Structural Change and the Environment

Unbundling the Contribution of Structural Change to Sustainable Consumption and Production

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Abstract

The objective of this chapter is to evaluate the contribution of structural change in production and consumption patterns with respect to sustainability analysis, with specific reference to sustainable production and consumption issues. Structural change and innovation dynamics are crucial for long-run sustainable growth, namely a pattern of reductions of environmental impacts and pressures that coexists with economic development. Economic sectors produce heterogeneous impacts on the environment and show different innovation features and demand composition dynamically evolves with changing impacts on the environment. In addition, increasing trade globalization makes necessary to analyse sustainable development both with reference to consumption and production. For instance, environmental policies in high income countries are often set in terms of emission reduction with reference to production, even though income growth appears to be more tightly correlated with consumption-based environmental pressures, including imports from emerging and developing areas of the world. In face of delocalization processes and value chain restructuring, the analysis of sustainable development must encompass both consumption and production dimensions. This structural change approach to sustainability stimulates political economy discourses. The focus on sectors, sector integration and innovation paths are the key pillars of a rich and solid 'structural change and the environment' approach.

The contribution of this chapter is threefold. First, we discuss the various components of structural change that contribute to changing environmental pressures based on an updated survey of the various relevant literature streams. Second, we provide evidence about recent (1995-2015) trends of structural change in production and consumption and their implications in terms of environmental pressures. Finally, we evaluate the extent to which economic growth is correlated with the structural change component of environmental pressures.

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1 Structural change, the environment and economic development towards sustainability

Structural change (SC) is mainly referring to changes in the employment and value added composition of the economy, driven by the evolution of markets, technology and demand. The composition of the economy - sector shares and sector integration at national and global level - explains key aggregate indicators like labour productivity. In the environmental side of the story, ‘environmental productivity’ (Gilli et al. 2014; Gilli et al. 2013) is one of the key factors that could explain a sustainable path along a SC-oriented sustainable development perspective[1].

Seminal analyses related to SC (McMillan and Rodrik, 2011; Timmer and Szirmai, 2000) emphasizes the role of SC as a driver of differential growth due to heterogeneous shifts from low to high value added activities, or vice versa. A key example is Asia that since the early 90s has moved from low to high value added sectors, compared to South America and Africa, which have operated changes along opposite directions. Another more recent paper that looks at structural transformation and more fundamental growth engines shows that cross country heterogeneity is high for emerging countries exposed to periods of very high and very low growth (McMillan et al. 2017).

The Baumol approach to structural change highlights the important roles of final demand and of heterogeneous labour productivities (and inflation rates) across sectors due to different innovation potentials (Baumol, 1967). Technological differentials are largely exogenous in the Baumol setting (services vs industry; cultural and other public sectors vs profit making industries) but contribute to a particular kind of structural change: for the final demand perspective, most of the structural change is ‘nominal’, while the ‘real’ composition of final demand does not appear to change much. On the other hand, the increasing relative cost (due to slow productivity growth) of services is likely to depress aggregate economic growth due to increasing wages in both services and non-service sectors.

In a recent contribution, Marin and Zoboli (2017) discuss the environmental implication of this so-called ‘Baumol-disease’ and highlight that: (i) the service sector is not so environmental efficient once vertically-integrated environmental pressures are accounted for; [2] (ii) the improvement in environmental efficiency of the service sector appears to be slower (and with less opportunities) than the one observed for manufacturing sectors.[3] These two findings suggest that while structural change toward services contributes to reducing the level of aggregate emissions, in the long run these emission reductions are likely to slow down due to the relatively weak pace of emission efficiency improvements in the service sector compared to industry.

[1] For a multi-disciplinary perspective on sustainability we refer to Spinozzi and Mazzanti (2018).

[2] Vertically integrated emissions are defined as the amount of emissions embodied in the production of all the intermediate inputs (using the Leontief total requirements matrix) worldwide to satisfy the final demand of a given sector.

[3] As an example, they find that the industry sector (mining and quarrying, manufacturing, power sector and construction) contributes to about 75% of EU27 direct CO_2 emissions but to just 62% of vertically-integrated emissions, while the service sector accounts for about 22% of direct CO_2 emissions but to as much as 35% of vertically-integrated emissions.

In an integrated structural change and environment (SCE) perspective, how sectors and regions differently react to environmental regulations is a central issue to investigate to shed light on the evolutions of economic and environmental performances. Dennis and İşcan (2009) analyse demand side effects (Engel) and supply side effects (productivity, capital deepening)[4], and point out that demand effects are very relevant especially in long-run settings, while technological, productivity-related issues may predominate medium run dynamics. Demand is important in environmental economics settings: both environmental good consumption and environmental policy support increase with income. Levinson and O'Brien (2018) analyse Engel curves for US pollutants and find income elasticity lower than one. This shows that even without technical progress, growth-led environmental impacts would have been reduced. Far from claiming the self-sufficiency of growth for achieving sustainability, the paper highlights the importance of detailing the various elements of economic development and environmental performances.

In a 'structural change and the environment' (SCE) perspective[5], sustainability depends on how macro and meso (sectoral) environmental efficiencies (e.g. CO_2/value added dynamics) are influenced by (i) composition itself (sectors are structurally different with regard environmental impacts depending on energy use, innovation potential, etc.) and (ii) policy induced technological change (Gilli and Mazzanti, 2018).[6] In this context some conceptual issues are of primary importance. The joint consideration of SC and (policy-led) innovation effects is a factor behind highly non-linear historical dynamics when economic-environmental data are observed (UNIDO, 2016; Gilli et al. 2013; Mazzanti and Musolesi, 2014). SCE is strongly linked to economic development and political economy discourses. Environmental policies, such a carbon tax, an emission trading system, a ban on hazardous substances, address the static and dynamic failures of markets with respect to environmental public good provision.[7] Policies may be introduced smoothly in the economic system or have an impact as unanticipated shocks. The latter case is likely to generate further disruption and non-linearities in development. Anyhow, environmental policies are a driver of change, through the activation of eco-innovation / green employment dynamics and the stimulus to more robust green demand patterns. On that basis, it is worth noting that environmental policies might deliver, or even be targeted to, sector specific innovation and economic effects (Marin and Mazzanti, 2013, Mazzanti and Rizzo, 2017).

The link between SC and sustainable development is also evident within the Environmental Kuznets Curves (EKC henceforth, see Mazzanti and Musolesi, 2017). The

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[4] Capital accumulation and structural change dynamics are analysed from an ecological economics perspective by Antoci et al. (2012). Saviotti (1991) examines the developments of industrialization in the Western world by posing attention to demands evolution and innovation dynamics.

[5] Duchin et al. (1991) and Perrings (1991) are papers that discussed a SCE approach well back in time, just before the 1992 Rio Convention on Sustainable Development and consequential actions against climate change, as the 1997 Kyoto Protocol.

[6] Tsai (2018) explores the Porter Hypothesis (by which well-designed environmental policies might spur innovation, see Jaffe et al. 1995 and Costantini and Mazzanti 2012) under industrial transition and structural changes.

[7] For a broader view that embraces long run fiscal sustainability within SCE analyses we refer to Speck (2017).

possibility to empirically observe a non-linear inverted U relationship between environmental pressures and income per capita largely depends on composition effects (industrialisation followed by de-industrialisation), demand effects (the environment is a luxury good, eco-investments and innovation can be driven by growth paths), policies. Pasche (2002) investigates the structural change dynamics towards the possibility of a long-run EKC pattern. Marsiglio et al. (2016) also explore structural changes in relation to the achievement of a long-run EKC. EKC-compatible equilibria seem to exist but also in a transitory phase, income-driven effects might re-generate linear and positive link between environmental pressures and growth in the very long-run.

Summing up, a comprehensive SCE framework is important to fully understand the nonlinear and heterogeneous development dynamics across income levels (e.g. high income and catching up countries), and the links that are activated by globalisation patterns between various and diverse development patterns (income and geographically determined). The 'observability' of EKC is rooted on SCE arguments.

The aforementioned EKC pattern, in other words the hypothesis that advanced economy may experience decreasing environmental impacts/pressures, is more and more influenced by internal composition factors and production delocalization. It is so true that the achievement of sustainability depends both on the emergence of new sectors and the greening of old mature sectors (EEA, 2014; UNIDO, 2016, 2018). The role of trade, delocalization, and international spillovers points to the necessity of analyzing both consumption (indirect emissions, vertically integrated approach) and production (direct emissions, the usual setting) perspectives to sustainability. This empirically means to observe the emissions embodied in imports and exports, and the flow of technological and knowledge spillovers. Sustainability is more and more an issue which is understandable only if we look at what dynamically happens 'at the interface'. Country boundaries are less and less relevant. Knowledge flows, trade relationships and spillovers matter. Policy setting should more and more adapt to this changing environment. Among others, Marin and Zoboli (2017) implement an environmentally extended input-output setting by using WIOD (World Input-Output Dataset) and find that the EU is transferring worldwide more emissions that value added and employment, in line with the pollution have hypothesis (Cole, 2004). Following on this, a third point is that the implementation of a SC framework of interest to environmental and ecological economics generates the necessity to investigate phenomena at macro and sector level, with refined disaggregation. Integrated environmental economic accounting assumes a crucial position if policy relevant and detailed results should be produced. The perspective of environmental accounting for the analysis of the relationships between the economic and environmental systems, especially regarding the satellite accounts like NAMEA (National Accounting Matrix including Environmental Accounts), is relatively recent (De Haan and Keuning, 1996) and partly originates within the 'beyond GDP' narrative (Costantini et al., 2013b). Green GDP, satellite accounts and integrated economic-environmental accounts are among the possible measures of human well-being as complements or alternatives to mere growth accounts (Managi and Kumar, 2018). NAMEA provides a comprehensive and integrated picture of the economic system (production and value) in association to the environmental system (physical pressures such as emissions) according to the same sector classification (Keuning et al., 1999; Steenge, 1999).

A very rich literature regarding these issues in environmental and ecological economics has consolidated in the recent years. Given the very large number of works at the intersection between sustainability, structural change, innovation, economic dynamics, etc., it is beyond the scope of this chapter to provide a full comprehensive literature survey. The following pages try to sum up the main research streams, in order to set a solid background to the empirical analysis.

2 Some insights from structural change, innovation and ecological economics literature streams

Ciarli and Savona (2019) in a recent survey deal with structural and climate changes. They offer a systematization of the empirical literatures that evolve around the two 'changes', and critically discuss literature streams. They conclude that decoupling of environmental pressures from growth is far from being achieved for the majority of countries, that tertiarization has not been sufficient to generate sustainable patterns, that environmental policy increasing stringency and consequential eco innovation effects are causing a reskilling of production (increased demands for skilled labor force),[8] that trade and globalization trends have caused delocalization of production and emissions as well.

Overall, macroeconomic evidence is clear in finding that real absolute decoupling from growth has not been achieved for major challenges like climate change mitigation and waste flows reduction, even in advanced countries (Musolesi and Mazzanti, 2014; Mazzanti and Zoboli, 2009).

In a SCE perspective, manufacturing sectors deserve specific attention. Manufacturing is still today the main engine for economic growth due to its large economic multiplier and technological opportunities (UNIDO, 2016; 2018). If on the one hand those sectors are directly and indirectly responsible for a large share of overall environmental pressures, raising concerns for the environmental sustainability of manufacturing-based development, on the other hand they produce more innovation than non-manufacturing sectors. In addition, manufacturing and services are more and more integrated (EEA, 2014).

Levinson (2015), adopting a structural change decomposition approach[9], questions why pollution emitted by US manufacturers declined markedly over the past several decades, even as real manufacturing output increased. He shows that most of the decline has resulted from technology, rather than changes in the mix of goods. He also shows that "*increased net imports of polluting goods accounts for only a small portion of the*

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[8] It is worth noting here that job effects, or developments, due to policy and innovations are linked and correlated to 'green skill effects' (Consoli et al. 2016, Vona et al. 2018). Policies, and then innovations, can produce an impact on jobs and/or skills (Cecere and Mazzanti, 2017). The effects on jobs and skills pertain in fact to a more general and comprehensive 'labour demand' framework of firms' capabilities, which can be potentially drawn out if we extend the theoretical reasoning to less mainstream schemes. Green strategies and innovation adoption broadly influence the development of the firm's capabilities.

[9] The Kaya identity is the conceptual pillar of decomposition analyses. Environmental pressures are driven by a set of aggregate factors: population/employment, wealth per capita, technological development, or broadly speaking innovation/knowledge changes. The latter factor, that might enhance environmental productivity (e.g. decreasing CO_2/GDP levels), is the one which compensates population and wealth 'scale' effects.

pollution reductions from the changing mix of goods. Together, these two findings demonstrate that shifting polluting industries overseas explains only a minor part -- less than 10 percent -- of the clean-up of US manufacturing" (p. 2177). This result confirms that the pollution haven hypothesis should be tested case by case (externality by externality, regulation by regulation, and sector by sector): environmental regulations are only a part of the overall cost of production and one of the many reasons behind offshoring and delocalization. While the size of the effect is to be measured, regulations are surely a key factor in international trade (Cantore and Fang Chin Cheng, 2018) and in international flows of FDIs (Borghesi et al., 2018).

Taking a worldwide view, in a recent paper Gilli et al. (2017) highlight that high-income countries are generally more environmental friendly than the average and tend to be specialised in high-tech and greener sectors: emission reduction is driven mainly by unobserved factors such as institutional quality and policy commitment. Regarding SCE, they claim that while production perspective shows some evidence of EKC dynamics, this result does not hold when shifting to the consumption perspective, which takes emission embodied in the imports of goods into account. Only some world areas are able to compensate the growth effect exploiting technology dynamics.

The suggested specialization of wealthier countries in less emission-intensive sectors is in line with the so-called pollution haven hypothesis. Cole (2004) suggests that the displacement of the most polluting steps of the supply chain in 'southern' (and weakly regulated) countries contributes, though modestly, to the emergence of the EKC. The modest role played by the pollution haven hypothesis is attributed to the fact that wealthy countries are also relatively well endowed with capital. leading to a comparative advantage in capital (and pollution) intensive products (Cole and Elliott, 2005).

As already noticed in the literature (Marin et al. 2012), the evidence on SCP has sky rocketed due to the increased availability of integrated accounts and environmentally extended sector defined datasets. There has been a fruitful intersection between ecological economics and economic systems/input-output analyses. Xu and Dietzenbacher (2014) is a special example of it. They clearly sum up the SCP issue: '*Producers and consumers in developed countries have shifted towards importing a larger share of products from emerging countries. This is the distinguishing feature that led to an increase of emissions embodied in imports for developed countries and an increase of emissions embodied in exports for emerging countries. These results suggest policy makers to monitor EET more carefully and take the effects of trade on emissions into consideration*'.

Among other publications, taking some key examples, Duarte et al. (2018) estimate embodied emissions in bilateral trade flows using data from WIOD. They assess the determinants of CO_2 emissions embodied in trade, combining input–output modelling with trade gravity analysis. Wiebe et al. (2012) also present the research potential of environmentally extended multi regional IO models that disaggregate sectors and regions over a dynamic setting.[10] Wiedmann and Barrett (2013) provide policy relevant indications linked to the analysis of environmentally extended multi regional IO

[10] Mazzanti and Montini (2010) and Costantini et al. (2013a) show the importance of generating and using regionalised sector based environmentally extended accounting.

outcomes. They conclude that '*specific, policy-relevant information that would be impossible to obtain otherwise can be generated with the help of EE-MRIO models*'.

Among the most recent empirically oriented works, we note Vale et al. (2018), who focus on North-South divide and different 'performances' relying on WIOD data. They claim that '*both the North and the South have become less pollution-intensive (technique effect) over the years*'. Interestingly, they '*find support to the hypothesis that the South has specialized in relatively more pollution-intensive activities (composition effect)*'. Mazzanti et al. (2018) also focus on differences across development levels by using EORA as data source for the manufacturing sector only. First, they find that industrialized countries are the only group that registered a negative trend for CO_2 emissions over the study period. Second, of the three components included in the decomposition analysis (scale, composition, efficiency), the scale effect always shows a positive impact on total emissions, the exception being the group of least developed countries. Third, the industry-by-industry analysis of income-CO_2 elasticities reveals a strong monotonic relationship between income and CO_2 (from the production and consumption perspective) and indirect material consumption.[11] Finally, a detailed component-by-component analysis shows that (i) the scale effect is relevant, as expected, (ii) the relationship between the composition effect and GDP indicates a negative slope, i.e. the manufacturing sector becomes greener as income increases, and (iii) technological change increases the environmental productivity of aggregate manufacturing.

A multi-regional structural decomposition analysis tool is implemented by Wang et al. (2017). They show sector relevance, trade effects and cross-country differences in performance. Their main results are that '*sectoral emission efficiency improvement was the main contributor to the slight decrease in global emission intensity during the period, while international trade marginally hampered improvement of global emission intensity. Comparisons of the performance between emerging economies and advanced economies reveal the importance of production structure and final demand structure in emission intensity reduction*'.

Country specific studies are also relevant, especially when focusing on major emitters. China is an example. Liang et al. (2017) apply a Sustainable Consumption and Production perspective to the Chinese case digging up the role of major local polluters. They state that the final production-based accounting framework can help to define and allocate emission responsibilities of Chinese provinces. Relevantly, '*It can complement production-based and consumption-based accounting frameworks to guide environmental policy-making in China*'. Geo-referenced analysis on China recently appeared, motivated by the high economic heterogeneity within the country. Liu and Wang (2018) adopt a multiregional input–output model of 30 provinces to examine the embodied emissions and to capture interregional flows and spillovers. Results show that

[11] Studies on material consumption are relatively scarcer compared to energy and climate change issues. Pothen (2017) uses WIOD to analyse global raw material use. He concludes that '*rising final demand was the predominant driver of growing Raw Material Consumption. Final demand, furthermore, shifted into countries that consume material-intensive goods, in particular due to infrastructure build-up in industrialising nations*. […] *Results confirm that the secular trends in structural change and technological improvements are insufficient to limit the use of materials*'. De Koning et al. (2015) stress the importance of high resolution in sector/geo disaggregated analysis, given that '*Consumption-based material footprints calculated with multi-regional input–output (MRIO) analysis are influenced by the sectoral, spatial and material aggregations*'.

‘*SO_2 embodied in exports contributes 15.17–22.08% of the total domestic SO_2 emissions, and 74.40–78.14% of the embodiment is in exports from the eastern provinces, where over 90% of China's exports occur. However, only about 70% of the embodied emission in eastern China's exports is discharged in the east; an increasing portion (24% to 34%) is released in the central and western provinces as a result of interregional production linkage*’. The work highlights the potentially very rich sector and geographic contents offered by SCE oriented analysis.

Recent decomposition analysis on Japan shows that the technological effect is relevant but its importance varies in time (source of non-linearity) and is strongly linked to sectoral developments. Notwithstanding the importance of final demand (level) and industry mix, technical efficiency at the level of each sector is behind the reduction of CO_2 (Akpan et al. 2015).

Regarding European countries, recent work at the European Environmental Agency (EEA, 2014) highlights that structural change, in terms of changes in the composition of final demand, contributes to reducing production-based and consumption-based CO_2 emissions over the period 1995-2015. However, other factors such as environmental efficiency and the scale of final demand appear to play much more important roles in explaining aggregate trends. Again regarding the EU, evidence was provided especially for countries where environmental economic accounts were more developed. Butnar and Llop (2011) focus on the service-manufacturing integration in Spain and show that ‘*services increased their CO_2 emissions mainly because of a rise in the emissions generated by non-services to cover the final demand for services. Decomposed effects show a decrease in CO_2 emissions due to technological changes between 2000 and 2005 compensated by an increase in emissions caused by the rise in final demand of services*’. Marin et al. (2012) compare Spain and Italy by testing the sensitivity of results to different sector aggregation. The work stresses that ‘*different sectoral aggregation significantly biases the amount of emissions for the consumption perspective, though differently in the two countries. Italy surprisingly show consumption/production ratios around or lower than one, but in line with some major work at EU level*’.

Brizga et al. (2014) analyse the development of Baltic countries, including the post-Soviet Union collapse period. It is shown that the growth of final demand is the major driver of CO_2: balancing factors are efficiency and structural change, with different importance across Baltic countries. Heterogeneity in development drivers and structural change economic dynamics are present even within sets of similar contiguous countries.

Mach et al. (2018) interestingly integrate input-output data and household expenditure data to estimate direct and indirect emissions, with emphasis on household expenditure heterogeneous impacts and sector differences, for the Czech Republic. They show that ‘*while the first expenditure decile of households is responsible for less than 4% of all emissions, the tenth decile is responsible for 20–24%. Consumption of services and goods is least emission intensive, while use of electricity, heating, and transportation remains responsible for the major part of emissions*’.

An analysis about raw material is proposed by Piñero et al. (2018) for Finland. They combine LCA and MRIO to provide a robust consumption-based perspective; they highlight the necessity to exploit LCA but also the limits in the current MRIO resolutions in terms of uncertainty. The authors observe that ‘*The analysis provides insights on how* *to identify critical supply chains and illustrates a relatively simple, replicable solution that can be used in other regions or environmental accounts*'.

The various publications and research lines that were briefly presented show the very rich set of tools, analyses and variety of results that a comprehensive SCE approach produces. Policy relevance is somewhat correlated with the increasing resolution of datasets by sector and geographical units, given the intrinsic limitations of 'one size fits all' approaches to policy making. Further enrichments might be derived from mergers of environmental extended input-output datasets with microeconomic data (household, firms) that allow a more detailed assessment of how household-level changes in income and wealth is related to changes in the environmental pressures generated to satisfy the household's need.

3 Evidence on the role of structural change in a sustainability perspective

As a first step of the analysis of the role of structural change for sustainability-related issues, descriptive evidence on the 'environmental' direction of structural change for different countries in the world is conveyed. As discussed in the first two sections, recent studies regarding structural change largely focused on the 'production-side' of structural change, while looking at changes in the composition of economies in terms of either gross value added, gross output or employment.

The other important dimension of structural change is related to changes in the composition of consumption bundles. Consumption bundles reflect the combination of average consumers' preferences within a specific country given the vector of relative prices and the level (and distribution) of income. If preferences were constant and homothetic and relative prices were constant, we would not expect any change in the relative composition of consumption within a country. However, on the one hand tastes change with changing income and, on the other hand, relative prices change too. In the initial stages of development, people have the priority to satisfy its basic needs. With growing income, new manufacturing goods are increasingly demanded. Finally, at very high income levels, once all material needs are already satisfied, the demand for services increases rapidly.

It is worth noting that, as a consequence of the increasing divergence between what is produced and what is consumed within a country due to increased trade openness, the two types of structural change may differ even substantially within the same country. It may well be the case that a country specializes in the production of chemical products (for the domestic and world market) and, at the same time, increases the demand for luxury goods (imported from abroad). For this reason, the consideration of both consumption and production is crucial when considering environmental issues with global consequences such as greenhouse gas emissions whose effects in terms of climate change are global, no matter where emissions are released.

In this chapter we focus on carbon dioxide (CO_2) emissions as a proxy for environmental pressures. The motivation depends on data availability, policy relevance, complexity of the 'economic problem', possibly the most radical challenge humanity has faced (Chomsky, 2017), due to the global public good nature of climate change (static cooperation problem), and the very long-run scenarios along which costs and benefits of mitigation actions (or lack of action) arise (dynamic cooperation problem). CO_2 emissions constitute 81 percent of global greenhouse gas emissions that contribute to climate change. These emissions are mostly generated in the process of combusting fossil fuels, which means that energy efficiency and transition to renewable energy both contribute to reducing CO_2.

3.1 Data sources

The evidence which is discussed in this chapter is based on data coming from the Eora26 database (Lenzen et al., 2012; 2013). Eora26 reports estimates of world multi-regional input-output tables for 190 countries with a breakdown of 26 sectors.[12] Satellite accounts include information, among others, on direct environmental pressures (including CO_2) and socio-economic accounts (including gross value added). Data are available from 1990 onwards: however, due the political disruption that followed the collapse of the Soviet Union, a rather balanced panel of countries with stable borders is available from 1995 onwards. We employ input-output tables to estimate emissions multipliers of final demand (Tukker et al., 2018) for all 190 countries.

Due to very volatile trends regarding small countries, our analysis will just focus on the 100 largest countries.[13] The main advantages of using Eora26 compared to other input-output database (e.g. WIOD, Exiobase) are its wide coverage in terms of countries and the length of the time series. These advantages come at the cost of two important limitations. First, the sectoral aggregation is high and the sectoral classification is not fully compatible with official classification such as the NACE classification. Second, there is no information on sector-country-year specific deflators. This limits the possibility to evaluate in detail structural changes in terms of quantities.[14]

3.2 Environmental aspects of structural change 1995-2015

Table 1 reports average emissions intensities (1995-2015) of final demand (consumption-based) and value added (production based) for different sectors and broken down by quartile of per capita GDP in 1995. This breakdown allows to appreciate the extent to which countries at different levels of GDP per capita are characterized by systematically different levels of environmental efficiency.

Overall, we observe a substantial degree of heterogeneity in emission intensity both across different sectors and across different country groups. The Electricity, Gas and

[12] We employ input-output tables estimated in basic prices.

[13] We include countries that account for more than 0.1 percent of the world total for at least one of the following variables: GDP (source: World Bank), population (source: World Bank), production-based CO_2 emissions (source: Eora26), consumption-based CO_2 emissions (source: own elaborations on Eora26). Overall, the 100 selected countries account for 94 percent of the world population, 97 percent of the world GDP and 95 percent of the world CO_2 emissions (both production- and consumption-based).

[14] The first best option would be to have information on input-output tables in sector-country specific previous year prices. Eora26 only converts input-output tables into US current dollars. As a second best, following Lan et al. (2016), we deflated input-output tables with sector-specific country-invariant deflators. More specifically, we used deflators for the US as input-output tables are expressed in US dollars. However, this simple approach does not allow differences in trends in product prices across countries, which is a very strong assumption. This limits the possibility to interpret coherently changes in the level of output or final demand, as it will combine both changes in quantities and changes in prices. Similarly, changes in emission intensity (of value added or output) also combine nominal and real changes.

Water sector is by far the most emission intensive across all different GDP quartiles, both when considering its direct emissions (production-based) and when considering emissions of the vertically integrated sector (production-based). The second most emission intensive sector (for both perspectives) is the transport sector. Manufacturing sectors appear to be emissions intensive both in terms of production- and consumption-based emissions. Services are generally less emission-intensive (except transport), but in some instances their emission intensity is larger than average: this happens for consumption-based emissions of Maintenance and Repair (third and fourth quartile), Wholesale Trade (fourth quartile), Hotels and Restaurant (first quartile) and Education, Health and Other Services (second quartile). Finally, also the Construction sector appear to be particularly emission intensive when looking at consumption-based emissions.

Table 1 – Emission multipliers of final demand (consumption-based) and emission intensity of value added (production based) by sector (EORA26) and quartile of GDP per capita in 1995

	Consumption-based average emission multipliers 1995-2015					Production based average emission intensity of VA 1995-2015				
	First quartile of GDP per capita in 1995	Second quartile of GDP per capita in 1995	Third quartile of GDP per capita in 1995	Fourth quartile of GDP per capita in 1995	Average	First quartile of GDP per capita in 1995	Second quartile of GDP per capita in 1995	Third quartile of GDP per capita in 1995	Fourth quartile of GDP per capita in 1995	Average
Agriculture	0.73	1.16	0.64	0.55	0.75	0.23	0.27	0.26	0.21	0.24
Fishing	0.62	1.07	0.80	0.61	0.78	0.16	0.19	0.21	0.27	0.22
Mining and Quarrying	1.73	3.75	2.60	1.17	1.57	1.86	1.33	2.55	0.88	1.28
Food & Beverages	1.37	1.53	0.82	0.49	0.65	2.87	1.60	1.10	0.48	0.74
Textiles and Wearing Apparel	1.61	1.44	0.82	0.62	0.73	1.53	1.64	0.84	0.29	0.69
Wood and Paper	1.36	1.91	0.72	0.60	0.71	1.04	1.14	0.60	0.25	0.37
Petroleum, Chemical and Non-Metallic Mineral Products	3.38	4.88	1.80	1.34	1.64	5.65	7.26	4.26	2.39	3.28
Metal Products	2.51	3.18	1.64	0.98	1.32	2.37	2.79	1.68	0.48	0.94
Electrical and Machinery	0.46	0.59	0.27	0.24	0.31	0.90	0.68	0.32	0.11	0.21
Transport Equipment	1.68	1.63	0.70	0.56	0.68	1.74	1.65	0.86	0.40	0.57
Other Manufacturing	1.60	1.61	0.67	0.55	0.65	3.73	1.56	0.88	0.29	0.53
Recycling	2.02	0.36	2.70	0.69	1.07	2.33	0.13	1.56	0.60	0.66
Electricity, Gas and Water	18.10	16.03	7.49	5.75	6.77	46.84	35.38	14.68	11.65	16.01
Construction	2.51	3.38	1.23	0.67	1.18	1.21	2.16	0.61	0.25	0.44
Maintenance and Repair	1.09	1.43	0.83	0.62	0.64	0.28	0.20	0.41	0.06	0.08
Wholesale Trade	0.98	1.12	0.74	0.58	0.63	0.07	0.14	0.07	0.04	0.05
Retail Trade	0.91	1.14	0.79	0.53	0.58	0.06	0.14	0.07	0.04	0.05
Hotels and Restraurants	1.66	0.82	0.77	0.43	0.46	0.54	0.40	0.16	0.07	0.10
Transport	7.08	3.82	4.09	3.36	3.78	3.39	2.53	5.94	3.80	3.85
Post and Telecommunications	0.54	0.85	0.42	0.32	0.35	0.08	0.09	0.20	0.04	0.06
Finacial Intermediation and Business Activities	0.45	1.00	0.31	0.22	0.26	0.08	0.16	0.08	0.04	0.05
Public Administration	0.34	1.34	0.65	0.48	0.50	0.04	0.21	0.07	0.04	0.04
Education, Health and Other Services	0.85	1.93	0.46	0.36	0.45	0.19	0.28	0.08	0.05	0.07
Private Households	1.33	1.52	0.32	0.19	0.24	2.11	0.47	1.08	0.04	0.09
Others	0.68	1.52	0.75	0.29	0.91	0.28	0.25	0.13	0.12	0.17
Re-export & Re-import	1.24	1.22	1.24	1.25	1.25	0.00	0.00	0.00	0.00	0.00
Total	1.42	1.63	0.81	0.55	0.69	2.08	2.41	1.12	0.56	0.79

The great degree of heterogeneity in terms of emissions intensity across sectors suggests that even small changes in the sectoral composition of consumption or production are likely to induce relevant changes in aggregate environmental pressures, especially so if changes happen in sectors that have very high or very low emission intensity.

Table 2 reports the average world (100 countries) composition of final demand and production (value added) for the first and last years of the observed period (1995 and 2015). A very first evidence about the likely role of structural change may be drawn by correlating the average consumption-based and production-based emission intensity with the change in the share of, respectively, gross value added and final consumption. A positive correlation would indicate that on average structural change goes into the direction of increasing emissions while a negative correlation would mean that structural change induces reductions of emissions. The correlation coefficients across sectors for the world as a whole for consumption-based emission intensity was -0.11 while for production-based emission intensity was -0.022. Overall, these correlation coefficients are negative but very small, suggesting a moderate contribution of structural change to decrease overall emissions.

Table 2 – Structural change (world average) for final demand and value added (1995-2015)

	Composition of world final demand in 1995	Composition of world final demand in 2015	Change in the composition of world final demand 1995-2015	Composition of world value added in 1995	Composition of world value added in 2015	Change in the composition of world value added 1995-2015
Agriculture	0.017	0.024	0.007	0.024	0.037	0.013
Fishing	0.002	0.003	0.001	0.002	0.004	0.002
Mining and Quarrying	0.003	0.001	-0.001	0.018	0.013	-0.005
Food & Beverages	0.080	0.055	-0.025	0.025	0.025	0.000
Textiles and Wearing Apparel	0.036	0.033	-0.003	0.011	0.017	0.005
Wood and Paper	0.009	0.007	-0.002	0.017	0.019	0.002
Petroleum, Chemical and Non-Metallic Mineral Products	0.041	0.021	-0.020	0.043	0.035	-0.009
Metal Products	0.007	0.006	-0.001	0.022	0.025	0.003
Electrical and Machinery	0.101	0.233	0.132	0.059	0.162	0.104
Transport Equipment	0.038	0.051	0.013	0.016	0.024	0.008
Other Manufacturing	0.019	0.019	0.000	0.007	0.009	0.002
Recycling	0.002	0.003	0.000	0.001	0.002	0.001
Electricity, Gas and Water	0.015	0.012	-0.003	0.023	0.022	-0.001
Construction	0.104	0.073	-0.031	0.057	0.037	-0.020
Maintenance and Repair	0.005	0.004	-0.001	0.006	0.004	-0.002
Wholesale Trade	0.016	0.020	0.004	0.057	0.043	-0.014
Retail Trade	0.038	0.047	0.009	0.058	0.059	0.000
Hotels and Restraurants	0.039	0.025	-0.015	0.025	0.020	-0.005
Transport	0.022	0.013	-0.008	0.044	0.041	-0.003
Post and Telecommunications	0.017	0.021	0.004	0.031	0.037	0.006
Finacial Intermediation and Business Activities	0.152	0.134	-0.017	0.252	0.218	-0.034
Public Administration	0.083	0.064	-0.019	0.074	0.044	-0.030
Education, Health and Other Services	0.141	0.115	-0.026	0.117	0.094	-0.023
Private Households	0.002	0.002	0.000	0.002	0.002	0.000
Others	0.007	0.010	0.003	0.006	0.008	0.002
Re-export & Re-import	0.003	0.002	0.000	0.000	0.000	0.000

Looking at specific sectors, we observe that the share of final demand for the two most emission-intensive (consumption-based emission) sectors, that is Electricity, Gas and Water, and Transport, has decreased over the period 1995-2015: they accounted for 3.7

percent of final demand in 1995 and for 2.5 percent of final demand in 2015. The same has happened for another emission intensive sector in terms of consumption-based emissions, that is the Construction sector, from 10.4 percent of final demand in 1995 to 7.3 percent of final demand in 2015. On the other hand, the sector that increased the most its importance in terms of final demand has been the Electrical and Machinery sector (+13.2 percent), whose consumption-based emission intensity was on average less than half of the world average (Table 1).

Regarding production-based emissions, we observe a slight decrease in value added share of the two most emission intensive sectors (Electricity, Gas and Water and Transport), from 6.7 percent in 1995 to 6.3 percent in 2015, while we confirm the positive role played by the Electrical and Machinery sector whose emission intensity is well below average and that experience the largest increase (from 5.9 to 16.2 percent of global value added between 1995 and 2015).

4 Drivers of environmental pressures for consumption and production

A powerful tool to isolate the contribution of structural change towards changing environmental pressures is structural decomposition analysis (SDA). SDA allows to estimate ceteris paribus figures. In our case, we are interested on what would have happened to total country-level emissions if everything else except the structure of the economy had remained fixed. The recent literature has explored a large variety of decompositions (see Xu and Dietzenbacher, 2014). For the purposes of this chapter, we focus on simple decompositions for production-based and consumption-based emissions with the aim of isolating the sole structural change component from other confounding factors.

For what concerns production-based emissions, we can define total country-level CO_2 emissions in year *t* ($CO_{2\,t}$) as the sum of sector-level direct emissions for all sectors *i* ($CO_{2\,i,t}$). However, total CO_2 emissions could also be calculated as the following identity:

$$CO_{2\,t} = \sum_i CO_{2\,i,t} \sum_i \left[\left(CO_{2\,i,t}/VA_{i,t} \right) \times \left(VA_{i,t}/VA_t \right) \times VA_t \right] \tag{1}$$

where $VA_{i,t}$ is gross value added of sector *i* in year *t*. By keeping emission intensity ($CO2_{i,t}/VA_{i,t}$) and the overall scale of the economy (VA_t) fixed at a certain level, the role of structural change to aggregate country-level changes in CO_2 emissions is defined as follows:

$$Structural\ change\ component\ (production - based) =$$

$$= \sum_i \left[\Delta \frac{VA_i}{VA} \times 0.5 \times \left(\frac{CO_{2\,i,t}}{VA_{i,t}} + \frac{CO_{2\,i,t-1}}{VA_{i,t-1}} \right) \times (VA_t + VA_{t-1}) \right] \tag{2}$$

Regarding consumption-based emissions, we adopt the simple approach of Los and Dietzenbacher (2000) to decompose the total change in country-level emissions into four components: emission intensity of production, production technology, final demand composition and final demand level with polar decomposition. Within this framework, the structural change component is defined with linear algebra as:

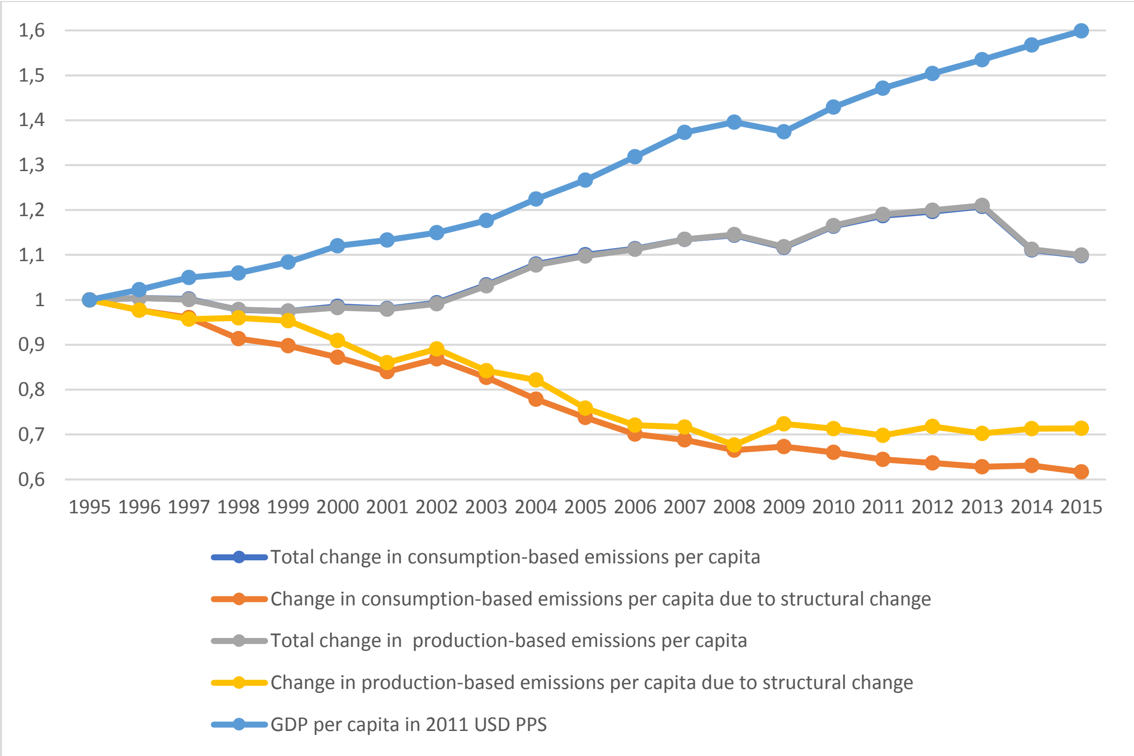
$$Structural\ change\ component\ (consumption - based) =$$

$$= 0.5 \times (\mathrm{e}_t + \mathrm{e}_{t-1}) \times (\mathrm{L}_t + \mathrm{L}_{t-1}) \times \Delta \frac{\mathrm{f}}{\sum_{\mathrm{i}} f_i} \times (\textstyle\sum_{\mathrm{i}} f_{it} + \sum_{\mathrm{i}} f_{it-1}) \qquad (3)$$

where e_t is the vector of direct emission coefficients in terms of emissions per dollar of gross output for year *t*, L_t is the Leontief inverse matrix based on the world input-output table for year *t*, f is the vector of final demand expenditure while $\sum_{\mathrm{i}} f_i$ is a scalar that is calculated as the sum of final demand for each sector within a country. This component considers how much would have emissions changed as a consequence of changes in the composition of final demand for given scale, technology and emission intensity.

Figure 1 reports our main results aggregated at the world-level, together with the aggregate trend in GDP per capita and production- and consumption-based CO_2 emissions per capita.

Figure 1 – Role of structural change for production-based and consumption-based CO_2 emissions (world average, 100 countries)



Overall, emissions per capita (grey and dark blue lines) grew by about 10 percent over the considered period.[17] Their growth, however, was slower than the one of GDP per capita, that grew, over the same period, by about 60 percent. This evidence confirms the relative decoupling evidence (UNIDO, 2016). The world economy has reshaped its income-environment relationship – greenhouse gases do not increase monotonically with income anymore, due to policy and oil shock factors – but not enough to achieve a negative elasticity and ensure sustainability concerning climate change. Though some signs of decoupling are present over 1995-2013, with the 2009 downturn influencing both income and emissions, a real break in the relationship appears over 2013-2015. Soon to state whether this is a real historical break or a short run phenomenon (Mazzanti and Musolesi, 2017).

The yellow and orange lines describe what would have been the trend in, respectively, production-based and consumption-based emissions per capita, if everything else (technology, scale effects) except the structure of production or consumption had remained unchanged. Thank to structural change, production-based emissions per capita would have shrunk by almost 30 percent while consumption-based emissions per capita would have shrunk by almost 40 percent: compared to the actual trend (+10%), the contribution of structural change reduced production- and consumption-based emissions by respectively 40 and 50 percent.

Figure 1 shows that the contribution of structural change was relevant in the considered period, namely a phase that witnessed a sharp increase in world trade, globalization-like flows, advent and diffusion of ICT. In that period China, India and other emerging countries affirmed their role in the global economy. In addition, relevant to SCE discourses, though with up and downs due to political cycles, environmental policies were introduced in many countries and environmental technologies were patented and diffused, especially in the realm of energy and climate change.

Table 3 reports aggregate results of the decomposition over 1995-2015 for a selection of large countries.[18] Within the first quantile, we do observe heterogeneous models of development and capitalism. In terms of SCE issues, poorest countries of Africa and East Asia show relative decoupling and relevant SC factors behind the trend of CO_2 emissions. Vietnam and India show very different performances even if starting from the same GDP per capita: while India shows decoupling trends and structural change at play, Vietnam is not decoupling growth from emission generation; structural change as well seems not in support of emission reduction in this case.

China represents most of the second quantile: Chinese growth in GDP and emissions is very high. Decoupling is nevertheless present, with GDP growing three times as much as emissions. Structural change is one of the forces behind this relative delinking.

[17] For our sample of 100 countries, the trend in production- and consumption-based emissions is almost identical. It should be noted that these to variables at the aggregate level should coincide exactly as the estimation of consumption-based emissions consists in the re-attribution of production-based emissions. This identity does not necessarily hold for specific countries due to international trade. In our case the two figures basically coincide due to the very complete coverage of our selected 100 countries of the world's total emissions.

[18] Countries with either GDP, population or CO_2 emissions greater than 1 percent of the world total.

In the very heterogeneous third quantile, all countries showed growth higher than emission growth. The gap is in some cases not large, very close to a unitary income-environment elasticity. Besides Ukraine, which shows a very idiosyncratic figure, SC factors are important and higher than in China. The highest values in this group are for the poorest set of countries (Nigeria, Philippines, Pakistan, and Egypt).

Table 3 - Role of structural change for production-based and consumption-based CO_2 emissions by country (only countries with either GDP, population or CO_2 emissions greater than 1 percent of world total)

	Average GDP per capita (2011 USD in PPS) in 1995	Growth rate of GDP per capita 1995-2015	Growth rate in consumption-based emissions	Growth rate in consumption-based emissions due to structural change	Growth rate in production-based emissions	Growth rate in production-based emissions due to structural change
Ethiopia	576	1.66	-0.11	-0.55	0.72	-0.65
Bangladesh	1441	1.18	0.73	-0.31	0.60	-0.31
Viet Nam	2042	1.78	3.56	-0.41	3.12	0.09
India	2058	1.78	0.65	-0.33	0.66	-0.32
Average first quartile	***1809***	***1.59***	***0.71***	***-0.35***	***0.72***	***-0.37***
China	2551	4.25	1.42	-0.38	1.24	-0.33
Average second quartile	***2526***	***4.00***	***1.32***	***-0.38***	***1.13***	***-0.34***
Nigeria	2740	1.06	0.14	-0.49	-0.36	-0.69
Pakistan	3364	0.41	0.28	-0.39	0.32	-0.41
Philippines	3960	0.75	0.00	-0.43	0.00	-0.45
Ukraine	5073	0.47	-0.14	0.00	-0.24	0.62
Indonesia	6023	0.72	0.70	-0.33	0.62	-0.33
Egypt	6420	0.60	0.55	-0.46	0.60	-0.35
Thailand	9417	0.63	0.40	-0.25	0.56	-0.26
South Africa	9730	0.27	-0.09	-0.45	-0.08	-0.33
Brazil	11012	0.31	0.12	-0.34	0.16	-0.32
Average third quartile	***6376***	***0.68***	***0.71***	***-0.22***	***0.21***	***-0.20***
Poland	11150	1.23	0.16	-0.13	-0.04	-0.11
Turkey	11530	0.64	0.51	-0.29	0.33	-0.31
Mexico	12619	0.31	0.18	-0.39	0.04	-0.40
Russia	12813	0.86	0.06	-0.10	0.05	-0.01
South Korea	16798	1.05	0.25	-0.12	0.29	0.01
Spain	25630	0.28	-0.01	-0.23	-0.08	-0.28
UK	28513	0.36	-0.09	-0.22	-0.22	-0.34
Australia	30348	0.44	0.19	-0.27	-0.06	-0.35
France	30823	0.21	-0.11	-0.12	-0.15	-0.25
Japan	31225	0.15	-0.11	-0.16	-0.04	-0.28
Canada	32226	0.33	-0.01	-0.23	-0.12	-0.34
Italy	32717	0.03	-0.08	-0.16	-0.11	-0.20
Germany	33850	0.30	-0.16	-0.10	-0.14	-0.17
Saudi Arabia	35325	0.42	0.70	-0.59	0.26	-0.57
USA	39476	0.33	-0.21	-0.53	-0.14	-0.24
Average fourth quartile	***26736***	***0.43***	***0.01***	***-0.27***	***-0.03***	***-0.24***
Total	**9392**	**1.68**	**0.68**	**-0.31**	**0.51**	**-0.29**

As far as advanced countries are concerned, GDP grew faster than emissions, which for most EU countries, Canada and USA slightly decreased over the period. Saudi Arabia is the only high-income country where emissions grew, even substantially. Poland and South Korea are the top GDP growing countries, Germany and the USA the top in terms of emission reductions.

Structural change is playing a role. Besides a unique case for South Korea (production-based SC change), all figures are showing a contribution to emission reduction. Top figures are for Mexico, Turkey and USA (consumption-based), and UK, USA, Canada, Mexico (production-based).

5 Sustainability, structural change and economic growth

Evidence from the previous section may suggest that structural change patterns differ across countries with different levels of GDP per capita in terms of their magnitude. This section evaluates the extent to which economic growth is correlated with emissions and, more specifically, to changes in emissions due to structural change.

To evaluate the extent to which economic growth (and not the level of production) is correlated with SCE-related factors, the following regression is used, separately for different measures of emission intensity:

$$\Delta \log(Emissions\ per\ capita_{it}) = \tau_t + \beta \Delta \log(GDP\ per\ capita_{it}) + \varepsilon_{it} \qquad (4)$$

We consider four measures of emission intensity: (i) consumption-based emissions; (ii) consumption-based emissions due to structural change; (iii) production-based emissions; (iv) production-based emissions due to structural change. Results are reported in Table 4. Overall, we observe that the elasticity of consumption-based (column 1) and production-based (column 3) emissions per capita with respect to economic growth is large and strongly significant. The estimated values point to a relative decoupling evidence as estimated elasticities are below one. Elasticities are higher as far as the consumption side is concerned. Elasticities consistently decrease in time. It is worth noting that the post crisis 2010-15 period witnesses halved values of elasticities, again always higher for the consumption side.

On the contrary, the change in emission per capita due to structural change (columns 2 and 4) does not appear to be related with economic growth. In the only case where the coefficient is significant, the economic significance is very low (column 4). As it descriptively appeared in Table 3, SC has occurred over the period along all development levels, being a force – differently from technological development – that exerts its effects independently on growth per se. Different models of economic development, institutional factors, industrial policies, geographical factors could possibly be more relevant and worth being investigated in future works. The typical ‘average’ econometric coefficient is not capable of capturing the very specific differences that SC factors may present across different models of economic development and geographical areas, independently on mere growth. This is also a signal that only growth figures often present limitations in explaining (correlating with) development issues.

Table 4 – Relationship between GDP per capita and emissions per capita (first differences)

	(1) Growth in total consumption-based emissions	(2) Growth in structural change component of consumption-based emissions	(3) Growth in total production-based emissions	(4) Growth in structural change component of production-based emissions
	Panel A - Average elasticity to GDP growth			
Growth in GDP per capita	0.697***	-0.00962	0.521***	0.00611
	(0.0755)	(0.0368)	(0.0581)	(0.0342)
R squared	0.316	0.131	0.409	0.407
N	2000	2000	2000	2000
	Panel B - Elasticity to GDP growth for 1995-2010			
Growth in GDP per capita	0.794***	0.00724	0.598***	0.0541**
	(0.0870)	(0.0427)	(0.0667)	(0.0228)
R squared	0.310	0.160	0.269	0.527
N	1500	1500	1500	1500
	Panel C - Elasticity to GDP growth for 2010-2015			
Growth in GDP per capita	0.335**	-0.0700	0.286***	-0.0615
	(0.145)	(0.0640)	(0.0782)	(0.103)
R squared	0.304	0.0729	0.587	0.250
N	600	600	600	600

OLS weighted with population on first-differenced data. Standard errors clustered by country in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Year dummies included in all regressions.

As we identified slightly different patterns of structural change across countries with different levels of GDP per capita, in Table 5 we report estimates split by quartile of GDP per capita in 1995.

Moving from a time oriented to a development oriented analysis of elasticities, some new insights arise: (i) in the second quantile, where large export oriented countries are present, consumption-based emissions elasticities are higher than production-ones, (ii) elasticities grow from the first to the fourth; advanced countries present consumption based elasticities that are twice as much, very close to unity; (iii) production based elasticities are higher in advanced countries and export-intensive emerging countries.

The three highlights confirm general expectations. Disaggregating by development levels, critical ‘sustainability hot spots’ can be highlighted with respect to the production side of export-oriented countries like China, and the consumption side of high-income countries. This evidence highlights the fragility of the current transition path towards sustainability, which has just witnessed the first signals of emission stabilisation worldwide.

As far as structural change is concerned, estimated coefficients in Table 5 re-assess that, even broken down by development stages, growth rates are not a factor that impact on the SC related emission trends.

Table 5 – Relationship between GDP per capita and emissions per capita (first differences) by quartile of GDP per capita in 1995

	(1) Growth in total consumption-based emissions	(2) Growth in structural change component of consumption-based emissions	(3) Growth in total production-based emissions	(4) Growth in structural change component of production-based emissions
	First quartile of GDP per capita in 1995			
Growth in GDP per capita	0.475***	0.0118	0.365*	0.0321
	(0.148)	(0.128)	(0.195)	(0.154)
R squared	0.464	0.509	0.546	0.618
N	440	440	440	440
	Second quartile of GDP per capita in 1995			
Growth in GDP per capita	0.751***	0.000125	0.834***	0.0839
	(0.139)	(0.0453)	(0.0513)	(0.143)
R squared	0.907	0.903	0.898	0.945
N	120	120	120	120
	Third quartile of GDP per capita in 1995			
Growth in GDP per capita	0.617***	0.0673*	0.344**	0.0388
	(0.223)	(0.0377)	(0.131)	(0.0606)
R squared	0.199	0.178	0.387	0.169
N	620	620	620	620
	Fourth quartile of GDP per capita in 1995			
Growth in GDP per capita	0.856***	0.0890	0.509***	0.0221
	(0.0992)	(0.0639)	(0.0821)	(0.0657)
R squared	0.368	0.267	0.262	0.545
N	820	820	820	820

OLS weighted with population on first-differenced data. Standard errors clustered by country in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Year dummies included in all regressions.

6 Conclusions

Over the investigated period of time (1995-2015), greenhouse gas emissions per capita grew by about 10 percent. Countries with either GDP, population or CO_2 emissions greater than 1 percent of the world total were considered in the analysis. The growth, however, was slower than the one of GDP per capita, that grew, over the same period, by about 60 percent. This evidence confirms the 'relative decoupling' evidence that science and media recently discussed. The world economy has achieved the first target, namely slowing emission growth. The second target is the stabilization and then reduction of greenhouse gas emissions, which should be around 80-90% compared to 1990 in order to avoid catastrophic events or, to be more precise, to enter an area of very high uncertainty characterised by un-estimable costs.

A first macroeconomic overview of the data suggests a moderate contribution of structural change to the decrease of overall emissions over 1995-2015. Even if the disaggregation of sector and country data indicates that small changes in the sectoral composition of consumption or production are likely to induce relevant changes in aggregate environmental pressures (especially if changes happen in sectors that have very high or very low emission intensity), SC remains a slow evolving force behind sustainability transitions.

The change in emission per capita due to structural change does not appear to be related with economic growth. SC appears as a force – differently from technological development – that exerts its effects independently on growth per se. what we have witnessed over the past decades is that pretty interestingly different 'models' are behind economic development – both in high income and emerging – developing countries. Institutional factors, industrial policies, geographical factors were possibly more relevant to explain those changes. As said before, polices aimed at reinforcing and achieving sustainability could be an additional important driver of sustainable SC in the next future.

The 'sustainable consumption and production' perspective adds knowledge to the picture. The elasticity of consumption-based and production-based emissions per capita with respect to economic growth is large and strongly significant in the econometric analyses. The estimated values re-emphasise the relative decoupling evidence: the estimated elasticities are below one. It is worth noting that the elasticities are higher as far as the consumption side is concerned and consistently decrease over time, marinating the descending pattern in the post crisis 2010-15 period.

Thank to structural change, production-based emissions per capita would have shrunk by almost 30 percent while consumption-based emissions per capita would have shrunk by almost 40 percent: compared to the actual trend (+10%), the contribution of structural change reduced production- and consumption-based emissions by respectively 40 and 50 percent.

Finally, decomposition analysis by country conveys interesting results around the heterogeneity of environment and development pillars. We note that poorest countries of Africa and East Asia show relative decoupling and relevant SC factors behind their CO_2 emissions. As examples, Vietnam and India show very different performances even if starting from the same GDP per capita: while India shows decoupling trends and structural change at play, Vietnam is not decoupling growth from emission generation; structural change as well seems not in support of emission reduction in this case. Within emerging countries, China represents most of the second income quartile: Chinese growth in GDP and emissions is very high, but GDP is growing three times as much as emissions. Structural change is one of the forces behind this relative delinking. SC is also a force, and more important than in China, in other countries like Nigeria, Philippines, Pakistan, and Egypt. As far as advanced countries are concerned, GDP growth increased faster than emissions, with SC being usually a force behind the reduction of emissions.

SC is relevant for sustainability, but it is a rather slow evolving factor: the sectoral reshuffling that moves the economy towards more efficient and greener sectors is a long run force. The process could be accelerated through environmental policies. As policies affect relative prices of fuels and energies, influence demand patterns, induce eco-innovation and knowledge, more stringent policies to tackle environmental challenges might help enhancing SC forces. General policies (e.g. uniform carbon tax) and especially sector oriented earmarked policies (e.g. recycling back ecological tax revenues to specific sectors and firms through incentivising schemes, or merely supporting R&D and innovation) would give sectors the opportunity to enhance their role along the sustainability-oriented path.

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