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Analysis of the Sustainability of Supply Chains with a Multi-Regional Input-Output Model

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Abstract

At present sustainable development enjoys a warm interest. However, without extra efforts on the topics of climate change, biodiversity and poverty global development aims are not achieved. Governments in many countries attempt to shift production and consumption into a more sustainable direction. Policies show an increasing interest in eco-efficiency of products and in sustainability of production-consumption chains. This interest is accompanied by a need for insights in the impacts on sustainability in the producing countries or regions along supply chains.

The paper presents an input-output model that can point out the supply-chain stages with the largest economic, ecological and social impacts at a sectoral level. The model is a multi-regional input-output model with feedback loops in trade between 13 world regions and is based on the GTAP database of economic data. In the application of the model in this paper, the emphasis lies on environmental aspects, but the model enables the incorporation of social and economic aspects too.

The model presented investigates supply chains from the consumption perspective providing insights in the contributions of regions and sectors in the production related to Dutch consumption. The analysis shows that the value added related to Dutch consumption is mainly created in the Netherlands, but that half of the greenhouse gas emissions occur abroad. More than 90% of land use for Dutch consumption lies in other countries. The model is demonstrated further by investigating an example chain, viz. the clothing chain. The relative contributions of foreign sectors in pressures for the Dutch consumption of clothing are even higher than for total Dutch consumption.

Keywords: Sustainability, supply chains, multi-regional input-output analysis, consumption.

1. Introduction

Quality of life is unevenly distributed in the world. There are large differences in income, life expectancy and education level between countries (UNDP, 2006). The trends in the Human Development Index (HDI) that is built on the indicators mentioned are positive. However, still many people in Africa, but also in parts of China and India, are unable to meet their basic needs. Sustainable development is directed at maintaining the quality of life at a certain minimum level under the constraint that natural resources are not running out and the natural system is not changed critically (MNP, 2008). Nowadays sustainable development enjoys a warm interest and governments in many countries have put sustainable development on their agenda's. However, it has been concluded that without extra effort on the topics of climate change, biodiversity and foreign development the global aims are not obtained (MNP, 2008). This also holds on the topics of water supply, air pollution and health (OECD, 2008).

In order to reach a more sustainable world, governments in many countries attempt to shift production and consumption into a more sustainable direction. Sustainable production and consumption should be directed at improving quality of life and diminish the effects mentioned so that the impacts on people and planet can be improved. Present production and consumption structures are not sustainable in a world with growing population and consumption per person. Governments, e.g. in the Netherlands and in the European Union, and other institutions, like OECD and EEA, show an increasing interest in the sustainability of production-consumption chains. This interest focuses on a need for insights in the impacts on sustainability in the producing countries or regions along supply chains. These insights offer clues for policy in addressing actors in the chains on the basis of interactions between these actors. There exist several studies on supply chains for specific products or companies, but an overall picture is often lacking.

This paper is directed at depicting at a macro-level the sectors and regions in which production and related pressures take place for consumption and the contributions of individual supply chains. On the basis of such a panorama view, chains may be selected for further research on a micro-level. This paper presents an input-output model that can point out the supply chain stages with the largest economic, ecological and social impacts at a sectoral level, the so-called hotspots. Furthermore,

region-sector combinations are identified that have minor contributions to the individual chains, but may have a substantial contribution in the overall impact of consumption. Contrary to value added creation, which usually occurs at the end of chains, environmental pressures occur mainly in the beginning of chains, e.g. resource extraction (Clift and Wright, 2000). Environmental problems, which usually go hand in hand with social-economic problems, often occur in developing countries. In order to account for these pressures, the model is set up as a multi-regional model with feedback loops in trade between 13 world regions, viz. 12 aggregated world regions and the Netherlands. The model presented investigates chains from the consumption perspective providing insights in the role of sectors and regions all over the world in producing for Dutch consumption. The model will be demonstrated by determining the contributions of individual chains in total consumption and, as an example, the clothing chain will be investigated further. Although the model should cope with all aspects of sustainability, the emphasis in the application presented lies on environmental aspects, since data on social pressures at the desired regional and sectoral level are scarce.

2. Background

One of the options to come to a more sustainable production and consumption is supply chain management, which is a broadening of the concept of integrated chain management (Seuring, 2004). The objective of integrated chain management is minimizing the environmental impact over the whole life cycle of products, so it is a form of cleaner production. Supply chain management also takes the economic and social dimension into account and therefore it is directed at overall-performances. This may lead to win-win situations, but may also result in trade-offs between the dimensions. Supply chain management enables the involvement of producers and consumers in the analysis and the interactions between the actors in the chain. In order to bring about sustainability, companies downstream in supply chains have to be responsible for the impacts upstream in the chain. A practical example of a framework for measuring and reporting the performances of companies on sustainability is the Triple Bottom Line (TBL) accounting approach (Wiedmann and Lenzen, 2007). This approach enables companies to quantify the trade-offs between the dimensions of sustainability. Foran et al. (2005) applied TBL accounting at the higher level of all economic sectors in the Australian economy.

Minimizing the pressures of supply chains requires insights in the impacts in the stages of chains from primary resource extraction to end use or waste disposal. Life-cycle analysis (LCA) e.g. is such a cradle-to-grave approach quantifying the environmental impacts of products (Guinée, 2002). There are two main approaches in executing an LCA. The first is process analysis, which is a bottom-up technique starting from an engineers' perspective. Process-based LCA uses a description in physical terms of the processes in the life cycle of products, so that the environmental pressures in the different processes may be determined in a detailed way. Since it is a difficult task to follow the whole chain in detail, there is a risk that process-based LCA misses significant parts of the impacts (Suh *et al.*, 2004). The second approach, input-output analysis (IOA), does consider whole tree structures of chains. Input-output analysis is a macro-economic top-down technique that uses input-output tables, which describe the monetary transactions between sectors, in order to determine the environmental pressures of chains by assigning overall emissions to sectors and regions. IOA has its origins in economics, but Leontief, who did a lot of pioneering work in the development of IOA, already intended to incorporate social and physical facets in analyses (Leontief and Ford, 1970).

A supply chain covers all activities from primary resource extraction to the end-use of a product or service. In practice a supply chain is not a linear chain, but a complex network of interactions between companies or sectors. E.g. several primary resources and manufacturing steps are necessary for one final product. On the other hand, raw materials are distributed across products and regions, and, with that, the related pressures are attributed to final products. The use of IOA enables a full exploration and unravelling of supply chains. Every step in production can be identified at the aggregation level of the IO table. Structural Path Analysis (SPA) is an IO technique that uses the series expansion of the Leontief inverse in order to determine the contribution of each step (upstream) in a supply chain (Lenzen, 2002; Treloar, 1997). However, the analysis presented in this paper is not a complete SPA, but aims to identifying the region-sector combinations that have significant contributions to the impact of chains in total consumption. If further analysis of the role of specific region-sector combinations in the chain is required, an SPA may be useful.

The use of IO analysis for life-cycle applications is very common, first in the energy field and later on in environmental applications. For several countries, studies were carried out, mostly at the single-country level. In studies on consumption, which include total environmental pressure over the whole supply chain of products, it was often assumed that imported goods and services were produced with the same technology as the domestic technology. However, there are differences in production technologies, efficiencies and output mixes in the same sector between countries. Technologies in more developed countries are, e.g. more efficient than technologies in less developed countries. The assumption that imports are produced with the same technology is discussed more and more in literature. Among others, Battjes *et al.* (1998) showed that the assumption of fixed technology, domestically and abroad, influences the outcomes significantly. The assumption on imports overestimates the consumption-related emissions in developing countries and underestimates these emissions in developed countries (Wilting and Vringer, 2007). Since the availability of international data sets covering multiple countries has increased, the use of multi-region models is growing (Wiedmann *et al.*, 2007). For these reasons, and for the required insights in where production takes place along supply chains, a multi-region input-output (MRIO) model is used in this paper.

3. Methodology

The MRIO model for determining the hotspots in production for Dutch consumption is straight-forward. The formulas are analogous to the formulas in common IO analysis for single-country analyses (Wilting and Vringer, 2007).

The following relationship between production **x** and final demand **y** exists for an **n**-region economy:

$$\begin{bmatrix} \mathbf{x_1} \\ \vdots \\ \mathbf{x_n} \end{bmatrix} = \begin{bmatrix} \mathbf{A_{11}} & \cdots & \mathbf{A_{1n}} \\ \vdots & \ddots & \vdots \\ \mathbf{A_{n1}} & \cdots & \mathbf{A_{nn}} \end{bmatrix} \begin{bmatrix} \mathbf{x_1} \\ \vdots \\ \mathbf{x_n} \end{bmatrix} + \begin{bmatrix} \mathbf{y_1} + \sum_{j \neq 1} \mathbf{y_{1j}} \\ \vdots \\ \mathbf{y_n} + \sum_{j \neq n} \mathbf{y_{nj}} \end{bmatrix} \tag{1}$$

where $\mathbf{x_i}$ is the vector of production in region i, $\mathbf{A_{ii}}$ is the matrix of domestic input coefficients of region i, $\mathbf{A_{ij, \, i \neq j}}$ is the matrix of import coefficients of region j importing from region i, $\mathbf{y_i}$ is the vector of domestic final demand of region i, and $\mathbf{y_{ij, \, i \neq j}}$ is the vector of imported final demand of region j importing from region i.

The domestic and import coefficients depict the intermediate input requirements per unit output for each sector and summed up they form the technological matrix per region. The model in (1) is a complete multi-region model with feedback loops (according to the terminology in Wiedmann *et al.*, 2007). Setting

$$\mathbf{x^*} = \begin{bmatrix} \mathbf{x_1} \\ \vdots \\ \mathbf{x_n} \end{bmatrix}, \ \mathbf{A^*} = \begin{bmatrix} \mathbf{A_{11}} & \cdots & \mathbf{A_{1n}} \\ \vdots & \ddots & \vdots \\ \mathbf{A_{n1}} & \cdots & \mathbf{A_{nn}} \end{bmatrix}, \ \mathbf{y^*} = \begin{bmatrix} \mathbf{y_1} + \sum_{i \neq 1} \mathbf{y_{1i}} \\ \vdots \\ \mathbf{y_n} + \sum_{i \neq n} \mathbf{y_{ni}} \end{bmatrix},$$

the multi-region input-output model is:

$$\mathbf{x^*} = \mathbf{A^*} \, \mathbf{x^*} + \mathbf{y^*} \tag{2}$$

The standard input-output model for calculating sectoral output $\mathbf{x^*}$ for a certain final demand $\mathbf{y^*}$, e.g. consumption, is derived by solving this equation for $\mathbf{x^*}$:

$$\mathbf{x^*} = (\mathbf{I} - \mathbf{A^*})^{\mathbf{-1}} \, \mathbf{y^*} \tag{3}$$

where $(\mathbf{I} - \mathbf{A^*})^{\mathbf{-1}}$ is the Leontief inverse matrix. Matrix $\mathbf{I}$ is the identity matrix.

The input-output model for calculating the total intensities of resource use, or environmental or social pressures is now:

$$\mathbf{e^*} = \mathbf{d^*} \, (\mathbf{I} - \mathbf{A^*})^{\mathbf{-1}} \tag{4}$$

with $\mathbf{d^*} = \begin{bmatrix} \mathbf{d_1} & \cdots & \mathbf{d_n} \end{bmatrix}$, where $\mathbf{d_i}$ is a row vector of direct intensities of pressure of region *i* (depicting the pressure of one unit of production for all sectors), and $\mathbf{e^*} = \begin{bmatrix} \mathbf{e_1} & \cdots & \mathbf{e_n} \end{bmatrix}$, where $\mathbf{e_i}$ is a row vector of total intensities of pressure of region *i*.

Assuming that the row vector of pressure intensities $\mathbf{e^*}$ defines the pressure per unit of output for all industries, the input-output model for calculating the pressure related to domestic final demand in region *i*, $\mathbf{E_i}$, is:

$$\mathbf{E_i} = \mathbf{e^*} \, \mathbf{y_i}^* + \mathbf{D_i} \tag{5}$$

with $\mathbf{y_i}^* = \begin{bmatrix} \mathbf{y_{1i}} \\ \vdots \\ \mathbf{y_{ni}} \end{bmatrix}$, and $\mathbf{D_i}$ is the direct pressure of final demand in region *i*.

In this paper, the MRIO formalism will be used for calculating where (in which region-sector combinations) production and related pressures mainly take place for Dutch consumption (private and public). The distribution of production for Dutch consumption over sectors and regions determines the distribution of pressures of sectors and regions.

Figure 1

Figure 1 gives an overview of the outcomes of the calculations. The rows depict the pressures over region-sector combinations for individual supply chains. The row totals depict the overall pressure of a complete supply chain. The column totals depict the overall production or pressure in a certain region-sector combination for total Dutch consumption (summing up over chains).

4.   Data sources and processing

4.1 Economic data

Economic data were derived from the GTAP database, version 6, which concerns the global economy in 2001. The database contains input-output data of 87 regions and 57 sectors (Dimaranan, 2006). Since not all environmental data were available for all 87 regions, the MRIO model used in this paper distinguishes 13 regions covering the 87 regions, viz. 12 aggregated world regions and the Netherlands. The model is an extension of the model in Wilting and Vringer (2007) that did not consider the Netherlands as a separate region. In Appendix A an overview is given of the aggregation scheme from 87 GTAP regions to 13 world regions in the MRIO model.

The aggregation of the GTAP data from 87 regions to 13 world regions was carried out by the GTAP aggregation tool GTAPAgg (Horridge, 2006). All imports of regions are summed up in the aggregation process to give the imports of the world regions. These imports then include the trade flows between countries/regions in the same aggregated world region. In this way, the intra-regional trade flows in a world region are unintentionally seen as imports of that world region. To tackle this problem, these intra-regional 'imports' were added to the domestic intermediate flows and final demand of the world region. Since the aggregated intermediate and final demand imports for each world region have no segmentation in region of origin, these imports

were split up by using GTAP trade data concerning bilateral trade flows at the level of 57 sectors and 87 regions. It was assumed that both intermediate demand for imports (per sector) and final demand imports have the same division across regions of origin.

The technological and import matrices for the world regions were based on the cost structure of firms and final demand on the cost structures of private household consumption and government consumption. All cost structures distinguish domestic and imported purchases and are expressed in basic prices (market prices in GTAP). Import taxes and subsidies were removed from imports in basic prices resulting in c.i.f. (cost, insurance, freight) prices (world prices in GTAP). Valuation in c.i.f. prices is based on f.o.b. (free on board) prices and transport costs (concerning costs of transport and insurance abroad). Transport costs were removed from c.i.f. prices and assigned to the transport sector rows as extra deliveries from these sectors. Data in f.o.b. were used in compiling the import matrices.

Capital investments in the past contribute to total resource use and emissions related to production for final demand, but do not belong to production in the current year. In order to account for these investments, replacement investments were included in the intermediate matrix. So replacement investments are seen as an approximation of capital goods included in production processes. Since the GTAP database does not distinguish replacement and extension investments, it was assumed for all countries that all investments concern replacement investments. The deliveries to the investments were, for each sector, assigned to the inputs in the intermediate matrices (domestic and imports) on the basis of depreciation per sector.

The GTAP data for the Netherlands differ substantially from the original IO data for the Netherlands (compiled by Statistics Netherlands and the Agricultural Economics Research Institute) on which the GTAP data were based. These differences are caused by the adjusting and updating procedures applied by GTAP in order to balance import and export flows between countries (McDougall, 2008). For the Dutch data in the GTAP database, especially the volume of imports is too high leading to an overestimation of pressures related to Dutch consumption abroad. For these reasons, the data for the Netherlands in GTAP were replaced by the original IO data (Koole and Van Leeuwen, 2006).

The application of the procedures mentioned resulted in a multi-regional IO table of 13 regions and 57 sectors per region. Final demand concerns aggregated consumption (private and public) in 13 world regions. The calculated production of this table by using equation 3 was compared with the original data on production in the GTAP database. Since the differences in total production per region were less than 0.5%, it was assumed that the imports and exports were translated in bilateral trade flows between regions in a sound way.

4.2 GHG emission data

Data on greenhouse gas emissions (CO_2, CH_4, N_2O and F-gases) for the 12 world regions were derived from several databases, viz. the EDGAR 3.2 Fast Track 2000 dataset (Van Aardenne et al., 2005) and the GTAP/EPA databases (Lee, 2005; Rose and Lee, 2008). Furthermore, data on GHG emissions for region 13, the Netherlands, were obtained from Dutch NAMEA (CBS, 2007). The GTAP/EPA databases, which are compatible with the GTAP 6 regions and sectors, are more detailed at the sectoral level than the EDGAR dataset. The EDGAR 3.2FT dataset represents a fast update of the EDGAR database, which is a set of global anthropogenic emission inventories of various trace gases for 234 countries. The latter database contains more emissions sources than the GTAP/EPA databases. The GTAP/EPA CO_2 database contains, for example, only fossil-fuel related CO_2 emissions and no process emissions such as seen in the production of concrete or emissions related to biomass burning. On the other hand, not all emission sources in the EDGAR database were included in the calculations. The CO_2 emissions do not include the emissions allocated to non-energy use and chemical feedstock, which are not actually emitted, and the emissions caused by tropical forest fires for deforestation. It is not always clear if these fires have an anthropogenic cause or if they are the result of thunderbolt. Similarly excluded were CH_4 and N_2O emissions from forests, savannah, shrubs and grassland fires.

Starting point for the CO_2 data compilation was the EDGAR dataset. Since the emissions in the EDGAR database are not at the detailed sectoral level of the GTAP database, the EDGAR emission data were further subdivided into 57 sectors on the basis of the emission data collected in the GTAP/EPA project. The non-CO_2 emission data were derived from the GTAP/EPA database and supplemented with EDGAR data. Residential emissions including private transport were allocated as direct emissions of

final demand. Methane emissions related to landfills were also allocated to direct emissions, since it is difficult to allocate them to industrial sectors or households.

4.3 Land-use data

Just as for emission data, land-use data were obtained from several sources. The main data source is the IMAGE model (MNP, 2006), consisting of land-use data for 24 world regions. Most data in the IMAGE model are based on FAO databases (FAO, 2006). For the compilation of crop land used for the multi-region model, data on crop area from the IMAGE model was combined with data on harvested area from the GTAP land-use database (Lee et al., 2005). The latter database consists of land use for crop production for 19 crops in 226 countries. These data were used to split up the aggregated land use from the IMAGE model further. The data were compiled at the level of 12 world regions. The IMAGE model also provided data on crop areas for biofuel production, which were assigned to the refinery sector. All land use data for the Netherlands were derived from the Agricultural Economics Research Institute (LEI, 2007).

Land use for pasture was directly obtained from IMAGE and assigned to two pasture sectors in GTAP: cattle and milk. The breakdown according to cattle and milk was based on several factors like animal feed (Eickhout, 2007). All land-use data apply to physical areas and no correction was made for extensive or intensive use of the land. Especially for pasture land, there are huge differences in local land-use intensities between countries. Land use for forestry products was obtained from the IMAGE model too (Van Oorschot, 2007). Finally, data on built-up land was derived from UN and HYDE databases (UN, 2004; Klein Goldewijk, 2006). Built-up land concerns urban land and land for infrastructure. Built-up land was not used for the calculation of the land-use intensities, but was directly assigned to final demand.

5.   Outcomes

5.1 Pressures of Dutch consumption

Before the pressures of individual supply chains are considered, an overview of Dutch consumption, private and public, and related pressures, which were calculated with the MRIO model, is presented. Figure 2 shows that about 90% of the goods and services consumed by Dutch government and households are of Dutch origin. Since Dutch producers on their turn use imports, the percentage of value added created by Dutch

production as share in total value added for Dutch consumption is lower. Nevertheless, value added creation related to consumption takes mainly place in the Netherlands and surrounding countries. In 2001, more than 80% of value added was created in OECD Europe[1].

Figure 2

The picture is totally different for the environmental pressures GHG emissions and land use. More than 50% of GHG emissions related to Dutch consumption take place abroad. These gases are emitted especially in the OECD Europe region, but the regions of China, the former Soviet Union and North America have substantial contributions too. In land use, the picture is even more extreme; more than 95% of land use is outside the borders of the Netherlands. It is noticed again, that the calculation is based on local (physical) hectares with very low efficiencies for the regions South-America, China and Oceania. Contrary, an important part of the land-related production in the Netherlands is exported (mainly to other European countries), and is therefore not assigned to Dutch consumption.

Table 1

In each region, value added and pressures related to Dutch consumption are distributed over the separate sectors. Sectors with high shares in total value added related to Dutch consumption are public and business services in the Netherlands. The sector other business services (sector 54) in OECD Europe is the highest non-Dutch sector in the list of sectors contributing to value added created by Dutch consumption with a contribution of 2.5%. Table 1 shows the region-sector combinations with the highest contributions in GHG emissions and land use. Direct GHG emissions of consumers contribute almost 20% in total GHG emissions related to Dutch consumption. Furthermore, the production of electricity is a main contributor to GHG emissions of Dutch consumption; the electricity sectors in the regions Netherlands, OECD Europe, China, former Soviet Union and North America, all have a high placing in the top ten. Electricity use is essential in many production processes. Other region-sector combinations with high contributions in GHG emissions are more diverse. The land-related sectors agriculture and forestry highly contribute to the land use related to

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[1] See Appendix A for the regions and Appendix B for the sectors distinguished in the analysis.

Dutch consumption. Agricultural sectors with high contributions are the cattle and dairy sectors and the production of oil seeds (for feed).

Figure 3

This paper is directed at the sustainability of supply chains. The investigation of specific chains starts with the determination of the contribution of each supply chain in the pressures of total consumption. So, GHG emissions and land use are considered from the perspective of 38 individual consumption categories (here seen as chains)[2], in which the environmental pressures in the consumption stage are included. Figure 3 shows for Dutch consumption of goods and services the expenditures and the corresponding GHG emissions and land use. Expenditures on financial and business services, public administration and other services have an important contribution in Dutch consumption pattern (private and public). Chains with high GHG emissions are services and of course oil products, natural gas (which include emissions during consumption) and electricity. Chains with high land use are services again and several food products like dairy products and meat.

Figure 4

Figure 5

The pressures of chains are the combined effects of the volumes in consumption and the total pressure intensities for the whole chain. So chains with high pressures have a high share in consumption, like services, or have high pressure intensities indicating the total pressure per unit consumption (based on the Dutch situation). Figures 4 and 5 show the GHG and land use intensities for the individual chains (on the basis of the product mix of origin in Dutch consumption). The financial units do not include levies and taxes on products. Chains with high GHG intensity are the three energy chains and transport. Land use intensities are high for forestry products and products from cattle (meat and leather).

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[2] The 59 sectors/commodities were aggregated to 39 consumption categories (chains) and trade was assigned to the different product categories.

5.2 Specific chain: clothing

In the previous section, total pressure of Dutch consumption was first unravelled in region-sector combinations in which pressures take place and, after that, in individual chains. The first analysis, viz. the unravelling of pressures of total consumption in region-sector combinations, as presented in figure 2 and table 1, can be carried out for each individual supply chain. Such an analysis will result in a panorama view that presents the contributions of sectors and regions in total pressure for each individual chain (according to figure 1). As an example, the outcomes for the clothing chain are discussed. The clothing chain is an interesting supply chain for further investigation, since not all clothes are produced in a sustainable way (see e.g. Tukker and Eggels, 2003; Allwood *et al.*, 2006). Environmental pressures take place in producing the raw materials for the clothing industry. E.g. the cotton cultivation requires pesticides, fertilizers and water, but other natural and synthetic resources have an environmental impact too. Furthermore, the processing of the raw resources, e.g. in textile industry, uses chemical products that may result in pollution, like chlorine or dye. In the use and disposal stage of the chain environmental pressure may occur, e.g. in cleaning or washing. Not only play environmental aspects a role in this chain, but social aspects too. In some countries, labour circumstances of needlewomen are bad due to low wages, long working weeks and monotonous work. Furthermore, a small percentage of child labour exists in clothing industry.

Figure 6

The supply chain of clothing differs per region, e.g. clothes produced in North America have another supply chain than clothes produced in China. Figure 6 shows per region the differences in GHG emissions per unit of production over the whole supply chain[3]. This intensity has the highest values for clothes produced in the former Soviet Union and the China region due to high emissions in the electricity sector in these regions. So for each region, the supply chain has a specific profile that can be investigated further.

Figure 7

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[3] The intensities are based on financial units that were not corrected for price differences between regions. So the differences in intensities are a combined effect of differences in efficiencies and prices.

The overall chain of clothes related to Dutch consumption is a mixture of the supply chains per region. Main part of the clothing chain concerning Dutch consumption of clothes lies outside the Netherlands. Clothes are imported from several regions and the the production of textiles for Dutch clothing industry takes place abroad for an important part. The lower bars in Figure 7 gives for Dutch clothes consumption an overview of the region of origin and the regions where value added is created. Almost 50% of clothes bought by Dutch consumers are of European origin (regions 10, 11 and 13), but often this concerns imports from clothes or textiles from China or other Asian countries which are upgraded in Europe. More than 40% of clothes consumed in the Netherlands origins directly from Asian countries. The two upper bars in Figure 7 show where environmental pressures take place. The total pressures of the clothing chain will be further unravelled in region-sector combinations. For GHG emissions and land use the situation is quite different from consumption and value added. More than 50% of environmental pressures related to the clothes chain take place in Asia.

Figure 8

Figure 8 shows the economic and environmental effects over sectors. All consumption takes place in the clothing industry[4]. Sectors directly related to clothes (textiles and clothing) have an high share in value added, but only have a small share in GHG emissions. Sectors with a high share are e.g. the energy sector, chemistry and refineries, and other manufacturing. For land use especially cattle breeding and other agriculture have a high contribution in relation to textile resources. The high share of cattle breeding is caused by the use of local hectares in the model (as mentioned above).

6. Final remarks

The methodology presented in this paper offers insights, both for research and for policy, where production and related pressures take place for Dutch consumption. The outcome is a detailed picture consisting of region-sector combinations with high contributions to the pressure of total Dutch consumption or specific supply chains (panorama view). Until now the analysis was carried out for GHG and land use only,

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[4] In this case study, the chain ends at the final production stage, i.e. the clothing industry. Part of the expenditures of consumers concern trade margins, but these margins were not assigned to goods and services yet. The trade margins mainly concern Dutch wholesale and retail, and the impacts of the trade sector on other countries are relatively low.

since the required data were easily accessible. It is imaginable that the analysis can be extended to other environmental pressures without much effort in searching the relevant data. In a complete sustainability analysis, social and economic aspects have to be considered too. In most cases, data on social pressures are not available on a global level for all regions and sectors. However in some cases, specific data on e.g. child labour or bad working conditions are available for specific region-sector combinations. The share of production for Dutch consumption in total production of that specific sector and region may be an indication of the pressure related to Dutch consumption. However, in general this share is small; most sectors produce mainly for their own domestic demand. The MRIO model can be used to determine for which final demand the production in a certain region-sector combination is intended.

The panorama view offers clues for selecting chains for further research, e.g. concerning the identification of options directed at reducing pressures. Selection criteria may be the share in pressures related to Dutch consumption and the pressures per unit of consumption[5]. So, interesting chains for further investigation are chains with high absolute pressures or chains with high relative pressures (pressure per unit) compared to other chains. The insights in the pressures along supply chains may be useful for optimising production-consumption chains over country borders too. In order to produce, e.g. clothes with fewer pressures, insights are required in which region-sector combinations pressures can be reduced. Such an optimisation, which requires an international approach, may involve a shift of foreign production to the Netherlands and produce more efficiently, or improve technology elsewhere in an active way. However, the optimisation has to be carried out with care, since an optimisation for greenhouse gases may lead to less optimal outcomes for other environmental themes, like acidification or land use. These themes are specific for certain regions, unlike climate change, which is a global problem. Furthermore, optimising on ecological aspects alone is too narrow from the view point of sustainability. Therefore, in optimising over countries, economic and social aspects have to be considered too.

The panorama view offers insights for policy too, e.g. that a substantial part of the pressures related to supply chains occurs outside the borders of the Netherlands. Dutch policy may use instruments both directed at the domestic actors as actors abroad

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[5] A selection criterion not based on the panorama view is attention in policy.

in order to reduce these pressures. Instruments for Dutch policy directed at actors abroad are the Kyoto mechanisms (Joint Implementation and Clean Development Mechanism). These mechanisms concern the financing of projects in other countries in order to reduce the emissions in those countries. The financing of new technologies in region-sector combinations with high pressures for Dutch consumption decreases the impact of Dutch consumption abroad. Furthermore, policy has possibilities to reduce foreign emissions via Dutch producers and consumers. Producers can be called on their chain responsibilities so that they face their suppliers with stringent conditions concerning the sustainability of production processes. Furthermore, financial instruments or hallmarks concerning the sustainability of chains may be used to stimulate consumers in choosing more sustainable consumption patterns.

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Appendix A   World regions based on the GTAP 6 regions

| World region | | | GTAP 6 region | | |
No.	Code	Description	No.	Code	Description
1	NAm	North America	21	can	Canada
			22	usa	United States
			24	xna	Rest of North America
2	CSAm	Central and South America	23	mex	Mexico
			25	col	Colombia
			26	per	Peru
			27	ven	Venezuela
			28	xap	Rest of Andean Pact
			29	arg	Argentina
			30	bra	Brazil
			31	chl	Chile
			32	ury	Uruguay
			33	xsm	Rest of South America
			34	xca	Central America
			35	xfa	Rest of FTAA
			36	xcb	Rest of the Caribbean
3	Oc	Oceania	1	aus	Australia
			2	nzl	New Zealand
			3	xoc	Rest of Oceania
4	JNIE	Japan and New Industrializing Economies	5	hkg	Hong Kong
			6	jpn	Japan
			7	kor	Korea
			8	twn	Taiwan
			13	sgp	Singapore
5	SEA	Southeast Asia	10	idn	Indonesia
			11	mys	Malaysia
			12	phl	Philippines
			14	tha	Thailand
			15	vnm	Vietnam
			16	xse	Rest of Southeast Asia
6	EA	East Asia	4	chn	China
			9	xea	Rest of East Asia
7	SA	South Asia	17	bgd	Bangladesh
			18	ind	India
			19	lka	Sri Lanka
			20	xsa	Rest of South Asia
8	ME	Middle East	71	tur	Turkey
			72	xme	Rest of Middle East
9	FSU	Former Soviet Union	69	rus	Russian Federation
			70	xsu	Rest of Former Soviet Union
10	EEU	Eastern Europe	54	xer	Rest of Europe
			55	alb	Albania
			56	bgr	Bulgaria
			57	hrv	Croatia
			58	cyp	Cyprus
			59	cze	Czech Republic
			60	hun	Hungary
			61	mlt	Malta
			62	pol	Poland

			63	rom	Romania
			64	svk	Slovakia
			65	svn	Slovenia
			66	est	Estonia
			67	lva	Latvia
			68	ltu	Lithuania
11	OEU	OECD Europe	37	aut	Austria
			38	bel	Belgium
			39	dnk	Denmark
			40	fin	Finland
			41	fra	France
			42	deu	Germany
			43	gbr	United Kingdom
			44	grc	Greece
			45	irl	Ireland
			46	ita	Italy
			47	lux	Luxembourg
			49	prt	Portugal
			50	esp	Spain
			51	swe	Sweden
			52	che	Switzerland
			53	xef	Rest of EFTA
12	Af	Africa	73	mar	Morocco
			74	tun	Tunisia
			75	xnf	Rest of North Africa
			76	bwa	Botswana
			77	zaf	South Africa
			78	xsc	Rest of South African CU
			79	mwi	Malawi
			80	moz	Mozambique
			81	tza	Tanzania
			82	zmb	Zambia
			83	zwe	Zimbabwe
			84	xsd	Rest of SADC
			85	mdg	Madagascar
			86	uga	Uganda
			87	xss	Rest of Sub-Saharan Africa
13	Nld	Netherlands	48	nld	Netherlands

Appendix B Sectors/commodities in GTAP 6

|		
1	PDR	Paddy rice
2	WHT	Wheat
3	GRO	Cereal grains nec
4	V_F	Vegetables, fruit, nuts
5	OSD	Oil seeds
6	C_B	Sugar cane, sugar beet
7	PFB	Plant-based fibers
8	OCR	Crops nec
9	CTL	Bovine cattle, sheep and goats, horses
10	OAP	Animal products nec
11	RMK	Raw milk
12	WOL	Wool, silk-worm cocoons
13	FRS	Forestry
14	FSH	Fishing
15	COA	Coal
16	OIL	Oil
17	GAS	Gas
18	OMN	Minerals nec
19	CMT	Bovine meat products
20	OMT	Meat products nec
21	VOL	Vegetable oils and fats
22	MIL	Dairy products
23	PCR	Processed rice
24	SGR	Sugar
25	OFD	Food products nec
26	B_T	Beverages and tobacco products
27	TEX	Textiles
28	WAP	Wearing apparel
29	LEA	Leather products
30	LUM	Wood products
31	PPP	Paper products, publishing
32	P_C	Petroleum, coal products
33	CRP	Chemical, rubber, plastic products
34	NMM	Mineral products nec
35	I_S	Ferrous metals
36	NFM	Metals nec
37	FMP	Metal products
38	MVH	Motor vehicles and parts
39	OTN	Transport equipment nec
40	ELE	Electronic equipment
41	OME	Machinery and equipment nec
42	OMF	Manufactures nec
43	ELY	Electricity
44	GDT	Gas manufacture, distribution
45	WTR	Water
46	CNS	Construction
47	TRD	Trade
48	OTP	Transport nec
49	WTP	Water transport
50	ATP	Air transport
51	CMN	Communication
52	OFI	Financial services nec
53	ISR	Insurance
54	OBS	Business services nec
55	ROS	Recreational and other services
56	OSG	Public Administration, Defense, Education, Health
57	DWE	Dwellings

Table 1

Region	Sector	GHG (%)	Region	Sector	LU (%)
Netherlands	direct	18.5	China EAsia	9 ctl	13.4
Netherlands	43 ely	12.3	OECD Europe	13 frs	5.5
Netherlands	56 osg	3.1	M-S America	9 ctl	5.3
OECD Europe	43 ely	3.0	Oceania	9 ctl	4.1
China EAsia	43 ely	2.2	M-S America	5 osd	4.1
form SU	32 p_c	2.1	Oceania	11 rmk	3.9
form SU	43 ely	2.1	Africa	8 ocr	3.8
Netherlands	48 otp	1.7	N America	5 osd	3.2
OECD Europe	17 gas	1.6	form SU	13 frs	3.2
N America	43 ely	1.5	Africa	9 ctl	3.2
OECD Europe	32 p_c	1.5	form SU	9 ctl	3.0
China EAsia	34 nmm	1.4	form SU	11 rmk	2.7
Netherlands	50 atp	1.3	OECD Europe	2 wht	2.5
Netherlands	54 obs	1.2	OECD Europe	3 gro	2.2
Netherlands	11 rmk	1.1	N America	13 frs	2.1
OECD Europe	48 otp	1.1	SE Asia	13 frs	1.8
Netherlands	47 trd	1.1	form SU	2 wht	1.6
Netherlands	33 crp	1.0	Africa	11 rmk	1.5
OECD Europe	34 nmm	1.0	Netherlands	direct	1.4
OECD Europe	33 crp	0.9	Netherlands	11 rmk	1.3

Region-sector combinations with the highest contributions in GHG emissions and land use for Dutch consumption with shares in percentages.
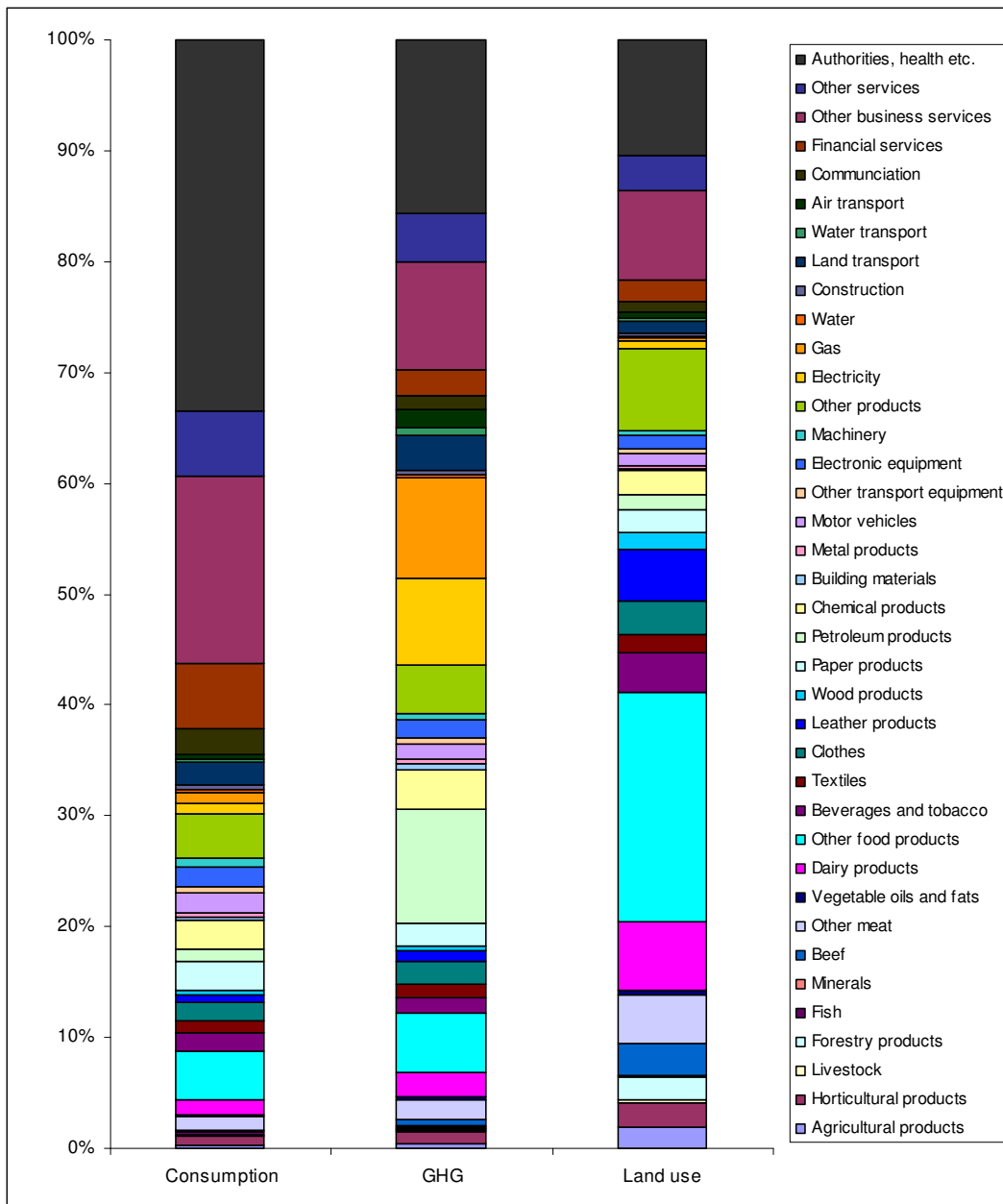
Figure 1

	Region 1						Region 2						Region 3						Region 4						T
	S1	S2	S3	S4	S5	D	S1	S2	S3	S4	S5	D	S1	S2	S3	S4	S5	D	S1	S2	S3	S4	S5	D	
Consumption																									
Chain 1																									
Chain 2																									
Chain 3																									
Chain 4																									
Chain 5																									

Panorama view of region-sector combinations in total consumption and individual
supply chains.

Figure 2
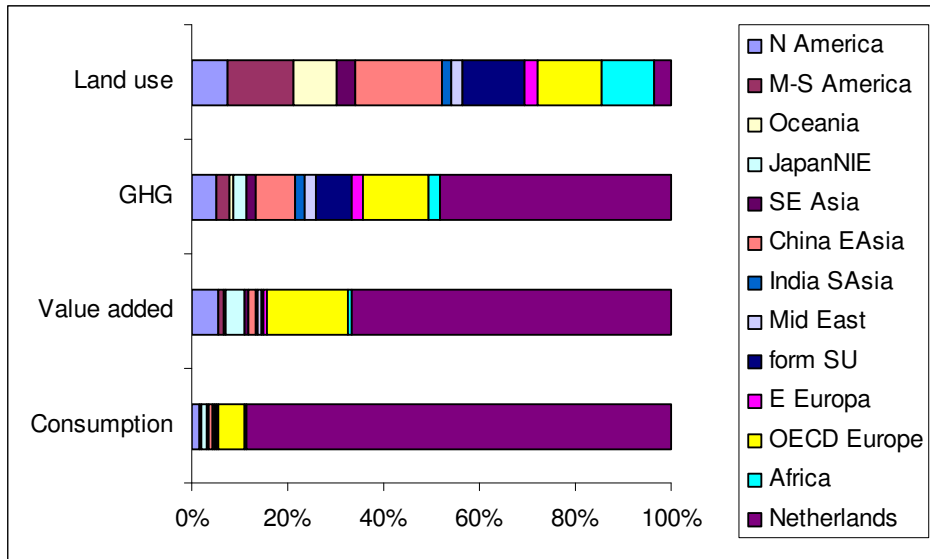
Contributions per region in Dutch consumption, related value added and environmental pressures.
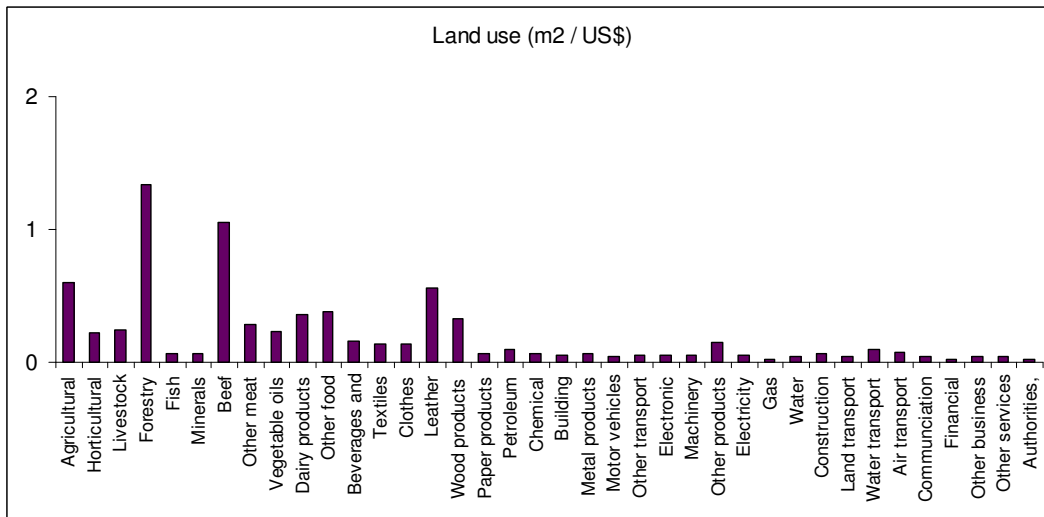
Figure 3

Contributions per chain in Dutch consumption and related environmental pressures.
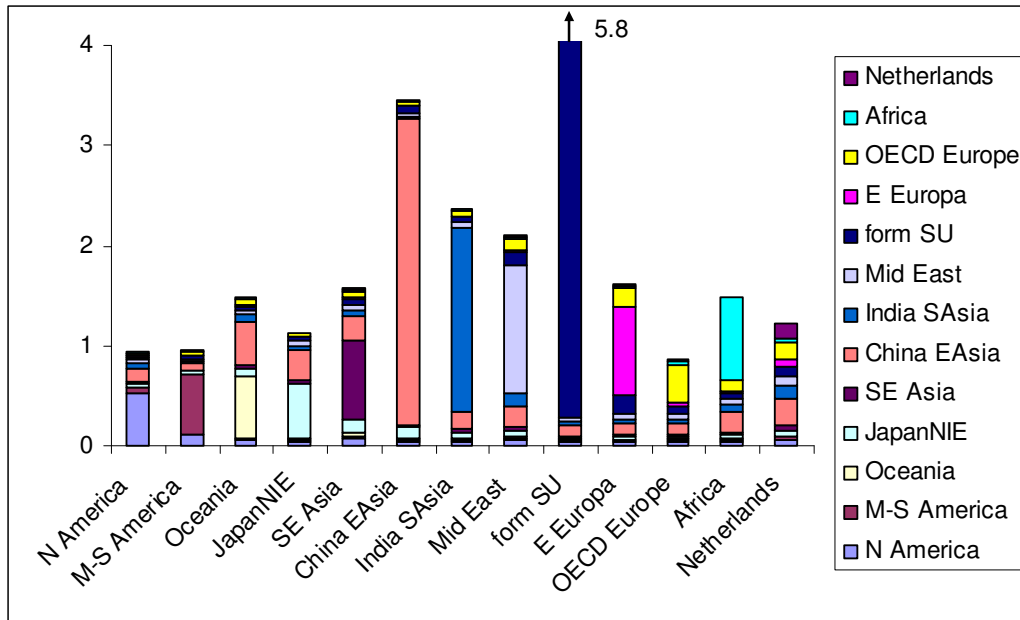
Figure 4
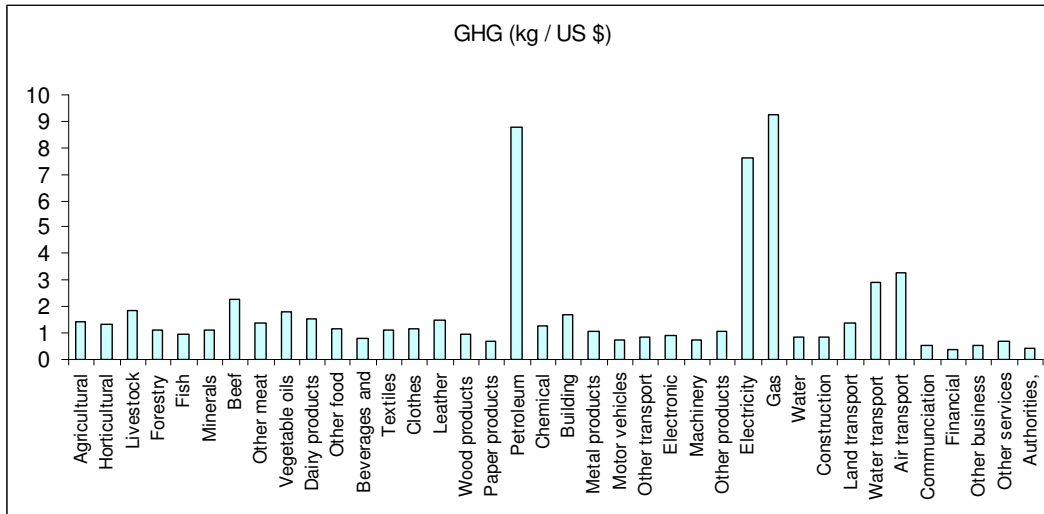
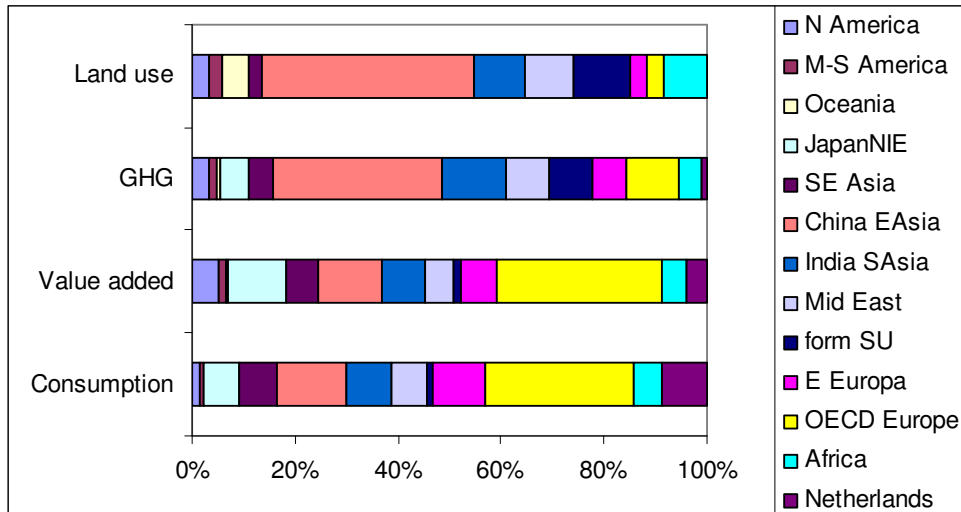Greenhouse gas intensities (kg/US $) of supply chains resulting in Dutch consumption.

Figure 5

Land use intensities (m^2/US $) of supply chains resulting in Dutch consumption.

Figure 6

Greenhouse gas intensities for the production of clothes per region (kg CO2-eq./US $); for each intensity is indicated in which region emissions take place.

Figure 7

Contributions of regions in Dutch consumption on clothes and related value added and environmental pressures.

Figure 8
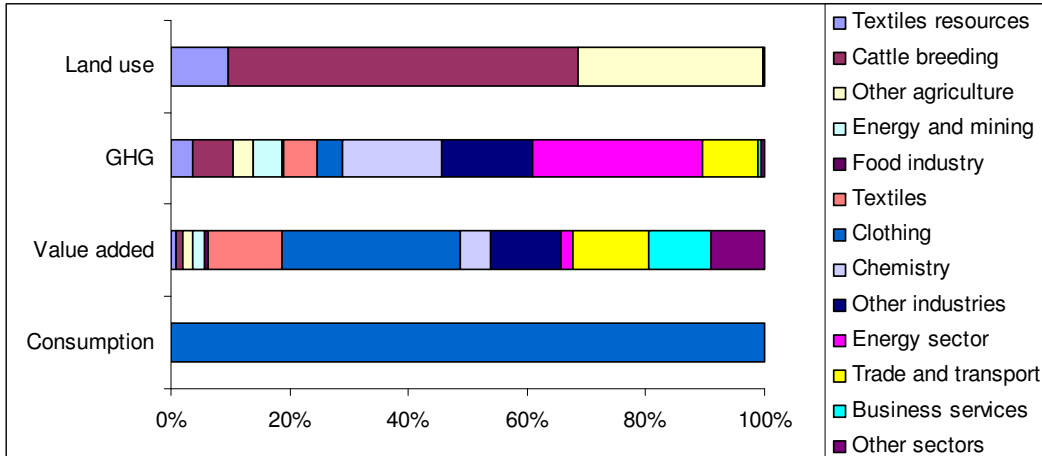
Contributions of sectors in Dutch consumption on clothes and related value added and environmental pressures.