissions (including the direct household emissions) the net carbon imports have fallen from 17% in 1995 to 8.3% in 2005.

This result is also corroborated by the results in Nakano et al. (2009), who also find a decrease in Austrian CO_2 trade balance between 1995 and 2000 by 4 mill tons. Though, their numbers for the absolute value of the CO_2 trade balance are much higher than in our results. The absolute amount of net carbon imports lies between 10 and 6.4 mill tons in the period 1995 to 2005 according to the calculations based on our model and our data set. Nakano et al. (2009) find a CO_2 trade balance of 31 (1995) and of 28 mill tons (2000). These differences in results are due to different aggregation issues in different categories of the data. On the one hand, in our study we only take into account one aggregate for the 'rest of the world' instead of differentiating between single regions and their trade relations and technologies, which might lead to underestimates of total emissions embodied in Austrian imports. This can be seen, when we compare emission coefficients in some industry (especially electricity generation) of the EU 27 as used in our study with the emission coefficients of other countries as described in Nakano et al. (2009). On the other hand, the industry classification in our study is much more detailed, so that emission-intensive sectors are generally more separated from other low emission activities. This property might also lead to lower estimates of embodied emissions in our study. Although empirical research on the effect of aggregation on the results of trade-embodied emissions is limited, there is a very new study that shows that aggregation biases might be very significant (Su, et.al., 2010).

Table 3: CO_2 emissions, embodied in trade flows (in 1,000 tons)

	1995	2000	2005
CO_2 in imports	47638	55725	71764
CO_2 in exports	36666	47138	65428
CO2 trade balance	-10972	-8587	-6336
in % of CO_2 in production	-23.8	-18.4	-11.3
in % of total CO_2	-17.0	-13.2	-8.3

Figure 2: CO_2 emissions, embodied in trade flows (in 1,000 tons)



At the sectoral level (Table 4 and 5) we observe large CO_2 net imports in 1995 as well as in 2005 for products from the following industries: 'Coke, refined petroleum products' (NACE 23), 'Rubber and plastic products' (NACE 25), 'Furniture and other manufactured goods' (NACE 36) and 'Electricity, gas, steam and hot water' (NACE 40). Large CO_2 net exports in both years can be found in 'Pulp, paper and paper products' (NACE 21), 'Other non-metallic mineral products' (NACE 26) and 'Basic metals' (NACE 27). Between 1995 and 2005 the CO_2 emissions embodied in the exports of these three emission-intensive industries increased by 17% ('Pulp, paper and paper products'), 76% ('Other non-metallic mineral products') and 46% ('Basic metals'), respectively. This can be seen as one of the main drivers behind the development of decreasing CO_2 net imports between 1995 and 2005. The high growth of world trade in this period, accompanied by trends of globalization (outsourcing) has benefitted the resource-intensive industries in Austria.

Those industries with negative CO_2 trade balances partially decreased their net imports between 1995 and 2005, like 'Electricity, gas, steam and hot water' and 'rubber and plastic products'. The net imports of 'Coke, refined petroleum products' increased significantly between 1995 and 2005.

In general, our results show that starting from 1995 with 10 mill tons difference between consumption-oriented and production-oriented CO_2 emissions (inventory), this gap has decreased in the period of globalization and high growth in world trade. Therefore transparency in Austrian emission data has increased and the high world demand for emission-intensive products has increasingly also be met by Austrian production. This large increase in emission-intensive, export-oriented production in Austria might translate into a large potential for future carbon leakage, if CO_2 emissions are strongly regulated in EU countries and are not in developing countries.

Figure 3: CO_2 emissions, embodied in trade flows (in 1,000 tons)

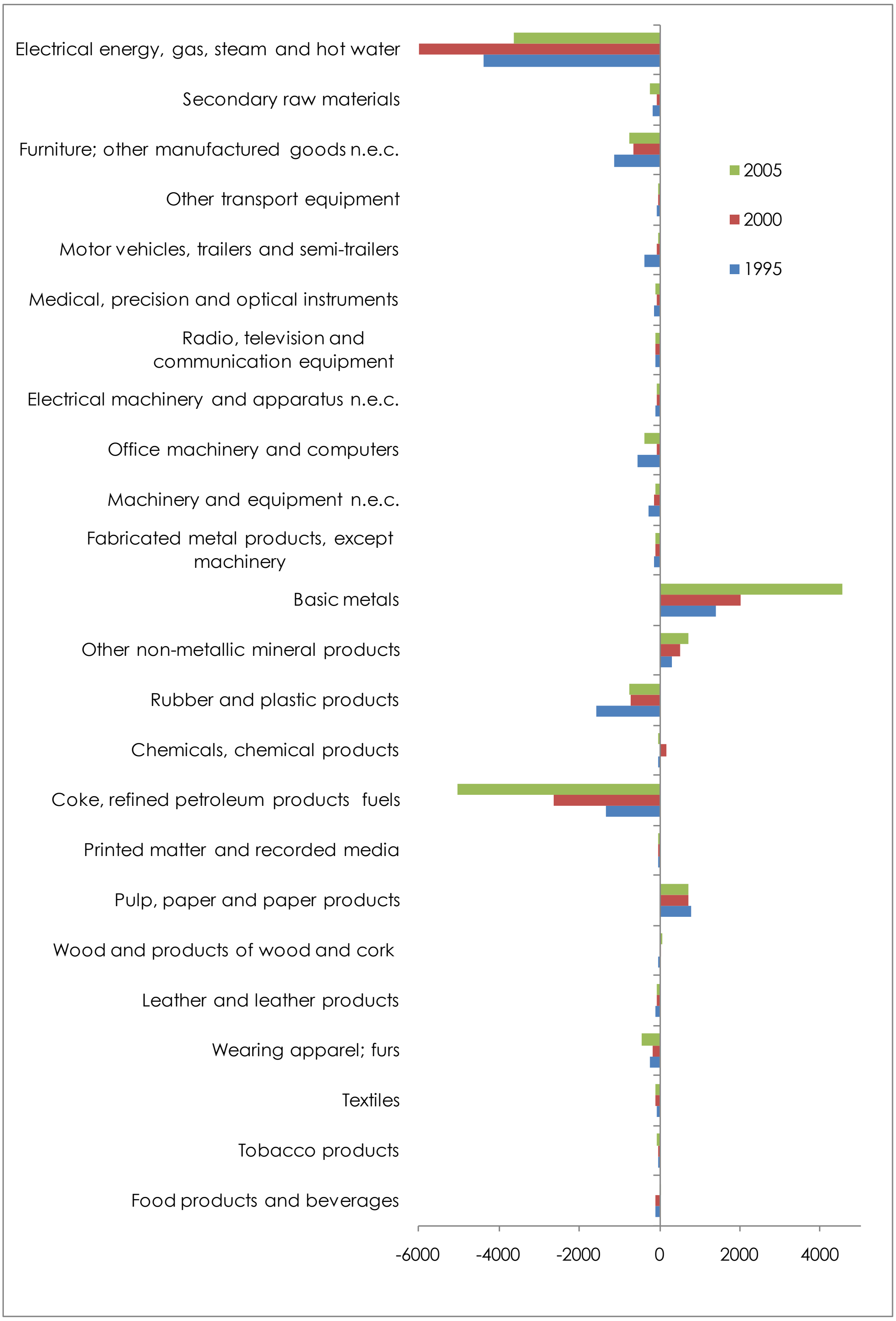


Table 4: CO_2 emissions, embodied in manufacturing exports and imports (in 1,000 tons), 1995

NACE		exports	imports	balance
15	Food products and beverages	221	331	-110
16	Tobacco products	2	10	-8
17	Textiles	330	409	-79
18	Wearing apparel; furs	33	258	-225
19	Leather and leather products	73	174	-100
20	Wood and products of wood and cork	306	308	-2
21	Pulp, paper and paper products	2949	2158	791
22	Printed matter and recorded media	26	37	-11
23	Coke, refined petroleum products and nuclear fuels	1932	3273	-1341
24	Chemicals, chemical products and man-made fibres	1750	1777	-27
25	Rubber and plastic products	1159	2738	-1580
26	Other non-metallic mineral products	1808	1510	298
27	Basic metals	12987	11569	1418
28	Fabricated metal products, except machinery and equipment	366	515	-148
29	Machinery and equipment n.e.c.	364	634	-269
30	Office machinery and computers	223	780	-557
31	Electrical machinery and apparatus n.e.c.	169	275	-106
32	Radio, television and communication equipment and apparatus	166	276	-110
33	Medical, precision and optical instruments, watches and clocks	68	205	-137
34	Motor vehicles, trailers and semi-trailers	682	1055	-373
35	Other transport equipment	50	130	-80
36	Furniture; other manufactured goods n.e.c.	191	1310	-1119
37	Secondary raw materials	171	358	-186
40	Electrical energy, gas, steam and hot water	5920	10287	-4366

Table 5: CO_2 emissions, embodied in manufacturing exports and imports (in 1,000 tons), 2005

NACE		exports	imports	balance
15	Food products and beverages	613	581	32
16	Tobacco products	12	97	-85
17	Textiles	246	362	-115
18	Wearing apparel; furs	125	561	-436
19	Leather and leather products	89	154	-65
20	Wood and products of wood and cork	550	490	60
21	Pulp, paper and paper products	3453	2743	710
22	Printed matter and recorded media	67	72	-5
23	Coke, refined petroleum products and nuclear fuels	6208	11231	-5023
24	Chemicals, chemical products and man-made fibres	3293	3305	-12
25	Rubber and plastic products	1036	1797	-761
26	Other non-metallic mineral products	3175	2447	728
27	Basic metals	18912	14377	4535
28	Fabricated metal products, except machinery and equipment	467	556	-89
29	Machinery and equipment n.e.c.	542	648	-106
30	Office machinery and computers	285	646	-362
31	Electrical machinery and apparatus n.e.c.	294	373	-79
32	Radio, television and communication equipment and apparatus	238	351	-113
33	Medical, precision and optical instruments, watches and clocks	94	182	-88
34	Motor vehicles, trailers and semi-trailers	405	452	-48
35	Other transport equipment	52	56	-5
36	Furniture; other manufactured goods n.e.c.	415	1171	-756
37	Secondary raw materials	426	660	-234
40	Electrical energy, gas, steam and hot water	12569	16192	-3623

8 Conclusions and future research

In this study the CO_2 emissions embodied in Austria's international trade have been quantified. For this purpose, the single country approach of input-output (IO) analysis has been extended towards a simple multi-regional approach with two regions (Austria and the rest of the world). The methodology has been applied by allowing for technology differences concerning the IO structure and the CO_2 emission coefficients (per unit of output) in both regions. The technology of the rest of the world has been approximated by the technology of the EU 27.

The analysis revealed large net imports of CO_2 in Austria, between 8% and 17% of total CO_2 emissions. One important result is that between 1995 and 2005 these net imports have decreased considerably. This is partly due to decreases of imported CO_2 emissions and of huge increases of exported CO_2 emissions. Especially the basic metal industry has increased its net exports between 1995 and 2005 and the electricity sector has decreased its net imports during the same period. The large increase in exports of CO_2 emissions of Austria between 1995 and 2005 is due the growth of emission-intensive Austrian exports (especially basic metals) together with the high growth in world trade in this period.

The falling trend of CO_2 net imports in Austria after 1995 is also corroborated by the most recent OECD study on this issue (Nakano et al., 2009). Comparing our results to this study we find that the absolute value of net imports of CO_2 is much higher in Nakano et al. (2009) than in our study. This might be due to different aggregation levels as well as to the differences between a single country approach and a multi-regional approach. The single country approach used in this study should in future work be extended towards a multi-regional approach by integrating bilateral trade data with IO tables. In a dynamic perspective it would also be interesting to integrate further macroeconomic feedback mechanisms into the analysis of carbon leakage.

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Annex

Table A1: Austrian exports and imports (input output table), 1995 and 2005, in mill €

		1995			2005	
	exports	imports	trade balance	exports	imports	trade balance
01	512	1457	-945	462	1657	-1196
02	0	0	0	68	521	-454
05	0	0	0	1	32	-31
10	1	205	-204	1	409	-407
11	19	1366	-1347	287	4987	-4700
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	134	182	-48	179	211	-32
15	1522	2208	-685	5242	4663	579
16	40	24	16	218	273	-55
17	1548	1643	-95	1609	2043	-433
18	824	1833	-1010	1045	2831	-1786
19	612	842	-230	983	1289	-306
20	1554	751	803	3056	1145	1911
21	2574	1296	1278	3471	2046	1425
22	582	845	-263	1474	1302	172
23	203	772	-569	1039	4448	-3409
24	3375	4947	-1572	8062	10098	-2036
25	1733	1816	-83	3230	3322	-92
26	1136	1053	83	1877	1543	334
27	3190	2722	468	7908	5928	1980
28	2007	2163	-157	3963	3824	140
29	5915	5923	-8	12340	9672	2669
30	380	1436	-1056	1135	2890	-1755
31	2125	2141	-16	4875	4525	349
32	2390	1879	511	4331	4691	-359
33	863	1414	-551	1981	2602	-620
34	5393	6427	-1033	13573	12699	874
35	514	811	-296	5249	4986	263
36	1401	1980	-579	2943	3018	-76
37	22	21	1	2	3	-1
40	303	235	67	1264	1134	130
41	0	0	0	1	0	1
45	197	59	138	767	730	37
50	326	1	325	404	5	399
51	2820	684	2136	6511	629	5882
52	0	73	-73	9	12	-3
55	13	837	-824	2249	2377	-127
60	1284	153	1132	4286	2670	1616
61	44	79	-35	293	692	-399
62	39	525	-485	1075	1020	55
63	728	140	588	1448	1278	170
64	240	240	0	823	712	111
65	473	541	-69	2521	943	1578
66	192	230	-38	782	532	251
67	0	0	0	27	27	1
70	57	90	-33	71	82	-11
71	314	91	223	342	224	118
72	96	267	-172	1559	834	726
73	180	157	22	851	240	611
74	1627	1664	-38	4291	3791	500
75	0	0	0	125	55	71
80	0	1	-1	15	127	-112
85	0	2	-2	112	378	-267
90	0	2	-2	10	16	-6
91	0	0	0	1	0	1
92	155	264	-109	235	931	-696
93	0	1	-1	9	28	-20
95	0	0	0	0	0	0