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Estonia's Energy-related Greenhouse Gas Emissions in 1995–2011: A Structural Decomposition Analysis

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Abstract: Estonia's economy has undergone significant changes between 1995 and 2011. The economy has increased two-fold over this period. However, this economic growth did not result in a corresponding increase in energy-related greenhouse gas (GHG) emissions, which remained at approximately the level of 1995. A structural decomposition analysis (SDA) was used to define the factors influencing the level of GHG emissions and to scrutinise the role of each contribution to the trends in the emissions over this period of 17 years. The main findings of the study highlighted that, although increasing final consumption of Estonia's goods and services both domestically and abroad resulted in the growth of GHG emissions, these emissions were successfully offset by the improvements in energy use efficiency undertaken primarily by the electrical and thermal energy generation industry and the continual optimisation undertaken by all other economic sectors involved in intermediate consumption of energy during the entire period.

Keywords: Input-output analysis, Structural decomposition analysis, Estonia, Greenhouse gases

JEL Classifications: Q41, Q430, Q54

1. Introduction

The latest report of the Intergovernmental Panel on Climate Change (IPCC) confirmed that human activities affect the climate system, which in turn presents risks to humans and natural systems. The influence of human activities has been caused by the increasing amount of GHG emissions during the last decades, particularly since the industrial revolution (IPCC, 2014). Hence, to minimise the present impact and to prevent further human burden, the development and evaluation of mitigation pathways and policies to reduce GHG emissions are required. The development of such mitigation pathways and policies needs implementation of a comprehensive and well-managed analysis based on detailed, complete, reliable, economy-wide data, allowing for the identification of the driving forces behind changes in GHG emissions and specifying the role of every single economic sector in contributing to the increase or decrease in GHG emissions.

Environmentally extended input-output based structural decomposition analysis (EEIO-based SDA) is one such approach to provide the required data. This approach is becoming increasingly popular and is now widely used in academia (Su and Ang, 2012; Tarancon and Del Rio, 2012) due to development of the comprehensive input-output datasets required to meet the requirements of the analysis (WIOD, 2014; Eurostat, 2013). In addition, in contrast to index decomposition analysis (IDA), which has been extensively used in earlier studies to examine, as a rule, the sectoral energy efficiency, associated GHG emissions and drivers for their changes (Hoekstra and van der Bergh, 2003; Su and Ang, 2012), the EEIO-based SDA focuses and measures GHG emissions related to the whole economy and to every economic sector; in particular, EEIO-based SDA provides the following: a) knowledge of how the economic sectors interact with each other and to what degree the changes in the cross-sectoral interrelationship affect alterations in GHG emissions released from one or another economic sector and b) an analysis of how the changes in consumer preference or the level of demand impact GHG emissions over a certain period of time (de Haan, 2001; Hoekstra and van der Bergh, 2003; Su and Ang, 2012).

To date, many developed and developing countries have been examined using the EEIO-based SDA approach (Duarte, et al., 2013; Tarancon and Del Rio, 2012; Su and Ang, 2012). As a rule, the studies focused on changes in GHG emissions and energy consumption as a result of alterations in different economic and technological parameters over time. In general, changes in the population within a country along with their changing level of demand in energy use per unit of good or service provided (i.e., commodity), transformations in the production structure implemented in each economic sector, the effects of export, and governmental demands are analysed as the main driving forces. The studies recognised that the growth in final demand along with the increase in population were the main driving forces for the increase in GHG emissions during recent decades. In contrast, improvements in energy use per unit of commodity produced and transformations in the production structure caused a decline in GHG emissions over the same period.

Estonia, which was considered in a study along with the other Baltic states (Brizga, et al., 2014), was not an exception in the overall tendency regarding the driving forces for changes in GHG emissions. The authors of the study determined that the intensive economic growth of Estonia's economy between 1995 and 2009 led to an increase in CO_2eq emissions by 143%, which was offset by changes in the cross-sectoral interactions within the economy (in the production structure) and improvements in energy use. However, with respect to the analysis performed and the results revealed, the study did not consider inter-annual interactions between Estonia's economic sectors and the associated GHG emissions in detail. This lack of detail limits the proper understanding of driving forces for changes in GHG emissions related to each economic sector, which could and should be used as valuable supplemental information in describing the trends of GHG emissions reported in the national GHG emission inventory annually submitted to international institutions (NIR, 2013), restricts development of a well-functioning national policy for combating climate change, and limits the evaluation of effective tools for mitigating actions in GHG emissions.

The goal of this paper is to consider the inter-annual changes in industrial energy-related GHG emissions[1] (hereafter referred as to GHG emissions) in 1995–2011, to explain the economic and technological driving forces for these changes and to examine how the economic sectors interact with each other and the associated GHG emissions.

This paper is structured as follows: *Section 2* describes the method and data used in the analysis in detail; *Section 3* describes the main results obtained; and *Section 4* presents the main conclusions drawn from the SDA performed to determine and understand the driving forces for the changes in GHG emissions over the past 17 years in Estonia.

2. Method and Data

2.1 Input-Output Analysis

Monetary input-output (IO) analysis is an advanced and comprehensive tool that provides a detailed description of the final demand for commodities by consumers, the total output of each

[1] 85–90% of the total GHG emissions in Estonia (NIR, 2013); GHG emissions from fuel consumption by residential sector were omitted from the study.

sector, and the interrelationship between the economic sectors within the economy to produce commodities for intermediate and final consumption (Eurostat, 2008). Algebraically, the interrelationships are expressed by equation (1)

$$x = (I - A)^{-1} \cdot y = L \cdot y \quad (1)$$

where the total output of each sector $\boldsymbol{x}$ is determined as a function of the vector of final demand $\boldsymbol{y}$, which indicates the sum of the domestic demand for commodities (by households and by government, for capital investments) and export (Eurostat, 2008; Minx et al., 2009). The direct and indirect monetary contributions to produce one unit of commodity used for final consumption are defined by $\boldsymbol{(I\text{-}A)^{-1}}$, called the Leontief inverse matrix ($\boldsymbol{L}$), where the technological coefficient matrix $\boldsymbol{A}$ defines the relationship between the economic sectors and indicates the input requirements for each commodity (domestically produced $\boldsymbol{A_d}$ and imported $\boldsymbol{A_{im}}$) to produce one unit of commodity in another sector. However, to focus on and analyse only the domestic activities occurring within the economy, the requirements for imported commodities ($\boldsymbol{A_{im}}$) must be removed from the system (Su et al., 2010). Equation (2) constitutes the modified economic input-output model:

$$x = (I - A_d)^{-1} \cdot y = L_d \cdot y \quad (2)$$

The extension of the monetary IO tables (IOTs) with energy data and GHG emissions, defined already as EEIO analysis, allows for the examination of the direct GHG emissions released from fuel combustion by each economic sector in the commodity production process, as well as the total (direct and indirect) GHG emissions distributed via the intermediate consumption activities, which are related to the final consumption of commodities, as given by equation (3) (Rørmose and Olsen, 2005):

$$f = C \cdot L_d \cdot y = c \cdot E_s \cdot g \cdot L_d \cdot y \quad (3)$$

where the vector $\boldsymbol{f}$ reflects the results of the direct and indirect GHG emissions for each sector, and C is a matrix representing the emission intensities of each commodity. The matrix $\boldsymbol{C}$ can be further decomposed into the determinants of emission factors (EFs) specified for each type of fuel ($\boldsymbol{c}$), fuel mix structure ($\boldsymbol{E_s}$) and energy intensity ($\boldsymbol{g}$), which are calculated as a sum of the energy consumed to produce each commodity divided by the total output of all of these commodities (Rørmose, 2010).

The evolution of the direct GHG emissions to the total GHG emissions related to each commodity (sector) can be visualised using a flowchart view because the graphic representation allows us to map and trace GHG emissions released from fuel combustion to produce commodities (i.e., production related emissions), the contribution of one sector's emissions to other sectors' emissions at each stage of intermediate consumption, as well as to clarify the GHG emissions released in one sector and distributed to others (i.e., consumption related emissions). The flowcharts were evaluated for the data of 1995, 2006, 2008, and 2011[(2)].

2.2 Structural Decomposition Analysis

The EEIO-based SDA (hereafter referred to as the SDA) has become commonly used to identify changes, as a rule, in industrial energy-related GHG emissions (hereafter referred to as GHG emissions) over time (Su and Ang, 2012). In general, the SDA is an important tool to determine the direct and indirect factors (determinants) that influence the increase or decrease in GHG emissions within each economic sector of a country's economy (de Haan, 2001). In other words, the SDA distinguishes and analyses how changes (e.g., the increase in the efficiency of

[2] The years were selected as follows: 1995 – the beginning of the considered period; 2006 – the peak of economic growth; 2008 – the year of the economic recession; and 2011 – the end of the period considered.

energy use or the decrease in the final consumption of commodities) originating in an economic sector influence the changes in other sectors via intermediate consumption of commodities.

Algebraically, the total variation of GHG emissions ($\Delta \boldsymbol{f}$) between two points of time could be expressed by the following equation $\Delta f = f_t - f_{t-1}$. By expanding the formula in accordance with the determinants of the present study, the expression becomes (4):

$$\begin{aligned}\Delta f &= \Delta C L_d y + C \Delta L_d y + C L_d \Delta y = \\ &= \Delta c \cdot E_s \cdot g \cdot L_d \cdot y + c \cdot \Delta E_s \cdot g \cdot L_d \cdot y + c \cdot E_s \cdot \Delta g \cdot L_d \cdot y + c \cdot E_s \cdot g \cdot \Delta L_d \cdot y + c \cdot E_s \cdot g \cdot L_d \cdot \Delta y \qquad (4)\end{aligned}$$

where the contribution of each determinant is identified by Δ changes; the determinant $\Delta \boldsymbol{C}$ denotes the changes occurring in the total GHG emissions because of alterations in the emission intensities of commodities resulting from alterations in the GHG emission factors, namely: $\Delta \boldsymbol{c}$ reflects the changes in emission factors, i.e., changes in technology and fuel quality; $\Delta \boldsymbol{E_s}$ defines the fuel mixture effect, i.e., changes in fuel consumption from one fuel type to another; and $\Delta \boldsymbol{g}$ denotes the energy intensity effect, i.e., changes in the energy used to produce a commodity. The second determinant $\Delta \boldsymbol{L_d}$ denotes how modifications in production structure affect the changes in GHG emissions, and the $\Delta \boldsymbol{y}$ determinant specifies how the growth or decline in the level of the final demands contributed to GHG emission changes.

The contribution of each determinant depends on the time index selected for the determinant (i.e., *t* or *t-1*), which is considered to be a methodological problem regarding the 'non-uniqueness' of the SDA results. Hence, to address this problem, an average of all possible n! decomposition forms for n factors was computed in the present study (Dietzenbacher and Los, 1998).

2.3 Data Preparation

The estimates were completed using IOTs from a world input-output database (WIOD) developed by a consortium of leading universities across Europe to analyse the economic, environmental and social changes and interactions that occurred due to extending globalisation and trade liberalisation (WIOD, 2012). The WIOD includes IOTs for 60 countries, including Estonia, and consists of 35 sectors over the period of 1995–2011 (WIOD, 2014). The IOTs were evaluated based on three datasets provided by national statistical authorities: supply and use tables (SUTs), national accounts and international trade statistics. Because the SUTs are only available for a limited set of years, the unevaluated SUTs were extrapolated and benchmarked by using an approach outlined in (Temurshoev and Timmer, 2011), which proved itself as a reliable and valid methodology (WIOD, 2012). Hence, the synergy of the collected statistical and manipulated data benefited the evaluation of transparent, accurate and time-complete IOTs.

The IOTs are expounded at current prices in terms of American dollars (US$) (WIOD, 2014). Hence, to take into account (i.e., to remove) the effect of inflation in the estimations, which can lead to some unknown extent of the variation of GHG emissions over time (Rørmose and Olson, 2005), the current US$ prices of the IOTs were converted to euro-constant prices (€) of 2005 using the annual exchange rates presented in the WIOD and price indices developed by the Estonian Statistical Office (ESO) (WIOD, 2014; ESO, 2013).

Data on the consumption of energy sources according to economic sectors were obtained from the ESO (ESO, 2013). In addition, information presented in Estonia's national inventory report (NIR) was consulted (NIR, 2013), which allowed for the fuel types reported as "other fuels" to be specified in Estonia's energy balances. Moreover, because the annual energy balances include data on fuel consumption for the 16 main economic sectors, the data on energy consumption were treated and allocated in accordance with the number of economic sectors applied in the integrated IOTs. A method described in (Fujimori and Matsuoka, 2011) was applied thereto. In addition, the

ESO datasets were used to evaluate electricity and thermal energy consumption in mega joule (MJ) per € of gross output for each economic sector and to observe trends in electrical and thermal energy consumption over the considered period.

To calculate GHG emissions, CO_2, CH_4, and N_2O EFs per MJ of fuel combusted were obtained from guidelines published by the IPCC (IPCC, 2000) and from Estonia's NIR (NIR, 2013). CO_2, CH_4, and N_2O EFs were considered to be constant for all fuel types, with the exclusion of GHG EFs for oil shale and shale oil gas. The emissions of the three main GHGs were recalculated as CO_2eq using the global warming potential from (IPCC, 2000).

The results of the study on 35-sectoral changes in energy-related CO_2eq emissions were aggregated and presented for the six main branches of the economy to simplify the overview and understanding. The flowcharts of CO_2eq emissions were also presented for these six sectors.

3. Results

3.1 Overview of Estonia's Economy and GHG Emissions

During the period of 17 years, Estonia's economy has undergone significant changes: Estonia recovered and achieved slow growth by 1995, i.e., after the collapse of the Soviet Union, which ruined the economy by depriving export markets and consumers of commodities produced in Estonia. A slight recession occurred again in 1998, due to the economic default in Russia, but the economic growth was accelerated in the 2000s. In total, Estonia's economy increased by 2.3 times from 1995 to 2007, but further growth was hindered by the global economic crisis, even causing a reduction of the economy back to the level of 2005. The post-crisis period has been characterised by slow growth (Utno, 2011). Overall, Estonia's gross output has changed two-fold between 1995 and 2011 (Figure 1).

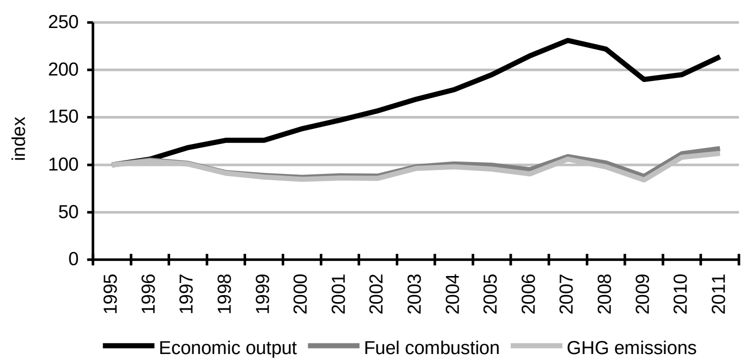


Figure 1. Trends for the gross economic output, combustion of energy resources, and energy-related CO_2eq emissions between 1995 and 2011 in Estonia, 1995 level = 100.

Fuel combustion did not increase during the 1995–2011 period (Figure 1). Solid fuels (i.e., oil shale) were dominant in the total fuel consumption balance (65–75% of the total consumption), followed by liquid oil fuels and natural gas (ESO, 2013). The minor changes in fuel mixture resulted in GHG emissions closely following the trend for fuel consumption but not being correlated with Estonia's economic growth over its development in the period of 1995–2011 (Figures 1–2). This result confirmed that in addition to significant steps made towards finding new markets and consumers, Estonia's economy has undergone important changes in its technological and productive capacities (Utno, 2011). However, these transformations were undertaken in an unbalanced manner among Estonia's economic sectors. In particular, the electrical and thermal energy generation industry was and still remains a main source of CO_2eq emissions within Estonia's economy over the entire given period, which influences the GHG emission balance of the other economic sectors. All other economic sectors attempted to minimise their fuel consumption per unit of gross output and the related GHG emissions (Figure 2).

Nevertheless, in spite of the pictures providing an impressive visualisation and allowing us to understand the main CO_2eq emissions flows and their sources, the figures do not determine the key driving forces behind the changes in GHG emissions from one year to another during the period of 1997–2011. The latter is within the competence of the SDA, the results of which are presented in the next sections.

3.2 Decomposition Results according to the Branches of Estonia's Economy

3.2.1 Agriculture, Forestry, Fishing, and Hunting Sector

According to the WIOD data (2014), the share of the agriculture, forestry, fishing, and hunting sector in Estonia's gross output decreased from 6% to 3% in the period of 1995–2011. Nevertheless, the absolute value of the total output was found to have increased by over 1.3 times over this period. In general, the sector was nearly unaffected by the global economic recession of 2007–2009, as both the final demand caused by growth in domestic consumption and the export of commodities for the sector continued to increase (see also Figure 2).

The results of the SDA illustrated that the increase in the *final consumption* of the sectors' commodities were a dominant contributor to the growth in CO_2eq emissions. Figure 3(a) indicates a significant increase in GHG emissions occurred in 1997–1998, 2000, 2003, 2007, and 2011, which occurred mainly due to the export expansion of the sectoral commodities to the international market enabled by the high yields of cereals and other vegetables (ESO, 2013). The SDA revealed also that this CO_2eq emission growth consisted of direct GHG emissions within the sector and indirect emissions occurring in the process of electrical and thermal energy production and in the transportation sector, which were intermediately consumed by the agriculture, forestry, fishing, and hunting sector.

This growth in CO_2eq emissions was offset by the transformations in the *production structure* of the sector and in the direct and indirect energy use by the sector, as it is shown in Figure 3(a). The sector minimised its consumption of electricity per unit of final commodity, which was proven by the ESO (2013) data: in particular, over the period considered, the sector reduced its consumption from 1.8 MJ of electricity (MJ_{el}) per € of the total output in 1995 to 0.7 MJ_{el}/€ in 2011. Hence, it could be said that the sector addressed inefficiency because the electrical energy generation industry is one of the most energy-consuming sectors (Table 1, Figure 2). The reductions in consumption positively affected minimisation of GHG emissions related to the agriculture, forestry, fishing, and hunting sector.

The SDA determined that transformations in *energy intensity* had different impacts on the changes in GHG emissions associated with the sector during this period of 17 years. Figure 3(a) and Table 1 elucidate that direct energy intensity has been changing in waves: starting with a decline between 1996 and 1998, followed by growth in 1999–2004, and then another fall and increase in the subsequent years. Detailed research allowing for the specification of the reasons for the observed trend has not been completed yet. Nevertheless, a brief study of the fuel mixture consumed, based on (ESO, 2013), illustrated that the sector increased consumption of liquid fuels for vehicles in the years when the increase in direct intensity occurred. The total energy intensity related to commodities of the sector, reported in Table 1, decreased during the period considered, mainly due to the changes that occurred in energy consumption in the electrical and thermal energy generation industry and the transportation sector.

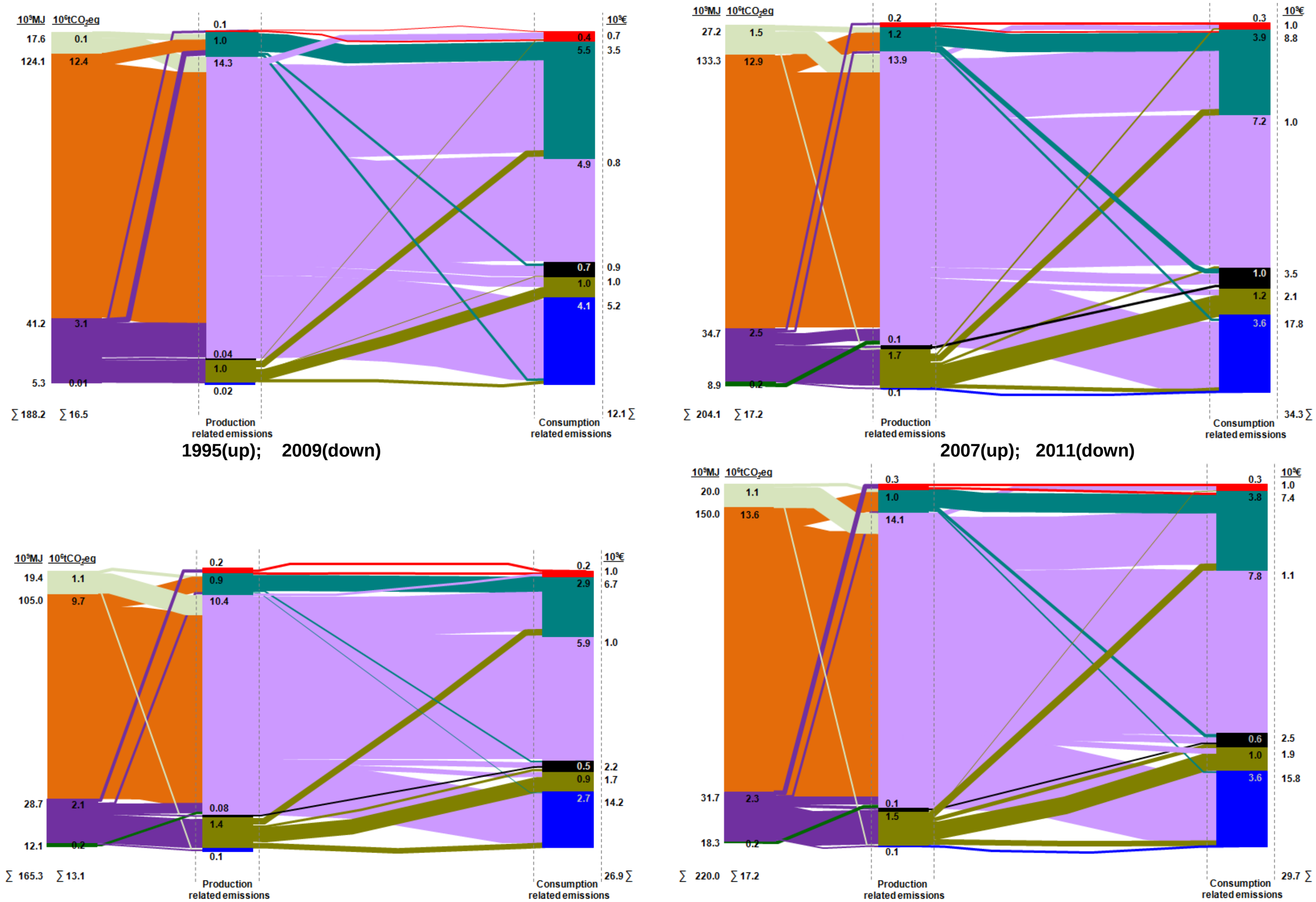
Moreover, the SDA identified that changes in the *fuel use mixture* had nearly no effect on the changes in GHG emissions because the sector changed its package of fuels over the period: consumption primarily includes liquid oil fuels used for vehicles (85–90% of the total amount of fuels consumed directly) (Figure 2; ESO, 2013), and a slight indirect change in CO_2eq emissions was produced by the changes to the electrical and thermal energy generation sector. Alterations in *EFs* related to the fuels did not influence the changes in CO_2eq emissions associated with the sector over the study period.

Table 1. Direct and total (direct and indirect) energy efficiency of the economic sectors of Estonia in 1995–2011, MJ per total gross output (MJ/€)

Year	**Direct**						**Total** (direct and indirect)					
	Agriculture sector[1)]	Manufacturing industry	Electricity and thermal energy generation	Construction sector	Transportation sector	Commercial sector	Agriculture sector[1)]	Manufacturing industry	Electricity and thermal energy generation	Construction sector	Transportation sector	Commercial sector
1995	2.3	3.4	198.9	0.6	14.7	0.1	20.6	25.5	222.9	11.3	24.6	12.8
1996	2.5	3.2	197.3	0.6	12.9	0.1	18.6	22.0	219.3	10.8	21.2	10.6
1997	2.2	2.5	194.5	0.6	9.7	0.0	14.5	18.3	215.6	9.1	16.3	8.5
1998	2.0	2.1	187.2	0.6	8.1	0.1	11.7	14.2	203.8	7.1	13.3	7.5
1999	2.1	1.5	175.6	0.5	8.8	0.1	11.6	12.3	192.2	6.7	13.4	7.3
2000	2.3	1.3	162.9	0.5	8.2	0.1	10.2	9.5	175.9	4.8	11.9	6.1
2001	2.7	1.4	165.3	0.5	9.9	0.1	11.3	9.9	178.6	4.2	13.3	5.5
2002	3.3	1.2	163.3	0.6	11.2	0.1	11.3	8.7	181.2	4.8	15.7	5.7
2003	3.8	1.3	165.2	0.7	9.7	0.1	12.3	9.1	183.7	4.9	14.0	5.6
2004	3.7	1.4	160.8	0.7	9.9	0.1	10.5	8.7	175.8	4.3	13.2	4.9
2005	3.4	1.4	148.9	0.6	10.6	0.1	9.9	7.9	162.2	3.5	13.7	4.6
2006	3.2	1.2	141.1	0.5	11.4	0.1	9.6	6.9	156.0	3.5	14.4	4.1
2007	2.7	1.4	147.6	0.5	11.2	0.1	8.6	7.0	165.4	3.5	13.9	4.0
2008	2.6	1.3	142.8	0.4	11.7	0.1	8.2	6.4	158.9	3.1	14.4	3.8
2009	2.7	0.9	125.5	0.5	11.1	0.1	7.3	6.0	142.6	3.2	13.5	3.8
2010	3.0	0.8	154.9	0.5	12.4	0.2	9.1	6.9	174.7	3.5	15.4	4.5
2011	3.5	0.9	155.7	0.6	11.0	0.1	9.6	7.2	177.0	3.6	13.8	4.6

1) "Agriculture sector" is short for the "Agriculture, forestry, fishing, and hunting sector".

The data of (WIOD, 2014) defined that the share of the electrical and thermal energy generation sector in Estonia's total output decreased from 7% in 1995 to 4% in 2011. Nevertheless, the contribution of direct GHG emissions from the sector was approximately 80–90% of the total emissions occurring within Estonia's economy. As it is seen from Figure 2, direct emissions were distributed to the other economic sectors via the intermediate consumption of electricity and thermal energy. The figure also illustrates that the total sectoral output, determined by the growth in final consumption and the development of other Estonian economic sectors, slightly increased by almost 1.4-fold over this period of 17 years, where the rate of intermediate consumption changed by only 1.1 times, but the level of final consumption increased by over two-fold.



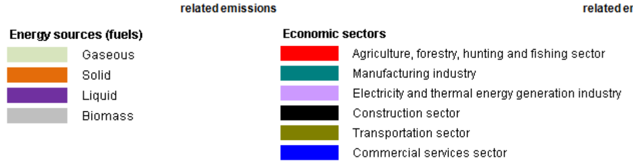


Figure 2. Energy-related CO_2eq emission flows within Estonia's economy ($10^6 \times tCO_2eq$), energy consumption (10^9 MJ), and values gross output (10^9€) in 1995, 2007, 2009 and 2011; the figures present only flows of emissions that are higher than $0.02 \times 10^6 tCO_2eq$.

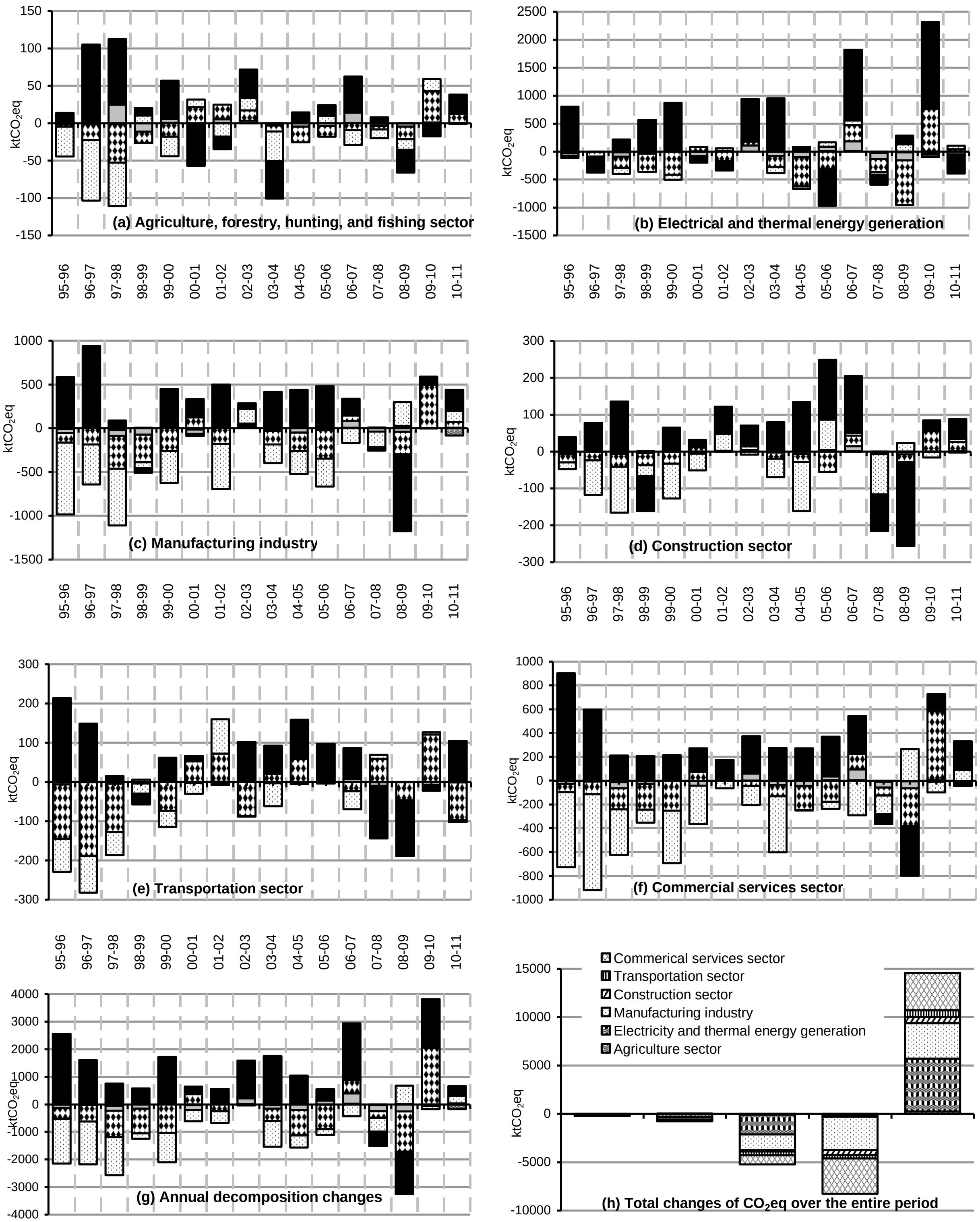
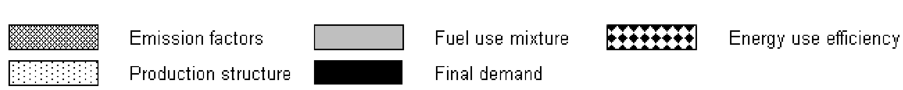


Figure 3. Structural decomposition of CO_2eq emissions in 1995–2011, ktCO_2eq



3.2.2 Electrical and Thermal Energy Generation Industry

The SDA revealed that the growth in *final consumption* was associated with a significant release of GHG emissions, with the exception of the several years when a decline in the emissions was observed due to decreased export of electricity or minimised consumption of electricity and thermal energy by households – the trend is recorded in Figure 3(b). The analysis of the ESO data (2013) confirmed this increase and demonstrated that oil shale has been the dominant fuel and continues to be the dominant fuel for electricity generation, accounting for more than 90% of the total energy consumed for generation. Nevertheless, the prevalence of oil shale slightly declined under the pressure of international policies (COM, 2011) to decrease (direct) GHG emissions from the electricity generation process; the share of wood biomass was enhanced in the fuel mixture from 3% in the total fuel energy consumed for electricity generation in 2009 to 6% consumed in 2011. The ESO data (2013) also indicated that the generation of thermal energy, based on liquid oil fuels and oil shale, which was replaced by wood biomass and natural gas over the years for the considered period. Hence, transitioning from fossil fuels to renewable fuels in the electrical and thermal energy generation sector is the primary cause of the reduction of CO_2eq emissions, with the exception of 2003 and 2007, when the share of oil shale in the fuel mixture increased.

Changes in *EFs* have also resulted in annual reduction of the emissions, but the impact was negligible (Figure 3(b)).

According to the results on direct and indirect *energy intensity* received from the SDA, the main contributor to decreasing GHG emissions from the sector, and as a consequence in other economic sectors, was the reduction of direct energy intensity by 20% during this period of 17 years – from 199 MJ per € of the total output in 1995 to 156 MJ/€ in 2011. These values are recorded in Table 1. The analysis of the ESO data (2013) allowed to define significant steps in the improvement of direct energy intensity, which were achieved due to minimisation of the losses in networks in the process of electricity transmission. Namely, the losses decreased from 20% in 1995 to 7% of the total electricity distributed via the networks in 2011. Improvements also occurred in the transmission of thermal energy from producers to consumers, but these changes were not so remarkable – from 13% of the total generated thermal energy, which was lost in the distribution networks in 1995, to 11% in 2011. In addition, the share of renewable electricity generated by wind noticeably increased during the period considered – from the first wind turbine established in 1997, wind power accounted for 3% of the total power in 2011. Gavrilova *et al* (2010) indicated another factor contributing to improvements in energy intensity, which was the replacement of power blocks at oil shale-electricity generation power plants by blocks with a higher coefficient for fuel combustion. Nevertheless, there were several years when the energy intensity per output of the final commodity grew, bringing about a significant increase in CO_2eq emissions – namely in 2007 and 2010, which are clearly seen from Figure 3(b). This growth was caused by the increase in oil shale in the total fuel mixture due to the expansion in exports of oil shale-based electricity during these years; specifically, there was a connection for transmission of electricity between Estonia and Finland – Estlink 1 – established in 2007, and the rate of oil-shale electricity export increased from 3.6×10^9 MJ in 2006 to 10.0×10^9 MJ in 2007. The exports of oil shale-based electricity from Estonia increased from 10.5×10^9 MJ in 2009 to the peak value of 15.7×10^9 MJ in 2010 (ESO, 2013).

The SDA's focus on changes in the *production structure* within the sector indicated also that the associated GHG emissions practically did not occur during the period of 1995–2011. Because the production processes established for electrical and thermal energy generation were stable over the entire period, e.g., oil shale was used and transported from domestic oil shale mines to power plants using the same technology over the last 60 years. Only an increase in the use of wood biomass produced slight changes in the associated emissions to the wood production sector;

however, these changes are not significant. The trend of CO_2eq emissions is demonstrated in Figure 3(b).

3.2.3 Manufacturing Industry

The WIOD data (2014) determined that the manufacturing sector's contribution to the total gross output changed from 29% in 1995 to 25% in 2011 – see Figure 2. The ESO (2013) and Utno (2011) also identified that structural changes occurred within the industry over the period of 1995–2011 as well. For example, the food, beverage, and tobacco industry decreased its contribution to the total output from 33% in 1995 to 18% in 2011, and the contribution of the textile and leather product industry also decreased – from 12% in 1995 to 5% on 2011. On the contrary, the wood and wood product sector's share in the total output increased from 7% in 1995 to 13% in 2011, as well as the contribution of the fabricated metal industry, and the electrical and optical equipment industry increased from 10% in 1995 to 24% in 2011. In absolute value, the total output of the manufacturing industry increased by over two-fold because of the development of all sectors between 1995 and 2011. However, the peak growth rate was achieved in 2007, which was interrupted by the global economic crisis.

The SDA revealed that the economic activities were either determined by the increasing needs for commodities consumed by Estonia's *final consumers* or by expansion of *exports* by more than three-fold. Such intensive annual growth caused significant release of CO_2eq emissions related to the industry, which are illustrated in Figure 3(c). Nevertheless, detailed examination of the SDA results elucidated that different sectors contributed by different degrees to the GHG emissions over the period considered. For example, significant growth in GHG emissions of the first two years was caused by the increase in the final consumption of commodities of the wood and wood products sector and the coke, chemical, and plastic products industry. The latter industry slowed its development in the period; as a result, GHG emissions declined between 1997 and 1998. However, since 1999, the production and consumption of the commodities in the coke, chemical, and plastic products industry has been restored, thereby causing an increase in CO_2eq emissions. During the same period, the contribution of GHG emissions associated with the electrical and transport equipment sector increased as well. The remarkable decrease in GHG emissions between 2007 and 2009 was caused by the economic decline of all sectors of industry due to the global economic crisis. However, the sectors recovered in 2009 and caused an increase in GHG emissions in this period.

The ESO (2013), consulted under the SDA, revealed that the most efficient measure dedicated to the reduction of CO_2eq emissions was the changes in electricity consumption per unit of output. In total, the industry minimised its consumption of electricity from 2.2 MJ_{el} per € of total output in 1995 to 1.2 MJ_{el}/€ of total output in 2011. The maximal reduction rate occurred during the first years of the considered period, followed by a more linear decrease during the remaining period. The food, beverage, and tobacco sector, the textile and leather production sector, and the paper production industry succeeded in reducing GHG emissions to a greater degree. Hence, the changes in the *production structure* undertaken by the sectors of the manufacturing industry and demonstrated in Figure 3(c) were the primary cause of the reduction of GHG emissions related to the industry.

Another important contributor to reducing GHG emissions related to the manufacturing industry, analysed within the SDA, was the improvements in direct and total *energy intensity* (Figure 3(c)). In particular, Table 1 specifies that the industry improved its direct energy intensity from 3.4 to 0.9 MJ/€ and optimised the total energy intensity rate 3.5-fold over the period of 1995–2011. Almost all sectors of the industry minimised their direct consumption of fuel per unit of output, except for the textile and leather manufacturing sector and the pulp and paper production sector. The total energy intensity improved significantly during the first three years of the study period, which corresponded to a remarkable reduction in GHG emissions.

The changes in the *fuel use mixture* and the *EFs*, examined under the SDA and reported in Figure 3(c), insignificantly affected the changes in GHG emissions released by the industry because the structure of fuels was nearly unchanged over this period of 17 years. As the ESO (2013) defined that the main fuels used in production over the study period were oil shale, coal, and natural gas, which replaced heavy liquid oils. A key share of the liquid oils contributed more than 80% to the total fuel consumption within the industry. Minor changes in the fuel use mixture in electrical and thermal energy generation did not influence changes in CO_2eq emissions related to the manufacturing industry.

3.2.4 Construction Sector

The WIOD data (2014) determined that the construction sector's share in the total gross output increased from 7% in 1995 to 9% in 2011. The peak for economic development in Estonia was in 2007, when an increase in the total output of the sector reached 10% or 3.9-fold in absolute value. In contrast, the total output decreased in the years of the global economic crisis. In total, the sector grew 2.9-fold between 1995 and 2011 (see Figure 2). The WIOD (2014) stated also that the economic activity of the sector was determined by the growth in commodities intermediately consumed by other sectors in Estonia and by the increasing demand for final consumption, which increased 3.3-fold over this period, mainly because of the growth in capital investment.

The results of the SDA indicated that significant development of the sector and increase in the level of *final consumption* of commodities were a key driving force for the GHG emissions increase in the sector over the entire period, which are recorded in Figure 3(d). Insignificant declines in GHG emissions occurred only in the years of Russia's economic default and the years of the global economic crisis – between 1998 and 1999 and in the period of 2008–2009.

Nevertheless, the SDA displayed that changes in *production structure* have generated an offset in the increase in GHG emissions. The maximal inter-annual reduction of GHG emissions due to transformation of the production structure was achieved in the beginning of the period considered: an important reduction of electrical and thermal energy consumption per unit of output generated by the sector occurred in this period. In addition, the ESO (2013) confirmed that the sector reduced its consumption of electricity from 0.5 MJ_{el} per € of the total output in 1995 to 0.1 MJ_{el}/€ in 2011, and the thermal energy decreased from 0.3 MJ of thermal energy (MJ_h) per € of the total output in 1995 to 0.1 MJ_h/€ of the total output in 2011. In contrast, a slight increase in inter-annual consumption in electricity caused a growth in GHG emissions in the periods of 2001–2002 and 2005–2006 (Figure 3(d)). The cement production sector optimised its production, which resulted in a decrease in GHG emissions related to the construction sector.

The changes in *energy efficiency* were additional tools in decreasing GHG emissions from the construction sector according the SDA. Table 1 determines that the decrease mostly occurred due to actions in the other economic sectors instead of within the construction sector because the direct energy efficiency remained nearly unchanged in 17 years or even increased in 2002–2005. In particular, remarkable changes occurred in energy use efficiency in the electrical and thermal energy sector, the manufacturing industry (i.e., the cement production sector), and the transportation sector, which resulted in the overall decline of the total energy efficiency in the construction sector and thus the reduction of GHG emissions. The increase in CO_2eq emissions in the periods of 2006–2007 and 2009–2011, which can be observed in Figure 3(d), is explained by the growth of energy use efficiency in the electrical and thermal energy generation sector.

The lowest contribution to the reduction of GHG emissions was provided by the changes implemented in *fuel use mixture* (Figure 3(d)). The structure for the direct consumption of fuels remained nearly unchanged over the period considered. Nevertheless, the alterations that occurred in the fuel mixture of the electrical and thermal energy generation sector caused inter-annual changes in CO_2eq emissions associated with the construction sector.

3.2.5 Transportation Sector

The detailed WIOD data (2014), which are also visualised in Figure 2, indicated that the transportation sector's contribution to the total gross output decreased from 8% in 1995 to 7% in 2011. The total output of the sector reached a peak at 2007, when the absolute value increased 2.2-fold from the 1995 value. However, the economic decline that occurred in 2007–2008 inhibited further growth and even reduced growth to the level of 2005 by 2011. Overall, the total gross output of the sector has doubled over the period considered. The output was determined by the over 2.5-fold increase in the required transportation commodities for intermediate consumption within Estonia's economy and by the 1.7-fold growth in the final demand level. Within the final consumption, a key driving force was domestic consumption and expansion of exports. In particular, demand for transportation services provided by inland transport increased more than two-fold compared to the 1995 level. The latter constituted a main part of the total output of the transportation sector – approximately 60–70%.

The SDA revealed that the dynamic growth in the *final demand level* had an associated increase in GHG emissions related to the sector. The remarkable increase noted during the first years of the period was hindered by Russia's economic default occurring in 1998 but was restored afterwards. A slight decline occurred again in 2002, mainly because of a decline in transportation provided by water transport. Nevertheless, in total, demand for the commodities of the transportation sector increased from one year to another up until 2008, as confirmed by the associated increase in GHG emissions. The emissions are recorded in Figure 3(e).

The main driving force for the GHG emissions decrease was the improvements in *energy efficiency* per unit of gross output taken either by the sector itself or by Estonia's other economic sectors. In general, according to Maanteeamet (2011), the remarkable achievements in direct energy use efficiency of the sector during the first three years in the period considered were due to the replacement of old vehicles with new and more efficient ones. In addition, Table 1 explains also that the changes in energy use efficiency of the electrical and thermal energy sector played an important role in the total energy intensity of the transportation sector, contributing to the reduction of emissions related to the sector. Nevertheless, increases in CO_2eq emissions in 2001–2002 and in 2007–2008 were determined mainly by the increase in the direct intensity of the transportation sector – see Figure 3(e).

Another determinant considered under the SDA is alterations in *production structure* of the sector. In particular, changes in this factor contributed significantly to the decrease in GHG emissions during the first years of the period considered, as it is illustrated in Figure 3(e). The ESO (2013) indicated a reason for this decline: enterprises of the transportation sector modified their consumption of electricity and thermal energy and the consumption of electricity was minimised to a greater degree between 1995 and 1998 – from 0.7 MJ_{el} per € of the total output in 1995 to 0.3 MJ_{el}/€ in 1998, decreasing slowly over the next 13 years until reaching 0.1 MJ_{el}/€. The decrease in consumption of thermal energy was more linear – from 0.1 MJ_h per € of the total output in 1995 to 0.05 MJ_h/€ in 1998 and 0.01 MJ_h/€ in 2011.

There were no shifts from one fuel to another in the *fuel use mixture* that occurred in the sector because the sector relied mainly on motor liquid fuels with the same values of EFs. Hence, alterations in GHG emissions due to the shifts were at a low level or did not occur at all over the given period as it is shown in Figure 3(e).

3.2.6 Commercial Services

According to the WIOD data (2014), the commercial sector's contribution in the total gross output increased from 43% in 1995 to 53% in 2011. The trend is recorded in Figure 2. The absolute value of the sector's output grew almost three-fold in the entire period, although the sector lost 20% of its development in the years of the global crisis. Within the sector, financial and insurance activities, administrative and support services, and information and communication services developed more intensively. The development in the economic activity of the sector was caused by the three-fold increase in the requirements for commodities of the sectors consumed in the intermediate production of other Estonian sectors and by the increase in demand by final consumers: mainly by domestic households and government, which contributed approximately 70–75% of the total final consumption over the period considered.

Figure 3(f) demonstrates the increase of GHG emissions in the sector, occurred due to the growth in the *final consumption* of commodities produced. The analysis of the SDA results confirm that the most noticeable increase in GHG emissions occurred between 1995 and 1997, mainly due to the expansion of the wholesale trade and commission trade sector, the retail trade sector, and the real estate sector; in this period, the total energy intensity of the commodities was the highest (Table 1). The subsequent years of the period exhibited a linear and stable inter-annual growth in GHG emissions up until 2008, i.e., the year of the global economic crisis.

Changes in *production structure* were a dominant driver in decreasing GHG emissions related to the sector in accordance with the SDA. The key steps contributing to the CO_2eq emission decrease were the minimisation of the consumption of electricity and thermal energy. In total, the sector reduced the consumption of electricity from 1.0 MJ_{el} per € of the total output in 1995 to 0.5 MJ_{el}/€ in 2011, with a slight increase in 2009. Consumption of thermal energy decreased from 1.6 MJ_h per € of the total output in 1995 to 0.5 MJ_h/€ of output in 2011. A significant rate of consumption decrease occurred during the first years of the period. Hence, the decrease in CO_2eq emissions was significant in the years, which are illustrated in Figure 3(f).

Another key offset against the increase in GHG emissions, determined by the analysis, is related to improvements in *energy use*. Table 1 indicates that the direct energy intensity of the commodities produced by the sector doubled in 2002. However, because the direct energy efficiency of commodities are/were remarkably low, as can be noted in the table, the doubling of the direct energy intensity had almost no influence on the total energy intensity and the GHG emissions associated with changes in energy efficiency use – the dominant role in the total energy intensity rate was determined by the electrical and thermal energy generation sector, which resulted from the improvements of its direct efficiency regarding energy use.

The SDA also indicated that growth in the use of natural gas has significantly changed the *fuel use mixture* of the sector, but GHG emissions related to the commercial sector changed only slightly (Figure 3(f)). The observation is explained by the low direct consumption of energy in the total energy value required for operation of the commercial sector. The values are demonstrated in Table 1. In addition, the SDA revealed that the main changes in GHG emissions were caused by alterations in the fuel use mixture provided by the electrical and thermal energy generation industry, which, to a great extent, is consumed by the commercial sector, all the points are clearly demonstrated in Figure 2. Changes in *EFs* contributed insignificantly to the change in emissions.

4. Conclusions

The growth in final demand level was the main driving force for the inter-annual increase in GHG emissions (Figure 3(g)) over this period of 17 years, except for the years of the global economic crisis.

The changes in energy efficiency and production structure contributed to a decrease in GHG emissions. Important steps in the decline of GHG emissions due to improvements in energy efficiency were achieved in the period of 1997–2000, due to improvements in the electrical and thermal energy sector. A remarkable increase in GHG emissions due to changes in energy intensity was also determined by the changes occurring in the electrical and thermal energy generation sector because of the growth in the export of electricity to Finland. The decline in GHG emissions due to changes in the production structure contributed to a greater degree during the first years of the period considered. Here, on the contrary, all other economic sectors except for the electrical and thermal energy generation sector succeeded in the reduction of CO_2eq emissions because enterprises established new modern equipment and technological processes to reduce expenses and become more competitive in new markets.

Changes in fuel mixture and EFs contributed to changes in GHG emissions to a lesser degree because Estonia completely relied on solid fuels and liquid oil fuels. An effective change in fuel use was implemented: heavy oil fuels were replaced by natural gas and biomass, providing a decrease in GHG emissions from one year to the next.

In total, CO_2eq emissions due to changes in the final consumption composed 14,573 ktCO_2eq in the period of 1995–2011 (Figure 3(h)), and the main contributing sectors were the electrical and thermal energy generation sector, the manufacturing industry, and the commercial sector. The emissions were offset by an overall decrease in emissions due to improvements in the efficiency of fuels used per unit of total gross output (-5,225 ktCO_2eq), where the electrical and thermal energy generation and manufacturing sector were the leaders. The changes in production structure contributed to a total decrease of -8,258 ktCO_2eq over the period of 1995–2011, mainly because of operational changes in the manufacturing industry and commercial sector. The changes occurring due to changes in the fuel mixture used contributed to a decline of -756 ktCO_2eq, mainly due to the use of gas and wood biomass instead of heavy oil fuels.

5. Discussion

The electrical and thermal generation industry was a dominant sector in determining Estonia's emissions during this period. This sector can be characterised as monumental, heavy and static due to its almost unchanged fuel mixture use and the overall contribution to the total CO_2eq emissions related to the production. The sector both in the past and currently has the highest direct energy efficiency among all other sectors of Estonia's economy, and Estonia's economy has the highest GHG emission intensity among the European countries (Eurostat, 2013), in spite of the fact that energy efficiency has improved by approximately 20% during the period considered. Nevertheless, the change in the efficiency of the electrical and thermal energy generation industry contributed to the decline in CO_2eq emissions in the period of 1995–2011. In contrast, all other sectors of Estonia's economy, which may be defined as dynamic and flexible, succeeded in decreasing CO_2eq emissions due to the optimisation of production processes, i.e., via minimisation of the other sectors' consumption of commodities per unit of output, where the key decrease was provided by a reduction of the electricity and thermal energy use by the economic sectors.

Hence, the mitigating activities that must be established in Estonia's economy are absolutely evident – in particular, crucial reforms must be taken in the oil shale-based electricity generation sector, particularly if the Estonian economy aspires to achieving the European-average parameters in the future (Eurostat, 2013). As further growth would cause an increase in GHG emissions due to growth in demand for the output of all economic sectors including electricity, it is expected that electricity consumption will increase from 24.8×10^9 MJ in 2010 to 41.8×10^9 MJ in 2030 (MoE, 2013).

The first steps toward implementing mitigating actions have been proposed by the Estonian government, chiefly due to the pressure of European and international mandates and authorities (COM, 2011); in particular, Estonia declared that it would move away from oil shale-based electricity. The decline in consumption was reported to occur due to the closure of oil shale-based power plants and due to the replacement of domestically produced oil shale-based electricity with imports from other European countries. It is expected that Estonia's production of electricity will decrease from 35.5×10^9 MJ in 2010 to 18.4×10^9 MJ in 2030.

Undoubtedly, the proposed steps would justify themselves because Estonia would decrease GHG emissions from the electricity generation sector (MoE, 2013). In turn, the decline in the GHG emission intensity of the sector would cause improvements in the total (direct and indirect) emission intensities of all other sectors of Estonia's economy as well. Oil shale resources remaining unused by electricity generation are projected to be directed to the shale oil production industry – a proposed increase in the production of shale oil from 4.5×10^6 t in 2010 to 13.3×10^6 t in 2030, with nearly 100% expected to be exported abroad (MoE, 2013). This exporting of shale oil would cause a slight increase in GHG emissions but not as significant an increase as from the use of oil shale-based electricity. However, time will tell to which degree these steps will be realised because the ways in which economic welfare would change due to minimising the output of one of the important economic sectors (i.e., the electricity generation sector) in Estonia has not yet been predicted. However, current partial replacement of the electricity requirements of Estonia with that imported from Finland in the first quarter of 2014 indicated that Estonia's economy is decelerating due to this replacement (ESO, 2014). The level of effect on the economy due to the increase in shale oil production has not been calculated yet, but it could be assumed to be positive because the output of the industry will grow along with the increase in the oil price (OPEC, 2012). In any case, Estonia's economy would stand at the forefront of great modifications if these mitigating activities are established.

The proposed activities would raise an important question regarding GHG emissions embodied in international trade. If Estonia plans to import electricity from abroad, then which "GHG emission responsibility" would be associated with the electricity imported (Peters, 2008)? Undoubtedly, this question requires that additional research be performed; however, note that the neighbouring countries of Estonia produce electricity with significantly lower GHG emission efficiency (Eurostat, 2013). Hence, Estonia would reduce GHG emissions. Nevertheless, GHG emissions and other environmental pressure (Gavrilova, et al., 2010) embedded in shale oil would be shifted to the consumers' shoulders. Hence, this environmental burden should also be taken into account in terms of the environmental pressure associated with Estonia's production and consumption activities.

Hence, well-weighted and sophisticated steps should be a basis for development of a modern, comprehensive, and adequate climate and environmental policy for Estonia that covers both sides of the domestic economy (i.e., producers and consumers) as well as international trade.

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