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Research article

Key drivers of the textile and clothing industry decarbonisation within the EU-27

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ABSTRACT

The European Union has identified the Textile and Clothing industry as one of the essential objectives towards carbon neutrality in 2050 in line with the "European Green Deal". There are no previous research papers focused on analysing the drivers and inhibitors of the past greenhouse gas emission changes of the textile and clothing industry in Europe. This paper aims to analyse the determinants of the changes in these emissions, and the disassociation level between emissions and economic growth, throughout the 27 Member States of the European Union, from 2008 to 2018. A Logarithmic Mean Divisia Index that explains the key drivers of the changes in greenhouse gas emissions of European Union Textile and Cloth industry and a Decoupling Index have been applied. The results generally conclude that the intensity and carbonisation effects are key factors that contribute to reducing greenhouse gas emissions. The lower relative weight of the textile and clothing industry throughout the EU-27 was noteworthy, and favours lower emissions, partially counteracted by the activity effect. Also, most Member States have been decoupling the industry's emissions from economic growth. Our policy recommendation shows that if further reductions in greenhouse gas emissions are to be achieved, energy efficiency improvements and cleaner use of energy sources would offset the potential increase in emissions of this industry as a result of a relative increase in its gross value added.

1. Introduction

The textile and clothing industry (T&C industry) is one of the biggest and most important industries in the world (HOC, 2019). This industry consumes a significant amount of energy, due to the lengthy supply chains (Hasanbeigi and Price, 2012; Leal Filho et al., 2022). The total energy consumed by the T&C industry depends on the structure of the manufacturing sector that could range between 4% of final energy use in China and less than 2% in the United States of America (Bravo and Iturralde, 2022). In the case of European Countries, this percentage is circa 1.54% (Eurostat, 2020a). Fossil energy is the main energy supplied in this sector, circa 80% in the case of EU-27 (Eurostat, 2020a), which entails a strong impact on the environment, as pointed out in previous literature (Farhana et al., 2022; Qing et al., 2022). Additionally, the T&C industry is one of the most polluting (Boström and Micheletti, 2016; Christis et al., 2019), generating around 1.2 billion tonnes of CO_2 equivalent (Leal et al., 2022) and being responsible for approximately 10% of greenhouse gas (GHG) emissions (EP, 2020b) worldwide. Also, it has been estimated that up to 20% of industrial wastewater pollution is caused by the textile industry (Kant, 2012).

The actual business model of the T&C industry, known as the fast fashion model, leads the worldwide T&C industry to a linear economy model (Fieldson et al., 2009; Beton et al., 2014; Christis et al., 2019) characterised by a high number of collections, mass production, short shelf life of products, low quality and prices (Niinimäki and Hassi, 2011; Christis et al., 2019; EP, 2019; HOC, 2019), increasing its detrimental environmental impact (Boström and Micheletti, 2016; Piontek and Müller, 2018). With the aim of reducing this impact, in 2018, the T&C industry, within the United Nations Framework Convention on Climate Change (UNFCCC) Fashion Industry Charter for Climate Action, committed to a 30 per cent reduction in greenhouse gas (GHG) emissions by 2030 (from a 2015 baseline) and net-zero emissions by 2050 (ILO, 2021).

The environmental impact of the T&C industry is worldwide as it causes significant damage to water, land and air (Alkaya and Demirer, 2014; Hasanbeigi and Price, 2015; Ellen MacArthur Foundation, 2017; EP, 2020a). Water is contaminated with chemicals (SYS, 2017) and microplastics (Rocha-Santos and Duarte, 2015); microplastics have a

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negative impact on aquatic fauna (Wright et al., 2013; Do Sul and Costa, 2014; Wardrop et al., 2016); and, as a consequence, it has an impact on humans (Rochman et al., 2015; Kerr and Landry, 2017; Laitala et al., 2018). The land is contaminated through deforestation and degradation (EP, 2020b) and energy use is the major contributor to GHG emissions throughout the T&C industry.

Apart from the above, the industry has a negative impact on human life, working conditions, and biodiversity (Boström and Micheletti, 2016; Piontek and Müller, 2018). The impact on humans includes allergic reactions (Kant, 2012), impact on the reproductive system (Fei et al., 2009; Joensen et al., 2009) and immune systems (Grandjean et al., 2012), and has a carcinogenic effect (Swedish Chemicals Agency, 2016). Biodiversity is affected by overexploitation, pollution, and climate change (Brat and Pathak, 2020), which can have an impact by depleting resources and annihilating species (Ceballos et al., 2017).

In Europe, the T&C industry plays an important role from an economic perspective. The EU (*including the United Kingdom and Intra-EU trade*) is the second T&C exporter in the world, accounting for 194 billion euros in 2019 (EURATEX, 2020). In the field of business, the EU-27 T&C industry is currently composed of approximately 160,000 companies, generating a turnover of 162 billion euros (EURATEX, 2020; EC, 2021b). Most of the companies are micro, small and medium-sized (Beton et al., 2014; Cesar da Silva et al., 2021), they are usually private equity groups, and only a few are publicly traded, such as Inditex (Stengg, 2001). Finally, circa 67% of the companies are driven to produce clothing and the rest, circa 33%, to produce textiles (Stengg, 2001; EURATEX, 2020).

However, the environmental impact of the EU-27 T&C industry is also relevant as it is an energy and GHG emissions intensive industry (Ellen MacArthur Foundation, 2017). The energy sources used for production within the EU T&C industry are also relevant for the GHG emissions. To a large extent, the use of fossil fuels and nuclear energy sources stands out, although they are losing significance, whereas renewable energies have become more important in the last decade. As can be seen in Table B2 of Annex B, renewable energies went from being 493.76 thousand tons of oil equivalent (TOE) in 2008 to 602.81 TOE in 2018, while fossil fuels went from 4419.35 TOE in 2008 to 2836.34 TOE in 2018 (Eurostat, 2020a).

The EU-27 have identified the T&C industry as one of the essential goals towards carbon neutrality in 2050 in line with the "European Green Deal", supported by the "Circular Economy Action Plan" (CEAP), the "Industrial Strategy" and, specifically, the EU Strategy for Sustainable and Circular Textiles (EC, 2021a; EC, 2022a). Among the goals to be achieved by these strategies in 2030 are improving the competitiveness and sustainability of the EU T&C industry, and solving its environmental and human impacts (EC, 2021a; EC, 2022a).

Specifically, Directive 2012/27/EU focuses on improving energy efficiency in the European T&C industry, promoting a decrease in energy consumption and therefore, as has been shown before, allowing lower GHG emissions. The reports conducted by the EU show that Directive 2012/27/EU has been the key driver for energy efficiency improvements in the T&C industry in recent years (EC, 2015; EC, 2017a; EC, 2017b; EC, 2019; EC; 2020). More recently, some tools have been made available to T&C companies in order to provide them with some guidance related to energy efficiency in textile or clothing manufacturing (EMM, 2022). Additionally, Directive 2010/75/EU has focused on reducing GHG emissions and other air emissions from pre-treatment and dyeing where the treatment capacity exceeds 10 tons per day, and from tanning hides and skins where the treatment capacity exceeds 12 tons of finished products per day. The evaluation conducted through several studies has concluded that the Directive has played an important role in reducing air emissions of pollutants (EC, 2022b). The policy instruments implemented by Directive (2012)/27/EU were promoting energy efficiency, promoting energy audits, establishing energy efficiency obligation schemes or removing barriers to energy efficiency, whereas, Directive 2010/75/EU established schemes for emissions reduction and emissions control and monitoring, among others.

The purpose of this paper is twofold. Firstly, to contribute to a better understanding of the key determinants of changes in GHG emissions in the T&C industry within the EU-27 Member States (MSs) (MS is used to abbreviate a single Member State) during the period 2008–2018. Secondly, to analyse the explanatory factors of the degree of decoupling between the GHG emissions of the MS and the economic growth of the T&C industry in the EU. The results will provide information to policy makers in order to design specific policies for this sector which contribute to further reducing GHG emissions and energy consumption in the coming decades.

The revision of the preceding literature related to the T&C industry and emissions shows firstly, that there are not many papers focusing on this issue and secondly, that most of this research analysis has been conducted in Asian regions, especially in China. The link between production in the textile industry and the consequences for the climate change has been highlighted recently by Leal Filho et al. (2022). Also, Valodka et al. (2020) have contributed to identify the main polluting countries in the European textiles and clothing trade through a Multiregional Input- Output model. The importance of fossil fuels on textile production and the potential of renewable energies and advanced technology on this industry in terms of reducing CO_2 emissions and improving energy efficiency, have been explored by Farhana et al. (2022). In relation to energy use in the textile industry, Çay (2018) shows that an energy savings potential can be identified in the textile industry, contributing to reduce energy consumption and CO_2 emissions. Additionally, Bravo and Iturralde (2022) suggest the importance of having a more efficient energy management in the textile industry to achieve important results in what regards this industry's competitiveness. Similarly, Haseeb et al. (2020) have analysed the positive link that exists between energy intensity and textile production in Asian countries, where textile manufacturing is dominant.

The research to identify the drivers of GHG or CO_2 emission changes in the T&C industry has also been conducted mostly in Asian countries. Specifically, using an additive time-series decomposition analysis approach, Lin and Moubarak (2013) and Huang et al. (2017) analyse the drivers of GHG or CO_2 emission changes in China. Additionally, following the same approach, some papers analyse the drivers of energy intensity or energy footprint in Indonesia and Shaoxing (Salamah et al., 2019; Wang et al., 2017, 2020). Finally, environmental research on the T&C industry is sometimes included in a global analysis of the manufacturing industry such as those conducted for China (Liu et al., 2019 and Zhou, 2022) and the Philippines (Ng and Lopez, 2021).

The novelty of this paper is twofold. Firstly, although improving the competitiveness and sustainability of the EU T&C industry is among the objectives to be achieved in 2030, there are no previous research papers focused on analysing the drivers and inhibitors of the past GHG emission changes in the T&C industry in the EU-27. This is a key analysis that seeks contributing to identify the most important variables that governments should focus on towards decarbonisation. The current paper covers this gap in the research literature providing this key analysis through a decomposition approach based on the Logarithmic Mean Divisia Index (LMDI). This approach provides a better comprehension of the past changes in GHG emissions in the EU27 T&C industry. Secondly, a decoupling analysis of the GHG emissions in the T&C industry within the EU-27 is provided to determine if they are decoupled from economic growth, and to establish if there is still room for improvement. This second methodological approach is considered relevant for the analysis provided that it contributes to identify if past efforts in energy efficiency gains have been counteracted by economic activity growth, reducing the effectiveness of energy policy efforts to reduce GHG emissions in the T&C industry. With these two novelties, the current paper brings important results and findings, attempting to resolve this lack of information and promote new lines of research, based on the European T&C industry.

The structure of this paper is the following. After this introduction, the second section addresses the methodology approach and database used. The discussion section examines the results and compares them with those obtained by the research literature. Lastly, the conclusions section summarises the outcomes of the analysis.

2. Data and methodology

2.1. Methodology

The methodology approach used in this paper has been twofold. Firstly, the Index Decomposition Analysis (IDA) has been applied through the Logarithmic Mean Divisia Index (LMDI) and secondly, a decoupling analysis.

The LMDI approach seeks to examine the level of influence of certain determinants in the GHG emission changes within the EU-27 T&C industry during the period from 2008 to 2018. Following the methodological considerations provided by Ang et al. (1998); Ang (2004); Ang (2005); Ang and Liu (2007) and Ang (2015), the main advantages of applying this method are an easy formulation, the results of the decomposition without unexplained residuals and the consistency in aggregation. Also, it has a homogeneous formulation and is not complicated to apply regardless of the number of factors (Ang and Zhang, 2000). The LMDI method can be divided into multiplicative and additive decompositions. The multiplicative decomposes percentage or ratio changes, whilst the additive decomposes physical quantity changes (Ang et al., 1998). Our research is conducted using the multiplicative decomposition since it allows better comparison result among EU27 MS. An additional advantage of this method compared to other decomposition approaches (such as kaya identity) is that it allows for a sectoral analysis of the variables contributing to obtain results that are relevant from a microeconomic perspective (Ang, 2015). In order to take advantage of this approach and improve its possibilities, this paper analyses GHG emissions by gas, sector and county.

The decoupling analysis is based on the LMDI approach. Therefore, when using an additive approach of LMDI, a decoupling index is obtained following the methodological proposal of Diakoulaki and Mandaraka (2007). The aim of this analysis is to examine the effectiveness of the past measures implemented to reduce GHG emissions and the degree of dissociation, that exists between economic growth and GHG emissions, within the EU-27 T&C industry, during the analysed period.

2.1.1. LMDI analysis

The total GHG emissions of the T&C industry (j) of a MS (i) of the EU-27 (GHG_{ij}) can be factorised as follows:

$$GHG_{ij} = \sum_k GHG_{ikj} = \sum_k \frac{GHG_{ikj}}{GHG_{ij}} \bullet \frac{GHG_{ij}}{E_{ij}} \bullet \frac{E_{ij}}{Q_{ij}} \bullet \frac{Q_{ij}}{Q_i} \bullet Q_i = \sum_k G \bullet C \bullet I \bullet S \bullet Y \quad (1)$$

Where GHG_{ikj} represents k GHG emission of MS i in the T&C industry (j); which are the carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFC), perfluorocarbons (PFC), nitrogen trifluoride (NF_3) and sulphur hexafluoride (SF_6) emissions. Henceforth, the subscript $k = 1, 2, 3$ will represent the following GHG emissions: $k = 1$ (carbon dioxide emissions); $k = 2$ (nitrous oxide emissions); and, $k = 3$ (methane and other emissions). Also, E_{ij} is total energy consumption of MS i in T&C industry (j); Q_{ij} is the gross value added of MS i in the T&C industry (j); and Q_i is the gross value added of MS (i).

The GHG_{ij} can be explained through five factors. The Gas weight factor *(G)* represents the importance that each k a GHG emission has on total GHG emissions of the T&C industry in a MS. The Carbonisation factor *(C)* expresses how dirty or polluting the energy uses are in the T&C industry of each MS. The Intensity factor *(I)* represents the energy consumption efficiency in the T&C industry production in each MS. The Structural factor *(S)* shows the relative weight of the T&C industry in the economy of each MS. Lastly, the Activity factor *(Y)* represents the output, production, or gross domestic product of an economy in a MS.

According to Ang (2015), the GHG_{ij} changes during one period can be decomposed, using the LMDI to assess the importance of decomposition effects on GHG emission changes in the EU-27 T&C industry. The multiplicative form of this method was chosen, given its simplicity for the analysis conducted and to make comparisons between MSs easier. According to the LMDI method, the ratio changes in the aggregate GHG emissions, during a period T, are equal to the multiplication of the effects on which it depends (*during that same period T*). These effects, the result of factor decomposition, can be expressed as follows:

$$D_{tot} = \frac{GHG_{ij}^t}{GHG_{ij}^0} = D_{gas} \bullet D_{carb} \bullet D_{int} \bullet D_{str} \bullet D_{act} \quad (2)$$

The emissions effect (D_{gas}) measures the influence that each k GHG emission has had on GHG_{ij} changes during the analysed period. This effect will allow identifying the gases that have increased and are most affecting GHG_{ij}. The carbonisation effect (D_{carb}) shows how dirty or polluting the energy uses are and how they influence GHG_{ij} changes during the analysed period. Therefore, values higher than 1 will imply that the GHG per unit of energy use has increased and therefore, also, the GHG_{ij} for the analysed period. The intensity effect (D_{int}) measures the efficiency of the T&C industry, considering the relationship between energy uses and the output. Therefore, values higher than 1 will show that energy intensity has increased, reducing energy efficiency (the contrary for values between 0 and 1) and increasing GHG_{ij}. The structure effect (D_{str}) indicates the importance of the T&C industry, that is, its weight in the total economic activity. Consequently, values higher than 1 will show that the T&C output has increased its weight on total output, pushing up the GHG_{ij} during the analysed period (the opposite for values between 0 and 1). Finally, the activity effect (D_{act}) measures the evolution of the economic activity. Thus, values higher than 1 will show that the output of the economy and possibly of the T&C industry has increased, boosting GHG_{ij} during the studied period (and the reverse for values between *0* and *1*).

According to Ang (2015), the decomposition effects following the LMDI-I version are calculated as follows:

$$D_{gas} = \exp\left(\sum_k \sum_j w_{ikj} \ln\left(\frac{G^t}{G^0}\right)\right) \quad (3)$$

$$D_{carb} = \exp\left(\sum_k \sum_j w_{ikj} \ln\left(\frac{C^t}{C^0}\right)\right) \quad (4)$$

$$D_{int} = \exp\left(\sum_k \sum_j w_{ikj} \ln\left(\frac{I^t}{I^0}\right)\right) \quad (5)$$

$$D_{str} = \exp\left(\sum_k \sum_j w_{ikj} \ln\left(\frac{S^t}{S^0}\right)\right) \quad (6)$$

$$D_{act} = \exp\left(\sum_k \sum_j w_{ikj} \ln\left(\frac{Y^t}{Y^0}\right)\right) \quad (7)$$

$$w_{ikj} = \frac{\left(GHG_{ikj}^t - GHG_{ikj}^0\right) \big/ \left(\ln GHG_{ikj}^t - \ln GHG_{ikj}^0\right)}{\left(GHG_{ij}^t - GHG_{ij}^0\right) \big/ \left(\ln GHG_{ij}^t - \ln GHG_{ij}^0\right)} \quad (8)$$

With w_{ikj} being the weighting factor of decomposition effects.

2.1.2. Decoupling index based on the LMDI approach

A decoupling index based on the LMDI approach is used to analyse to what extent the implemented environmental measures have made it possible to reduce emissions in the analysed industry and to decouple them from economic growth.

Following the proposal of previous research literature on this topic (Diakoulaki and Mandaraka, 2007; Zhang and Da, 2015; Roinioti and Koroneos, 2017; Román-Collado et al., 2018; Román-Collado and Colinet, 2021), the activity effect was suppressed in order to evaluate to what extent the change in GHG emissions was due to alternative reasons, linked to the effects of the other determinants used in the LMDI decomposition. Using an additive LMDI-I decomposition analysis, the decoupling index will show the determinant effects (excluding the activity effect) which explain the degree of dissociation, between economic growth and GHG emissions, from a base year *0* to a year *t*.

In this paper an analysis of the GHG emissions decoupling process of the EU-27 T&C industry, during the period from 2008 to 2018 is conducted. With this aim, the change in GHG emissions between period 0 and t is decomposed following the additive LMDI-I analysis, according to Ang (2015), and using previous factorisation in equation (1):

$$\Delta GHG_{ij} = GHG_{ij}^{t} - GHG_{ij}^{0} = \Delta GHG_{gas} + \Delta GHG_{carb} + \Delta GHG_{int} + \Delta GHG_{str} + \Delta GHG_{act} \tag{9}$$

The formula for the decomposition effects of the additive LMDI-I analysis is shown in Annex A. Based on the seminal papers of Diakoulaki and Mandaraka (2007) and Jiang et al. (2016), reordering equation (9), the effect of mitigation measures ($\Delta GHGE^{T}$) for period T (t-0) is defined as follows:

$$\Delta GHGE^{T} = \Delta GHG_{ij}^{T} - \Delta GHG_{act} = \Delta GHG_{gas} + \Delta GHG_{carb} + \Delta GHG_{int} + \Delta GHG_{str} \tag{10}$$

The effect of mitigation measures ($\Delta GHGE^{T}$) shows the changes in GHG emissions attributed to emission, carbonisation, structure and intensity effects, excluding the activity effect. This mitigation effect will be useful to summarise the effects that the mitigation measures, taken in the MSs of the EU-27 T&C industry, have had on the change in GHG emissions in the analysed period. If ($\Delta GHGE^{T}$) is negative, it means that the sum of the emission, carbonisation, intensity and structure effects is negative, and consequently, the environmental measures have been effective. On the contrary, if ($\Delta GHGE^{T}$) is positive, this means that the sum of the emission, carbonisation, intensity and structure effects is positive, and consequently, the environmental measures have not been effective.

According to Diakoulaki and Mandaraka (2007) and Jiang et al. (2016), with the aim of evaluating the degree to which the efforts mentioned above are effective, in terms of decoupling economic growth from changes in GHG emissions, a decoupling index (μ_t) is calculated. The decoupling index (μ_t) is determined as follows, depending on the values of (ΔGHG_{act}). If the activity effect is positive or equal to zero ($\Delta GHG_{act} \geq 0$), eq. (11) must be used.

$$\mu_t = -\frac{\Delta GHGE^{T}}{\Delta GHG_{act}} = -\left(\frac{\Delta GHG_{ij}^{T}}{\Delta GHG_{act}} - \frac{\Delta GHG_{act}}{\Delta GHG_{act}}\right) = -\left(\frac{\Delta GHG_{gas}}{\Delta GHG_{act}} + \frac{\Delta GHG_{carb}}{\Delta GHG_{act}} + \frac{\Delta GHG_{int}}{\Delta GHG_{act}} + \frac{\Delta GHG_{str}}{\Delta GHG_{act}}\right) = \mu_{gas} + \mu_{carb} + \mu_{int} + \mu_{str} \tag{11}$$

Additionally, if the activity effect is negative ($\Delta GHG_{act} < 0$), Román-Collado and Colinet (2021) suggest using eq. (12), which is different from that proposed by Jiang et al. (2016).

Table 1
Measurement units of the datasets.

Dataset	Measurement unit
Emissions (*greenhouse gases, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, nitrogen trifluoride and sulphur hexafluoride*)	Thousand tonnes of CO_2 equivalent
Energy consumption (*total energy consumption and energy consumption of the textile and clothing industry*)	Thousand tonnes of oil equivalent (TOE)
Production (*total gross value added and gross value added for the textile and clothing industry*)	Constant 2015 prices

Source: compiled by author

$$\mu_t = \frac{\Delta GHGE^{T}}{\Delta GHG_{act}} = \frac{\Delta GHG_{ij}^{T}}{\Delta GHG_{act}} - \frac{\Delta GHG_{act}}{\Delta GHG_{act}} = \frac{\Delta GHG_{gas}}{\Delta GHG_{act}} + \frac{\Delta GHG_{carb}}{\Delta GHG_{act}} + \frac{\Delta GHG_{int}}{\Delta GHG_{act}} + \frac{\Delta GHG_{str}}{\Delta GHG_{act}} = \mu_{gas} + \mu_{carb} + \mu_{int} + \mu_{str} \tag{12}$$

Moreover, these equations allow to obtain the decoupling indices resulting from the different effects: μ_{gas} (emission decoupling index), μ_{carb} (carbonisation decoupling index), μ_{int} (intensity decoupling index) and μ_{str} (structure decoupling index).

In line with Diakoulaki and Mandaraka (2007), the values of decoupling indices can be understood as follows. The decoupling index will have positive values when environmental policy efforts have been effective. If the decoupling index is ($\mu_t \geq 1$), it denotes strong decoupling efforts, and if it is between ($0 < \mu_t < 1$), it denotes weak decoupling efforts. Lastly, the decoupling index will have negative values when environmental policy efforts have not been effective.

2.2. Data

This paper is based on the Eurostat Database. The data selected are annual and cover the period from 2008 to 2018 for the MSs of the EU-27, which are: Belgium, Bulgaria, the Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland and Sweden.

The quality of the data was ensured since it was obtained from the same database and was generated using the same statistical standards that are being continuously implemented by the European Statistical System (ESS) (Eurostat, 2021). Moreover, Eurostat has 84 indicators to measure 16 principles that each set of data must comply with (Eurostat and ESS, 2018), so the relevance of the database can be considered high.

However, a data limitation was found while conducting the analysis because not all the MSs had GHG emissions data before 2008 (Eurostat, 2020a). In addition, in the case of Malta, the energy consumption data of the T&C industry has been slightly modified, due to a lack of these data, so for 2009 an interpolation was made, and for 2008 the “Last Observation Carried Forward” (LOCF) was used.

According to the European Classification of Economic Activities (NACE - 2) (Eurostat, 2008), the T&C industry is formed by three large divisions: “Manufacture of textiles” (C13), “Manufacture of wearing apparel” (C14) and “Manufacture of leather and related products” (C15). These divisions can be desegregated into a large number of activities, ranging from the preparation and spinning of textile fibres to the manufacture of footwear. It is important to point out that this paper, and the datasets selected, are based on this definition of the industry, which ensures the quality of the analysis and its results.

The data used was on emissions, production and energy consumption. The different units of measurement of the data are displayed below in Table 1. In general, the data was collected and used, except for production datasets which were processed to be obtained at constant prices. This was done through the Harmonised Index of Consumer Prices (HICP), which is another dataset from the Eurostat database. The calculation of Gross Value Added (GVA) used the general HICP, while the calculation of T&C production used a specific HICP that only considers prices of clothing, footwear, and household textiles (Eurostat, 2020c).

The energy consumption datasets were grouped together into four classifications, these being: fossil energy sources, nuclear energy sources, renewable energy sources and other energy sources (including peat, peat products and non-renewable waste energy). The electricity and heat energies were also added to the groups, in relation to the energy source they came from (Eurostat, 2020b, 2020d, 2020e).

3. Results and discussion

3.1. Decomposition analysis of GHG emissions within the EU-27 T&C industry

The decomposition analysis provides the level of influence of the determinants on changes in GHG emissions for the EU-27 T&C industry, from 2008 to 2018.

During this period, the EU-27 T&C industry became cleaner. The GHG emissions decreased by 34%, going down from 11,252.76 in 2008 to 7391.12 thousand tonnes of CO_2 equivalent in 2018 (Eurostat, 2020b). As can be seen in Fig. 1 and in Table B1 of Annex B, the global change of GHG emissions in the T&C industry was driven by the activity effect, while the carbonisation, intensity and structure effects were inhibitors. Finally, the emissions effect does not have an impact on that change.

The emissions effect, which represents the changes in the relative weight of pollutants, had values close to one in each year (see Fig. 1), indicating that there was neither transformation for the better, nor for the worse, in relation to the pollution caused by GHG emissions in the T&C industry.

The intensity effect, which represents the change in energy consumption in relation to the industrial output, was the major inhibitor. As can be observed in Fig. 1, in total, it accounts for 27% of the reduction, indicating that the industry has reduced its energy intensity, and therefore increased its efficiency.

The structure effect, which represents the change in the relative weight of the T&C industry, was the second inhibitor. As can be observed in Fig. 1, in total, it accounts for 10% of the reduction, which indicates that the relative weight of the industry on total output of the EU has decreased.

The carbonisation effect, which represents the changes in pollution generated by energy consumption, was the third inhibitor. As can be observed in Fig. 1, in total, it accounts for 6% of the reduction, which means that the energy uses in the industry have become cleaner. The data shows that the electricity and heat energy produced by renewable sources have increased, in comparison to those produced by fossil or nuclear sources, which have decreased during the analysed period (Table B2 of Annex B).

Finally, the activity effect, which represents the changes in the economic activity, was a driver of the change in GHG emissions, especially in the latter years of the period. As can be observed in Fig. 1, in total, it accounts for 6% of the increase, which seems to indicate that there has been a positive economic growth within the EU-27 economy.

Fig. 2 shows an analysis of the inter-annual change. Periods of strong growth in emissions can be observed, mainly caused by the carbonisation effect, such as those occurred during 2012–2013 and 2014–2015. The activity effect, as can be seen, begins to increase emissions from the 2013–2014 sub-period onwards, coinciding with the economic recovery. In general, the intensity effect has not driven the change in emissions, showing a continuous improvement in energy efficiency and consumption in the EU-27 T&C industry, during the analysed period. Finally, the structure effect begins to decrease emissions continuously in the latter sub-periods, showing a loss of its weight in the industry.

Two sub-periods can be observed in Fig. 2. In the first one, from 2008 to 2012, the GHG emissions diminished coinciding with the economic activity recovery after the 2008 crisis. In the second one, from 2013 to 2018, the GHG emissions increased in 2013–2014 and then showed a lower growth than that of the previous period and remained so until 2018.

3.2. Decomposition analysis of the GHG emissions in the EU-27 T&C industry

The results of the decomposition analysis of GHG emissions, within the EU-27 T&C industry from 2008 to 2018, can be examined in greater detail through the effects from a perspective based on the EU-27 MSs. During this period, the GHG emissions in the T&C industry of most MSs decreased. These only increased in Ireland, Lithuania, Luxembourg, Hungary, Malta, Romania and Finland (Eurostat, 2020b).

The emissions effect, as can be observed in Table B3 of Annex B, has not been a clear driver or inhibitor of GHG emissions in the T&C industry for most MSs. The emissions effect has only been an inhibitor in Estonia, accounting for in total 3.58% of the reduction, and indicating a transformation of the pollution of GHG emissions for the better.

Although, on average, the carbonisation effect is an inhibitor, as can be seen in Table B4 of Annex B, it has been an important driver of GHG emissions within the T&C industry for more than a half of the MSs. Some of these MSs and the total increase that has had this effect on them, during the period, are as follows: Belgium (17%), Germany (16%), Croatia (48%), Luxembourg (68%), Malta (233%), Austria (42%), Romania (77%) and Finland (136%).

The intensity effect, as can be seen in Table B5 of Annex B, has been an important inhibitor of GHG emissions in the T&C industry for most MSs, such as Bulgaria (43%), Denmark (39%) and Italy (29%). However, there are some MSs on whom the intensity effect has acted as a driver, with Belgium (13%), Ireland (164%), Greece (35%), Hungary (97%) and Malta (46%), showing an increase in energy intensity and in GHG emissions.

The structure effect, as can be seen in Table B6 of Annex B, has only been a driver of GHG emissions in a few MSs. These, and the total increase that the effect has had on them, are as follows: Spain (2%), Croatia (3%), Italy (1%), Latvia (8%), Lithuania (18%), Luxembourg (21%), Poland (8%), Portugal (51%) and Slovakia (7%). In these MSs, the T&C industry has increased its weight in the economy's total output during the analysed period, which has resulted in an increase in GHG emissions.

Between 2008 and 2013, the activity effect, as observed in Table B7

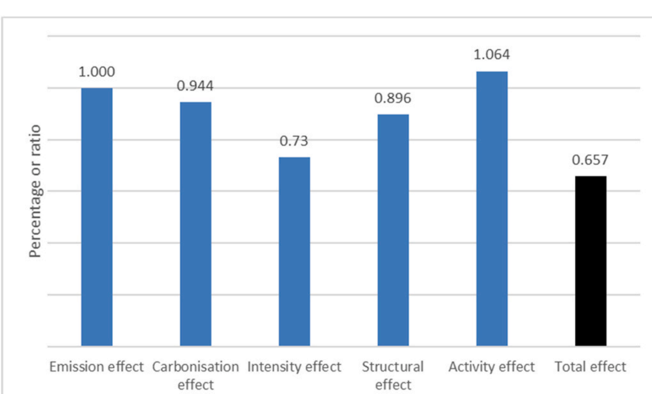

Fig. 1. Total decomposition of the change in GHG emissions for the EU-27 T&C industry from 2008 to 2018.
Source: *Own elaboration*

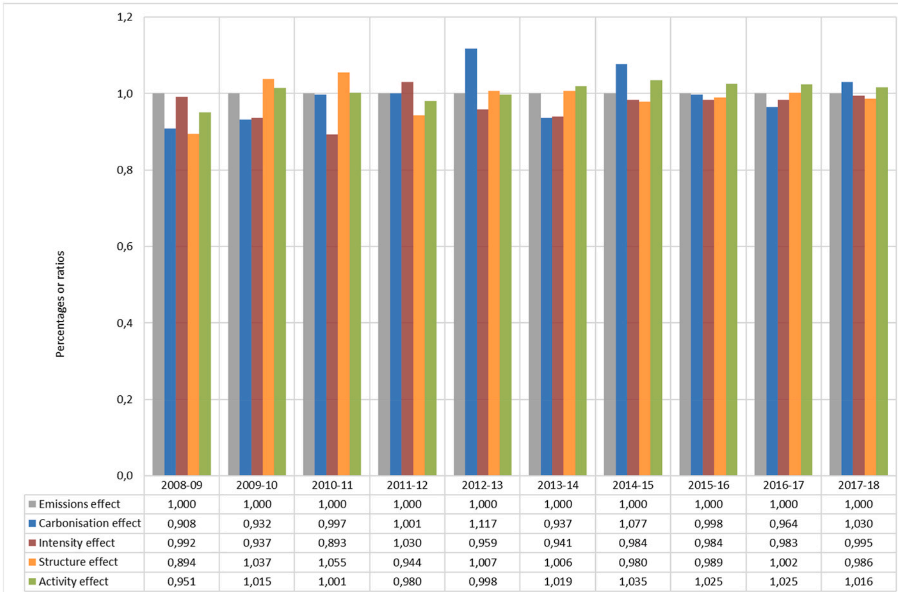

Fig. 2. Decomposition of change in GHG emissions in the EU-27 T&C industry during the period from 2008 to 2018.
Source: *Own elaboration*

of Annex B, has rarely been an inhibitor, particularly at the beginning of the 2008 financial crisis. From 2013 onwards, in general, the economy of MSs progressed considerably, coinciding with a recovery from the financial crisis. Focusing on the MSs on which the activity effect has been an inhibitor, during the analysed period, these, and the total reduction produced, are as follows: Greece (33%), Spain (5%), Croatia (8%), Italy (5%), Latvia (1%) and Hungary (4%).

3.3. Decomposition analysis of the GHG emissions for the EU-27 T&C industry based on the decoupling level of Member States

The decoupling analysis provides information related to whether it has been possible to disassociate the GHG emissions in the T&C industry from economic growth for the EU-27 during the period 2008 to 2018. In relation to this, Table 2 displays the decoupling index (μ_t), the decoupling indices of the effects ($\mu_{gas}, \mu_{carb}, \mu_{int}, \mu_{str}$) and the decoupling state (strong, weak or no decoupling) of each EU-27 MS, during the analysed period.

An important aspect to note is that circa 74% of MSs have been able

Table 2
Decoupling indices of T&C industry per EU-27 MS from 2008 to 2018.

Member State	μ_{gas}	μ_{carb}	μ_{int}	μ_{str}	μ_t	Decoupling state
Belgium	0.000	−1.702	−1.541	5.971	2.728	Strong decoupling
Bulgaria	0.001	0.453	2.274	0.368	3.096	Strong decoupling
Czech Republic	0.000	13.582	8.741	3.572	25.895	Strong decoupling
Denmark	0.005	3.578	4.583	3.864	12.031	Strong decoupling
Germany	0.000	−1.053	1.614	1.420	1.982	Strong decoupling
Estonia	0.242	0.125	7.624	3.076	11.066	Strong decoupling
Ireland	0.000	0.607	−1.326	0.649	−0.070	No decoupling
Greece	0.005	−0.989	0.920	1.177	1.113	Strong decoupling
Spain	0.010	0.206	5.645	−0.519	5.342	Strong decoupling
France	0.001	0.846	2.673	8.968	12.488	Strong decoupling
Croatia	−0.065	−5.080	4.683	−0.325	−0.787	No decoupling
Italy	0.004	5.282	5.173	0.798	11.258	Strong decoupling
Cyprus	0.013	6.959	−1.704	18.053	23.330	Strong decoupling
Latvia	−0.002	−2.200	12.864	−0.383	10.279	Strong decoupling
Lithuania	0.000	−0.752	1.729	−1.042	−0.065	No decoupling
Luxembourg	0.000	−1.841	2.530	−0.942	−0.254	No decoupling
Hungary	−0.004	6.098	−11.981	1.297	−4.591	No decoupling
Malta	−0.001	−1.948	−0.805	2.432	−0.323	No decoupling
Netherlands	0.000	−1.083	9.209	1.882	10.008	Strong decoupling
Austria	0.001	−3.791	1.698	4.454	2.362	Strong decoupling
Poland	0.001	3.065	5.650	−0.602	8.115	Strong decoupling
Portugal	0.312	172.744	3196.917	−1803.994	1565.979	Strong decoupling
Romania	0.004	−5.478	3.455	2.573	0.554	Weak decoupling
Slovenia	0.005	−49.197	147.207	55.270	153.285	Strong decoupling
Slovakia	0.000	−2.211	4.797	−0.620	1.967	Strong decoupling
Finland	−0.001	−44.282	19.021	18.572	−6.690	No decoupling
Sweden	0.000	1.089	2.815	1.698	5.602	Strong decoupling

Source: Own elaboration

to decouple, to a greater or lesser extent, the GHG emissions in the T&C industry from economic growth, within the analysed period. However, MSs such as Ireland, Croatia, Lithuania, Luxembourg, Hungary, Malta and Finland, have not been able to achieve such decoupling. On the other hand, circa 77% of MSs have seen a strong economic growth during the analysed period, allowing a large number of MSs to decoupling the GHG emissions in the T&C industry from intense economic growth.

The results for the decoupling indices involved in the decoupling process show that the carbonisation decoupling index mainly contributed to reducing the total decoupling index, which was negative in 14 out of 27 MSs. This was counteracted by the intensity and structure decoupling indices that acted positively, increasing the total decoupling index in 21 out of 27 and 16 out of 27 MSs, respectively. These results show the importance of the energy intensity index in the decoupling process of the EU-27 T&C industry.

In Fig. 3, the MSs have been organised into three groups, in relation to their decoupling index (μ_t) values, from 2008 to 2018 (Table 2). Following the proposed interpretation of this index by Diakoulaki and Mandaraka (2007), Fig. 3 shows the groups of MSs with strong decoupling in green (*decoupling index higher than one*), MSs with weak decoupling in yellow (*decoupling index between zero and one*), and MSs without decoupling in red (*decoupling index less than zero*).

The group of EU-27 MSs with strong decoupling (in green in Fig. 3 and Table B8 of Annex B) reduced the GHG emissions of the T&C industry by circa 36% from 2008 to 2018. The analysis of the decomposition results shows that the intensity, structure and carbonisation effects of this group of countries have acted as inhibitors, while only the activity effect acted as a driver.

Regarding the inhibitors, the intensity has been the major effect, accounting for, in total, 28% of the reduction in GHG emissions during the period. The structure effect was the second, accounting for, in total, 9% of the reduction. The carbonisation effect was the third, accounting for, in total, circa 8% of the reduction. Conversely, the activity effect, the only driver, was the determinant of change with a lower impact on GHG emissions, accounting for, in total, circa 6% of the increase during the analysed period.

Only Romania has been identified from the EU-27 MSs with weak decoupling (in yellow in Fig. 2 and Table B8 of Annex B), and has increased the GHG emissions of the T&C industry by circa 4%, during the period. In this case, the intensity and structure effects acted as inhibitors, while the carbonisation and activity effects acted as drivers.

Regarding the inhibitors, the intensity was the major effect, accounting for, in total, 35% of the reduction in GHG emissions. The structure effect was the second, accounting for, in total, 14% of the reduction. On the other hand, the carbonisation effect was the main driver, accounting for, in total, 77% of the increase during the period, and the activity effect was the second driver, accounting for, in total, circa 6% of the increase.

The group of EU-27 MSs without decoupling (in white in Fig. 2 and Table B8 of Annex B), increased the GHG emissions of the T&C industry by circa 37% during the period. Like in the previous group, the intensity and structure effects functioned as inhibitors while the carbonisation and activity effects acted as drivers. However, now, regarding the inhibitors, the structure effect was the greatest, accounting for, in total, 20% of the reduction in GHG emissions during the period, and the intensity effect was second, accounting for only 1% of the reduction. Conversely, the carbonisation effect has been the greatest driver, accounting for, in total, 38% of the increase, and the activity effect followed, accounting for, in total, around 26% of the increase.

3.4. Discussion

The EU-27 T&C industry has reduced its GHG emissions by 34%, during the period from 2008 to 2018. The energy intensity, carbonisation and structural effects were the inhibition factors of this change, only offset by the activity effect. The emissions effect was not decisive in the GHG emissions in the EU-27 T&C industry, as its values have generally been close to one throughout the analysed period.

The slowdown in GHG emissions has been particularity noticeable since the year 2012–2013, which coincides with the implementation of Directive (2012)/27/EU on energy efficiency, and Directive

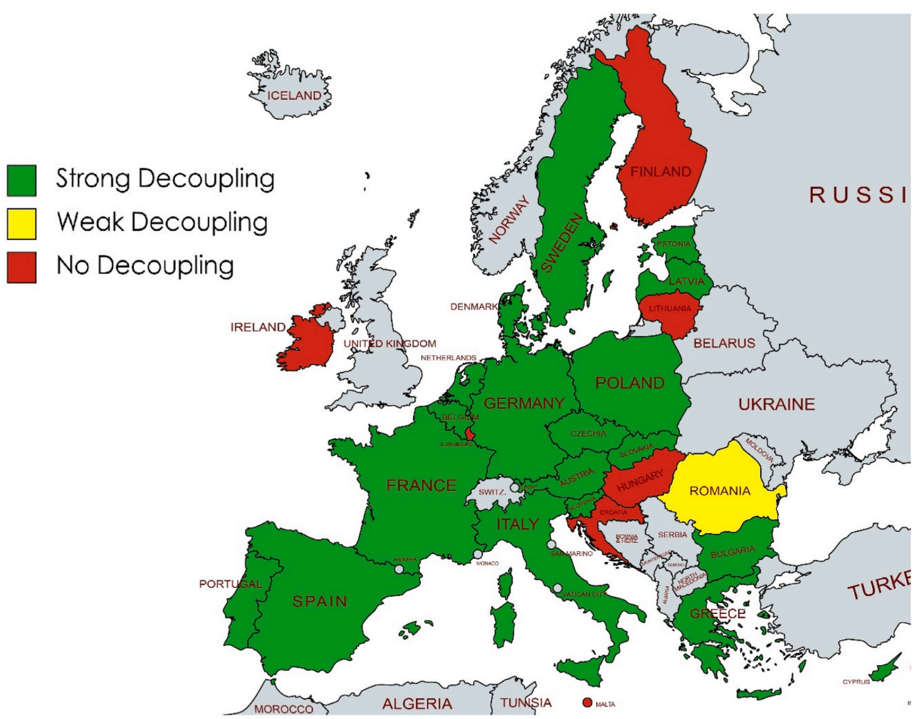

Fig. 3. Map of the EU-27 MSs by group based on decoupling indices from 2008 to 2018.
Source: *Own elaboration*

2010/75/EU on industrial emissions. These directives have been focused on reducing energy consumption and GHG emissions, and therefore have been key to achieve energy efficiency improvements (EC, 2015; EC, 2017a; EC, 2017b; EC, 2019; EC; 2020; EC, 2022b). The improvement of the energy efficiency measured through the analysis of the intensity effect has largely contributed to this reduction. In fact, our findings show that the intensity effect is the main inhibitor of GHG emissions, consistent with preceding literature, such as Lin and Moubarak (2013), Huang et al. (2017), Wang et al. (2017), Liu et al. (2019), Wang et al. (2020), and Ng and Lopez (2021). During the analysed period, the EU enforced several policies and regulations within the T&C industry, aimed at optimising energy consumption, reducing GHG emissions and improving energy efficiency (EC, 2003; EPC, 2008; Directive, 2010/75/EU, 2010; Directive, 2012/27/EU, 2012). Some of these policies seem to have met their objectives (EC, 2015; EC, 2017a; EC, 2017b; EC, 2019; EC; 2020; EC, 2022b), and therefore appear to have been key to achieving these results in the intensity effect. Specifically, Kocabas et al. (2009) investigated the impact of Integrated Pollution Prevention and Control (IPPC)/Best Available Techniques (BAT) policy (EC, 2003; Roth et al., 2023) in a large-scale textile mill, and concluded that these were essential to reducing energy consumption. Voluntary policies have also been implemented within the European T&C industry during the analysed period such as Ecolabel, which implied the reduction of water and air pollution (EC, 2022c), or the European Clothing Action Plan (ECAP), which attempted to implant a circular economy model in the industry (Textile exchange, 2016; WRAP, 2017a; WRAP, 2017b).

Additionally, the diminishing GHG emissions throughout the analysed period were accompanied by an important change in energy sources (Table B2 of Annex B). In fact, fewer energy sources have been used in the EU-27 T&C industry, but there was also a change towards cleaner energy uses. Specifically, all fossil fuels reduced their relative weight in the total energy use of the EU-27 T&C industry between 2008 and 2018 (from 83% to 76%), while renewable energy sources, particularly renewable electricity and heat, notably increased their relative weight in total energy use (9%–16%). This result explains why the carbonisation effect is also an important inhibitor of changes in GHG emissions in the T&C industry in the period 2008–2018 (although for some MSs it acts as a driver). The results of the carbonisation effect are in line with preceding scientific literature which highlights the importance of improving energy sources, in relation to achieving sustainable development in the industry (Lin and Moubarak, 2013; Huang et al., 2017; Wang et al., 2020).

The structure effect is the second inhibitor of GHG emissions, and its results are in line with Wang et al. (2017), who analyse energy consumption via the energy footprint in China's T&C industry, from 1991 to 2015. Between 2008 and 2018, the T&C industry's weight loss in total output within the EU-27 (4%) contributed to a decrease of GHG emissions. The economic recession might explain the important result for the structural effect in the period 2008/2009 and 2011/2012, which diminished GHG emissions by approximately 11% and 6%, respectively. Also, the specialised literature (Dima, 2015; Liu et al., 2017; Tian et al., 2017; Valodka and Snieska, 2020; Valodka et al., 2020; Zhao et al., 2021) pointed out the phenomena of the outsourcing process that might emerge among the European T&C companies which seek low energy costs, scarce environmental standards (Valodka et al., 2020), and a cheap labour force (EP, 2019), especially the most labour-intensive (Stengg, 2001) and energy-intensive (Christis et al., 2019). However, the results obtained do not allow us to clearly identify this phenomena, considering the magnitude of the change in the relative weight of the T&C industry in the total economy, and GHG emissions within the EU-27, between 2008 and 2018.

The emissions effect shows that the relative importance that each pollutant (CO_2, N_2O, CH_4 and other emissions) has remained almost constant throughout the analysed period in the total GHG emissions in Europe. However, the change in the relative weight of pollutants (CO_2, N_2O, CH_4 and other emissions) on total GHG emissions in certain countries, between 2008 and 2018, allows us to conclude some important results. Some countries such as Belgium, Bulgaria, Croatia, Cyprus, Estonia, France, Italy, Malta, Romania and Sweden have reduced the relative weight of CO_2 emissions in total GHG emissions, while only few (Greece, Hungary, Poland and Spain) have increased them. Additionally, the countries that reduced the relative weight of N_2O emissions in total GHG emissions were the Czech Republic, Denmark, Finland, Greece, Hungary, Ireland, Latvia, Poland, Slovenia, Slovakia and Spain, while the rest of the European countries increased these emissions. Finally, it should be highlighted that Austria, the Czech Republic, Germany, Ireland, Cyprus, Lithuania, Hungary, Malta and Romania reduced the relative weight of CH_4 emissions in total GHG emissions throughout the analysed period, while the rest of the European countries increased them. The comparison of these results shows that countries reduced, or mostly did not increase, the relative weight of CO_2 emissions in total GHG emissions between 2008 and 2018. However, the other two main contaminants, CH_4 and N_2O emissions, have increased their importance in total GHG emissions of most European countries (14 and 18 out of 27 countries, respectively). This analysis by pollutant has not been previously analysed by the research literature on the T&C industry, although some specific literature analyses aggregate GHG emissions by converting them into carbon dioxide equivalents (Xu et al., 2014). Thus, this analysis is recommended in order to identify, not only the change in the GHG emissions, but also the trend experienced by the components of GHG emissions in each country.

The activity effect is the main driver of GHG emissions during the analysed period, 2008–2018. Although the economic recession caused lower GHG emissions through the activity effect in 2008–2009 and 2011–2012 (5% and 2%, respectively) (see Table B1), the total balance for the period shows higher GHG emissions driven by the economic activity within the EU-27. These results have been similarly studied in the preceding scientific literature, so the results are in line with Lin and Moubarak (2013), Huang et al. (2017), Wang et al. (2017), Liu et al. (2019) and Wang et al. (2020). Also, Jeong and Kim (2013), Tian et al. (2013), Lin and Zhang (2016) and Talei et al. (2020), pointed out that the activity effect has an important influence on GHG emissions, becoming a driver during expansion periods.

The decoupling analysis contributes to evaluate the effectiveness of the efforts conducted and measured by the emission, carbonisation, intensity and structural effects, in order to decouple the economic growth from changes in GHG emissions during the analysed period. The decoupling analysis has shown that most EU MSs have been decoupling the GHG emissions of the T&C industry from economic growth during the analysed period, with the carbonisation effect being a key explanatory factor. The results show that besides the improvement in energy efficiency, the countries that have worked towards the use of cleaner energy sources and have reduced fossil fuel sources in the T&C industry, show strong decoupling processes.

Besides carbonisation, the main factor that has favoured the decoupling process in the T&C industry was the improvement in energy efficiency that reduced the GHG emissions, and therefore decoupled them from economic growth. These energy efficiency improvements have been promoted through certain European policies during the analysed period (EC, 2015; EC, 2017a; EC, 2017b; EC, 2019; EC; 2020), thus contributing to this result. The importance of energy efficiency measures for the decoupling process was also shown by Wang et al. (2017) who investigated the decoupling process of China's T&C industry from 1991 to 2015, and who also observed the influence of China's energy policies on the decoupling process.

This paper contributes to the theory of decarbonisation of the EU T&C industry. By using a global approach, conducted through a decomposition method (LMDI), this paper seeks to identify the driving and inhibition factors that explain the changes in GHG emissions produced in the EU T&C industry between 2008 and 2018. The first contribution to the literature relates to the geographical area of our research, the EU T&C industry, where, to our knowledge, no previous analyses have been conducted with this global approach. Our analysis addresses this gap.

Our findings using the LMDI approach are in line with the previous analysis for China which show that the activity effect continues to be the main driver of GHG emissions, which is offset by the other analysed effects that acted as inhibitors, thus contributing to an ultimate reduction in GHG emissions in the EU T&C industry between 2008 and 2018. Compared to previous research papers, our first contribution to the theory is the use of new variables in the decomposition analysis. Specifically, the structure effect is new and key because it helps to analyse to what extent there has been a change in the economic contribution of the EU T&C industry to total EU production between 2008 and 2018 and, consequently, a change in their GHG emissions.

Complementary to the previous one, another contribution of this analysis is related to the second methodology applied. The decoupling analysis helps to show that most EU MS have been able to decouple GHG emissions from the T&C industry from economic growth. This result should be highlighted because improvements in energy efficiency and optimisation of the energy structure are among the explanatory factors. But there is an additional conclusion that must be considered. Part of the GHG emission reductions have been explained through the lower economic weight of the T&C industry in total production in the EU. This result implies that the gross added value of this industry has decreased in the last decades in the EU, either due to a relocation of this industry to other countries (less demanding environmental regulations or lower production costs) or due to the economic crisis of 2008. Both reasons contribute to the decarbonisation of the EU T&C industry, although the implications are not the same.

Countries that have decoupled GHG emissions from economic activity are in a better condition to face the path to decarbonisation than those that have not. However, some differences emerge among these countries. Countries that have decoupled T&C industry GHG emissions from economic growth through efforts made in terms of energy efficiency improvements and cleaner energy use (instead of just relying on less weight of the T&C industry in total production) contribute to reducing T&C industry GHG emissions in the long term.

4. Conclusions

The GHG emissions of the EU-27 T&C industry diminished by 34% during the period 2008–2018, contributing to its decarbonisation. It should be borne in mind that the GHG emissions in the T&C industry in 2008 had achieved an important level after the expansion period. Since then, the interannual change of GHG emissions in the T&C industry shows that there was a reduction between 2008 and 2012, followed by sub-periods of increase and decrease. The decomposition analysis conducted has allowed us to identify the most important factors which explain such changes in GHG emissions in the EU-27 T&C industry throughout the period 2008–2018.

Firstly, the decomposition analysis shows the importance of improvements in energy efficiency on this process. Energy efficiency, measured with the energy intensity effect, contributed to reducing GHG emissions by 27%, showing that most MSs have improved the efficiency of the T&C industry during the period under review. In this regard, the policies enforced by the EU have had a key impact on these results. Specifically, the implementation of certain policies such as Directive 2010/75/EU and Directive 2012/27/EU, aimed at reducing GHG emissions and improving energy efficiency, respectively, should be underlined.

Secondly, the data show that the energy use of the EU-27 T&C industry has changed throughout the analysed period, reducing fossil fuels sources, such as solid fuels, natural gas and oil, and increasing renewable energies. This result has been evidenced through the carbonisation effect that shows a reduction of GHG emissions (6%) throughout the analysed period, thanks to the efforts made by the T&C industry towards a cleaner energy use per production unit. However, this change has not been similar for all MSs, only 14 out of 27 MSs contributed to emissions reduction through the carbonisation effect.

Thirdly, the T&C industry has reduced its relative weight in total output within the EU-27 during the period 2008–2018. This result explained diminishing GHG emissions (approximately 10%) through the structural effect. The declining importance of the T&C industry should be further analysed to identify changes in the output of European companies that lead to lower gross value added of the manufactured process, carried out in Europe. Additionally, the outsourcing strategies should be considered. To conclude, the activity effect is a driver of GHG emissions (increased by 6%) in the T&C industry, which shows similar results for most MSs during the analysed period.

Finally, the decoupling analysis allows us to conclude that most MSs within the EU-27 have achieved decoupling processes during the period under review. The decoupling intensity and structure indices are the key factors in this process. Consequently, energy efficiency improvements and the weight loss of the T&C industry have contributed to decoupling GHG emissions from economic growth. However, MSs such as Italy, Poland, Portugal and Spain should be highlighted, as they show a higher relative weight of the T&C industry and cleaner energy use, achieving strong decoupling.

The results lead us to provide our main recommendation to reduce GHG emissions from the EU-27 T&C industry considering its past behaviour. If further reductions in GHG emissions are to be achieved, energy efficiency must be improved, and the use of polluting energy sources must be reduced. In this way, the reduction of GHG emissions in the T&C industry due to the effects of intensity and carbonisation analysed with our decomposition approach, would help to offset the possible increase in emissions that this industry could have due to a relative increase in its gross value added in the economy in the near future.

Some of the challenges to be faced by the EU-27 T&C industry should be noted. First, the conversion to renewable energy must continue, as it is closely related to achieving a carbon neutral industry. Secondly, policies that promote the energy efficiency gains of the T&C industry must continue to be implemented, as has been done up to now. Thirdly, policies must be developed to favour the improvement of the added value generated by the T&C industry in Europe, with the aim of consolidating it as a strategic sector. Fourth, the effectiveness of national policies in terms of reducing emissions per unit produced is quite different between countries, which suggests the importance of designing the right mix of environmental and energy policies, aimed at reducing GHG emissions and increasing energy efficiency.

A future analysis of the carbon footprint of the T&C industry in the EU-27 and of the traceability of the added value of its economic activity through an input-output analysis would help to better understand the lower weight of this industry in Europe over the last decade.

Credit author statement

R. Román-Collado: Conceptualization, Methodology, Project administration, Writing- Reviewing and Editing. M.T. Sanz-Díaz: Data curation, Supervision, Visualization. L. Yamuza: Formal analysis, Investigation, Writing- Original draft preparation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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ANNEX A

$$\Delta GHG_{gas} = \sum_k \sum_j w_{ikj} \ln\left(G^t / G^0\right) \tag{A.1}$$

$$\Delta GHG_{carb} = \sum_k \sum_j w_{ikj} \ln\left(C^t / C^0\right) \tag{A.2}$$

$$\Delta GHG_{int} = \sum_k \sum_j w_{ikj} \ln\left(I^t / I^0\right) \tag{A.3}$$

$$\Delta GHG_{str} = \sum_k \sum_j w_{ikj} \ln\left(S^t / S^0\right) \tag{A.4}$$

$$\Delta GHG_{act} = \sum_k \sum_j w_{ikj} \ln\left(Y^t / Y^0\right) \tag{A.5}$$

$$w_{ikj} = \frac{GHG_{ikj}^t - GHG_{ikj}^0}{\ln GHG_{ikj}^t - \ln GHG_{ikj}^0} \tag{A.6}$$

ANNEX B

Table B1
LMDI-I effects of GHG emission changes within the EU-27 T&C industry from 2008 to 2018.

Geographical region	Effects	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
EU-27	Emissions	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Carbonisation	0.908	0.932	0.997	1.001	1.117	0.937	1.077	0.998	0.964	1.030	0.944
	Intensity	0.992	0.937	0.893	1.030	0.959	0.941	0.984	0.984	0.983	0.995	0.730
	Structure	0.894	1.037	1.055	0.944	1.007	1.006	0.980	0.989	1.002	0.986	0.896
	Activity	0.951	1.015	1.001	0.980	0.998	1.019	1.035	1.025	1.025	1.016	1.064
	Total	0.765	0.920	0.940	0.953	1.077	0.903	1.074	0.996	0.974	1.027	0.657

Table B2
Energy consumption in thousand tons of oil equivalent by energy group and energy sources in the EU T&C industry from 2008 to . 2018.

Group of energy source	Energy source	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Fossil energy sources	Solid fossil fuels	74.10	41.43	38.25	27.05	21.68	24.50	21.86	21.68	20.53	17.23	30.53
	Manufactured gases	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Oil shale and sands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Natural gas	2217.58	2002.88	1903.01	1858.43	1800.95	1820.51	1741.56	1706.46	1761.61	1844.97	1761.68
	Oil and petroleum products	612.74	478.42	403.02	294.08	284.68	219.95	206.26	211.20	211.11	178.55	167.90
	Fossil electricity	1303.76	1007.89	999.65	963.98	871.31	765.49	700.97	751.97	727.56	753.01	750.91
	Fossil heat	211.18	152.34	205.77	187.35	203.85	138.58	133.32	153.84	124.52	122.85	125.32
	Total	4419.35	3682.95	3549.70	3330.89	3182.46	2969.02	2803.98	2845.15	2845.34	2916.60	2836.34
Nuclear energy sources	Nuclear electricity	401.41	330.63	316.91	303.15	293.71	287.13	283.06	263.73	267.26	261.01	250.25
	Nuclear heat	0.61	0.51	0.41	0.40	0.29	0.22	0.21	0.23	0.28	0.30	0.40
	Total	402.03	331.14	317.33	303.55	294.00	287.35	283.27	263.96	267.55	261.31	250.65
Renewable energy sources	Renewable and biofuels	72.21	68.86	76.47	79.03	16.36	22.21	18.23	17.12	16.00	18.47	25.28
	Renewable electricity	410.11	388.50	460.14	430.34	445.54	527.35	558.67	524.73	522.54	489.20	552.30
	Renewable heat	11.44	9.27	14.51	20.15	24.51	18.55	21.67	22.77	18.25	18.89	25.24
	Total	493.76	466.63	551.13	529.52	486.41	568.11	598.56	564.62	556.79	526.57	602.81
Other energy sources	Peat and peat products	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
	Non renewable waste	0.02	0.00	0.00	0.01	0.18	0.20	0.48	0.04	0.14	0.66	1.06

(*continued on next page*)

Table B2 (*continued*)

Group of energy source	Energy source	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Other electricity	11.96	11.14	11.66	12.06	11.45	11.21	12.06	12.14	12.07	11.60	12.46
	Other heat	4.72	3.58	6.39	7.73	9.80	4.38	4.46	7.56	4.28	4.54	5.70
	Total	16.70	14.73	18.05	19.80	21.43	15.79	17.00	19.74	16.50	16.83	19.26

Table B3
LMDI-I Emissions effect of GHG emission changes by the T&C industry of the EU-27 MSs from 2008 to 2018.

Member State	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
Belgium	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bulgaria	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Czech Republic	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Denmark	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001	0.999	0.999
Germany	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Estonia	1.000	0.999	1.001	1.000	1.000	0.999	1.000	0.969	0.996	1.000	0.964
Ireland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Greece	0.999	1.000	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000	0.998
Spain	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000	1.000	0.999
France	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Croatia	1.000	1.000	1.000	1.000	1.000	0.996	1.009	1.000	1.000	1.000	1.006
Italy	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Cyprus	1.000	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Latvia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Lithuania	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Luxembourg	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hungary	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Malta	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001
Netherlands	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Austria	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Poland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Portugal	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Romania	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Slovenia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Slovakia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Finland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sweden	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table B4
LMDI-I Carbonisation effect of GHG emission changes by the T&C industry of the EU-27 MSs from 2008 to 2018.

Member State	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
Belgium	1.165	1.030	1.039	0.983	0.974	0.901	1.125	1.055	0.936	0.977	1.167
Bulgaria	0.822	1.256	1.065	1.124	0.640	1.132	1.040	1.104	0.916	0.952	0.896
Czech Republic	0.901	0.890	0.887	0.919	1.007	0.987	0.981	1.154	0.746	1.078	0.592
Denmark	0.949	1.043	0.971	0.987	0.907	0.984	0.995	0.976	1.035	0.852	0.726
Germany	0.967	0.876	0.955	0.998	1.292	0.989	0.907	1.064	0.925	1.263	1.165
Estonia	0.829	0.820	2.409	1.045	1.479	0.481	1.322	0.522	0.980	0.951	0.784
Ireland	0.691	0.637	1.474	0.756	1.211	0.770	1.078	1.144	0.992	0.999	0.559
Greece	1.597	1.023	1.123	1.645	1.045	0.969	0.773	0.622	0.977	0.350	0.502
Spain	0.878	1.180	0.796	1.271	1.234	0.854	0.870	1.006	0.894	1.118	0.968
France	0.954	1.126	0.869	0.927	1.072	0.990	1.079	1.032	1.061	0.915	0.993
Croatia	0.898	1.093	1.027	1.006	1.073	0.838	1.236	1.084	1.111	1.090	1.478
Italy	0.788	0.791	1.150	0.886	1.211	0.910	1.267	0.935	0.947	1.037	0.815
Cyprus	0.990	0.793	1.010	1.027	0.861	1.116	1.060	1.023	1.070	0.975	0.885
Latvia	1.036	1.102	0.947	1.210	0.931	0.941	1.079	0.929	0.987	0.930	1.055
Lithuania	0.747	1.191	1.062	0.921	0.949	1.207	0.920	1.021	1.053	1.111	1.094
Luxembourg	1.070	0.847	1.010	1.050	1.059	1.066	1.274	0.981	1.155	1.076	1.684
Hungary	1.062	0.829	0.967	0.634	1.350	1.028	1.003	0.899	1.038	0.981	0.689
Malta	0.960	1.171	1.073	1.176	1.461	1.381	0.915	1.210	1.021	1.031	3.334
Netherlands	1.018	0.986	0.991	1.024	0.924	0.982	0.949	1.056	1.050	1.076	1.046
Austria	1.134	1.264	0.913	1.058	0.787	0.959	1.150	1.098	0.992	1.083	1.419
Poland	1.030	0.914	0.969	0.943	0.974	1.092	0.905	0.985	1.039	0.900	0.763
Portugal	0.975	1.019	0.967	1.168	0.918	0.948	1.018	1.010	0.991	0.960	0.955
Romania	1.006	1.038	1.165	1.128	0.983	0.926	1.149	1.119	0.940	1.173	1.771
Slovenia	0.950	0.990	1.051	1.051	0.931	1.051	1.040	0.992	1.058	1.276	1.416
Slovakia	1.160	0.770	0.916	1.161	1.228	0.744	1.221	1.028	1.073	1.240	1.448
Finland	1.132	1.271	1.026	0.845	0.956	1.203	1.177	1.125	1.170	1.064	2.363
Sweden	1.250	0.948	1.081	1.026	0.960	0.748	0.918	0.933	0.973	0.855	0.672

Table B5
LMDI-I Intensity effect of GHG emission changes by the T&C industry of the EU-27 MSs from 2008 to 2018.

Member State	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
Belgium	1.030	0.982	1.109	1.046	1.060	0.808	1.034	0.972	1.079	1.041	1.134
Bulgaria	0.697	1.058	0.690	0.963	1.270	0.901	1.145	0.929	0.978	0.969	0.566
Czech Republic	0.820	1.085	0.947	1.043	0.959	0.974	0.975	0.954	0.969	0.991	0.734
Denmark	1.122	1.130	0.922	0.854	0.836	0.858	0.918	1.009	0.934	0.981	0.609
Germany	1.025	1.055	0.914	1.059	0.870	0.899	1.172	0.904	0.979	0.935	0.793
Estonia	1.006	0.904	0.803	0.957	0.929	0.982	0.908	0.849	0.750	0.988	0.364
Ireland	1.258	1.094	0.763	0.904	0.940	2.796	0.845	1.176	1.037	1.027	2.641
Greece	0.688	1.202	1.013	0.677	1.008	0.819	0.898	1.373	0.876	2.670	1.350
Spain	1.181	0.837	0.878	1.036	0.844	0.934	0.934	1.120	0.824	1.016	0.621
France	0.928	0.951	1.011	0.934	1.072	0.946	0.954	1.043	1.039	1.050	0.919
Croatia	1.121	0.887	0.946	1.096	0.902	0.936	1.119	0.877	0.904	0.908	0.700
Italy	0.990	0.928	0.852	1.083	0.960	0.952	0.960	0.986	1.023	0.945	0.709
Cyprus	1.136	1.041	0.956	1.102	1.314	0.835	0.928	0.908	0.915	0.850	0.896
Latvia	1.016	0.815	0.935	1.215	0.777	0.800	1.002	0.916	0.945	0.881	0.447
Lithuania	1.292	0.799	0.762	0.934	0.987	0.872	1.131	1.063	0.908	1.115	0.769
Luxembourg	1.104	0.677	0.845	1.271	1.051	1.062	0.790	0.845	0.937	0.906	0.507
Hungary	1.021	1.178	0.930	1.301	1.240	1.063	1.107	0.995	0.927	1.004	1.965
Malta	1.136	0.840	0.928	0.981	1.369	0.930	1.109	0.984	0.959	1.261	1.458
Netherlands	1.035	1.125	0.849	1.042	0.999	0.832	1.024	0.992	0.964	0.884	0.740
Austria	0.993	0.961	0.987	1.104	0.966	0.868	0.890	1.126	0.960	0.986	0.827
Poland	0.922	0.908	0.835	0.950	1.101	0.908	0.877	1.027	0.958	1.143	0.654
Portugal	0.979	0.949	0.933	0.764	0.941	0.937	0.944	0.924	0.977	0.998	0.496
Romania	1.039	0.656	0.789	1.312	0.983	1.133	0.962	0.845	1.083	0.936	0.647
Slovenia	0.875	1.310	0.761	0.923	1.138	0.778	0.966	0.940	0.886	0.710	0.407
Slovakia	0.899	0.879	1.382	0.717	0.856	1.120	0.746	1.040	1.112	0.741	0.479
Finland	0.968	0.837	1.115	1.278	0.975	0.965	0.888	0.841	0.897	0.947	0.690
Sweden	0.940	0.933	0.869	0.876	0.936	1.189	0.889	1.054	0.945	0.956	0.628

Table B6
LMDI-I Structure effect of GHG emission changes by the T&C industry of the EU-27 MSs from 2008 to 2018.

Member State	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
Belgium	0.807	0.994	0.907	0.932	0.980	1.002	0.989	0.945	0.959	0.971	0.580
Bulgaria	1.148	0.794	1.385	0.979	0.824	0.988	0.871	1.004	0.955	0.979	0.822
Czech Republic	0.972	0.941	1.016	0.972	1.057	1.030	0.935	1.004	1.008	0.927	0.863
Denmark	0.864	0.887	1.011	0.879	1.167	1.010	1.046	0.944	1.065	1.021	0.861
Germany	0.856	1.069	1.040	0.946	0.980	1.025	0.910	0.987	0.993	1.024	0.827
Estonia	0.916	0.989	0.946	0.988	0.928	1.030	0.964	0.981	0.972	0.967	0.719
Ireland	1.080	0.894	0.925	0.972	1.071	1.026	0.771	1.004	0.947	0.952	0.666
Greece	0.821	0.890	0.970	0.968	0.970	0.925	1.055	0.982	1.047	0.973	0.649
Spain	0.906	1.049	1.139	0.956	1.055	1.008	1.007	0.998	1.017	0.908	1.024
France	0.867	0.959	1.048	0.991	0.946	0.959	1.020	0.980	1.009	0.947	0.748
Croatia	0.932	1.008	1.051	0.982	1.037	1.079	0.886	1.014	1.039	1.013	1.027
Italy	0.882	1.042	1.051	0.976	1.030	1.019	0.997	0.983	1.026	1.016	1.011
Cyprus	0.881	0.841	0.921	0.818	0.823	1.042	1.035	1.028	1.080	1.126	0.620
Latvia	0.972	1.295	1.045	0.861	0.972	0.949	0.871	1.038	1.100	1.036	1.077
Lithuania	1.030	1.208	1.121	0.988	0.990	1.026	0.945	1.008	0.958	0.921	1.177
Luxembourg	0.861	1.484	0.946	0.800	0.970	0.902	1.242	1.133	1.026	0.994	1.214
Hungary	0.976	0.995	1.091	1.012	1.003	0.970	0.940	1.005	0.993	0.995	0.974
Malta	0.894	1.108	1.098	0.961	0.578	0.758	0.871	0.823	1.064	0.774	0.270
Netherlands	0.940	0.987	1.047	0.985	1.024	0.996	0.998	1.004	0.986	0.982	0.946
Austria	0.934	1.048	0.962	0.922	0.978	1.023	1.019	0.922	0.884	0.949	0.684
Poland	0.980	0.982	0.982	1.037	0.999	1.117	1.016	1.047	0.959	0.963	1.076
Portugal	0.958	1.030	1.084	1.104	1.080	1.079	1.039	1.020	1.012	1.020	1.506
Romania	0.852	1.628	1.267	0.722	1.016	0.885	0.943	0.943	0.922	0.920	0.860
Slovenia	0.835	0.875	1.075	1.006	0.967	1.064	0.910	1.041	1.041	0.987	0.790
Slovakia	0.915	1.441	0.856	0.985	0.954	1.152	0.957	0.895	0.866	1.183	1.073
Finland	0.927	0.951	0.955	0.964	0.901	0.927	0.989	1.053	0.993	0.993	0.695
Sweden	0.894	0.986	0.880	0.996	1.015	1.005	1.041	0.950	0.982	1.017	0.778

Table B7
LMDI-I Activity effect of GHG emission changes by the T&C industry of the EU-27 MSs from 2008 to 2018.

Member State	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
Belgium	0.986	1.024	1.003	1.000	1.005	1.022	1.029	1.011	1.011	1.011	1.106
Bulgaria	1.012	0.988	1.055	0.985	0.987	1.049	1.070	1.076	1.067	1.049	1.388
Czech Republic	0.916	1.043	1.022	0.946	0.965	0.994	1.068	1.038	1.068	1.069	1.119

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Table B7 (*continued*)

Member State	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
Denmark	0.953	1.030	0.993	1.004	1.013	1.026	1.025	1.037	1.032	1.017	1.134
Germany	0.956	1.039	1.023	0.999	1.009	1.035	1.026	1.033	1.023	1.011	1.161
Estonia	0.830	1.026	1.080	1.026	1.024	1.050	1.024	1.039	1.054	1.054	1.199
Ireland	0.926	1.016	1.003	1.003	1.034	1.085	1.366	1.033	1.108	1.092	1.812
Greece	0.980	0.889	0.874	0.923	0.969	0.998	1.004	0.976	1.006	1.000	0.670
Spain	0.982	0.964	0.965	0.944	0.968	1.010	1.047	1.036	1.021	1.017	0.952
France	0.975	1.010	1.005	0.992	1.003	1.008	1.020	1.012	1.013	1.005	1.044
Croatia	0.929	0.985	0.978	0.935	0.963	0.988	1.024	1.052	1.040	1.033	0.922
Italy	0.957	1.001	0.993	0.954	0.983	1.006	1.016	1.024	1.009	1.008	0.949
Cyprus	0.998	1.016	0.994	0.950	0.924	0.957	1.041	1.071	1.052	1.054	1.049
Latvia	0.746	0.949	1.090	1.065	1.029	1.020	1.037	1.025	1.033	1.047	0.991
Lithuania	0.795	1.027	1.074	1.039	1.039	1.039	1.023	1.034	1.046	1.050	1.143
Luxembourg	0.969	1.061	1.033	0.988	1.037	1.062	1.059	1.057	1.015	1.033	1.357
Hungary	0.832	1.006	0.988	0.917	1.007	1.040	1.059	1.033	1.068	1.036	0.961
Malta	0.985	1.075	0.981	1.038	1.073	1.091	1.138	1.048	1.092	1.051	1.729
Netherlands	0.961	1.014	0.996	0.980	0.984	1.012	1.024	1.021	1.029	1.030	1.050
Austria	0.974	1.010	1.012	1.000	0.997	1.015	1.025	1.029	1.010	1.024	1.099
Poland	0.847	1.103	1.008	0.993	1.005	1.040	1.061	0.990	1.071	1.049	1.155
Portugal	1.005	1.002	0.942	0.929	1.013	1.010	1.030	1.028	1.031	1.034	1.020
Romania	0.820	0.927	0.978	0.973	1.054	1.037	1.060	1.096	1.103	1.045	1.058
Slovenia	0.947	0.979	0.997	0.949	0.982	1.029	1.041	1.044	1.051	1.049	1.061
Slovakia	0.965	1.057	0.999	1.004	0.993	1.023	1.046	1.022	1.024	1.032	1.174
Finland	0.916	1.018	1.008	0.981	0.991	1.002	1.025	1.022	1.036	1.018	1.012
Sweden	0.866	1.169	1.092	1.033	1.023	0.993	1.031	1.008	1.012	0.961	1.172

Table B8

LMDI-I effects of GHG emission changes by decoupling groups of the EU-27 T&C industry from 2008 to 2018.

Group of decoupling	Effects	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
Strong decoupling	Emissions	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Carbonisation	0.902	0.931	0.994	1.004	1.122	0.935	1.074	0.990	0.961	1.024	0.922
	Intensity	0.989	0.955	0.901	1.007	0.955	0.925	0.982	0.990	0.980	0.996	0.719
	Structure	0.893	1.015	1.042	0.961	1.007	1.015	0.990	0.990	1.007	0.992	0.908
	Activity	0.958	1.017	1.003	0.982	0.996	1.017	1.027	1.023	1.021	1.013	1.056
	Total	0.763	0.919	0.937	0.953	1.075	0.893	1.072	0.993	0.968	1.025	0.635
Weak decoupling	Emissions	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Carbonisation	1.006	1.038	1.165	1.128	0.983	0.926	1.149	1.119	0.940	1.173	1.771
	Intensity	1.039	0.656	0.789	1.312	0.983	1.133	0.962	0.845	1.083	0.936	0.647
	Structure	0.852	1.628	1.267	0.722	1.016	0.885	0.943	0.943	0.922	0.920	0.860
	Activity	0.820	0.927	0.978	0.973	1.054	1.037	1.060	1.096	1.103	1.045	1.058
	Total	0.731	1.027	1.139	1.039	1.035	0.963	1.104	0.977	1.035	1.055	1.042
Not decoupling	Emissions	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001
	Carbonisation	0.951	0.937	1.035	0.839	1.179	1.156	1.091	1.057	1.094	1.040	1.384
	Intensity	1.107	0.912	0.891	1.120	1.022	1.053	1.014	0.965	0.937	0.993	0.988
	Structure	0.939	1.044	1.040	0.966	0.974	0.978	0.879	1.030	0.974	0.961	0.797
	Activity	0.901	1.017	1.006	0.977	1.011	1.040	1.142	1.033	1.068	1.054	1.257
	Total	0.892	0.908	0.965	0.888	1.186	1.239	1.110	1.085	1.066	1.047	1.370

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