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Research article

Exploring socio-economic externalities of development scenarios. An analysis of EU regions from 2008 to 2016

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ABSTRACT

A great debate around development scenarios has come to define conversations around the economy and the environment, two dimensions that struggle to find a proper balance. In this paper we apply unconditional growth model analyses to a new and unique dataset of European regions between 2008 and 2016 and identify four development scenarios – green growth, green de-growth, black growth and black de-growth – characterized by different relationships between CO_2 emissions and economic growth. We then map European regions across these four scenarios and describe the differences that occurred among regions in terms of socio-economic externalities, mainly competences, investments and well-being. Drawing on our analyses, we contribute to the debate on development scenarios and ecological macro-economics, as well as discuss implications for sustainability policy and research.

1. Introduction

Development scenarios (DSs) toward sustainability has come to define conversations around the economy and the environment—two dimensions struggling to find a proper balance (Cairns and Martinet, 2021; Hardt and O'Neill, 2017; Farley & Voinov 2016; Lorek and Spangenberg, 2014, UNEP, 2011). Among sustainable DSs, green growth has been widely recognized as the desirable one, allowing to ensure both economic growth and natural assets preservation (Hickel and Kallis, 2020). However, the transition towards sustainable levels of development requires fundamental and multidimensional shifts encompassing the economy and the society as a whole (Davies, 2013; Markard et al., 2012; Skellern et al., 2017). Current evidence suggests that green growth may be able to promote income generation and reduce environmental degradation, however it also improves unemployment rates and inequalities (D'Alessandro et al. 2020).

On the other hand, the de-growth literature stakes a more radical position on the question of whether economic growth can co-occur with decreasing environmental impact. The statement is that the two are incompatible, as the downscaling of economy is regarded as the only feasible way to meet the planetary boundaries and limit the climate change (Kallis, 2011; Stoknes and Rockström, 2018). However, drawbacks emerge also in this scenario, as economic downturns lead to high unemployment rates (D'Alessandro et al., 2020).

In response, several scholars have sought to align their arguments with one or the other perspective (Jackson and Victor, 2019), generating heterogeneity of positions. With our study, we do not intend to add a new perspective to the dilemma of which DS towards sustainability is either feasible or preferable. Rather, we explore that because economies are embedded within societies (O'Neill, 2020), any investigation of the interlink between economic and environmental dimensions must include complementary factors that can impact the entire society (Jöst and Quaas, 2009; Krausmann et al. 2017). Capasso et al. (2019) suggest that employees' competences, as well as investments in research, development and equipment, might represent socio-economic factors supporting the green growth. Additionally, the de-growth literature (Kallis, 2011) emphasizes the concept of well-being as a relevant factor to include in the analysis of DSs, as, together with environmental preservation, it is identified as the desirable trade-off for abandoning the strive towards economic growth, *de facto* accepting that there may be a limit to growth (Cairns and Martinet, 2021), in favour of the de-growth (Hardt et al., 2021; Heikkinen, 2015).

Additionally, an exclusive focus on sustainable DSs, which only refer to reducing environmental degradation, might be limiting, as empirical evidence suggest that other scenarios characterized by increased environmental impact might also occur. Exploring socio-economic

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externalities without considering these additional scenarios of increased environmental impact, would not allow to capture the whole picture regarding DSs and result as a relevant lack in the field.

Moreover, we argue that the lens to be applied in order to evaluate all these scenarios invites a relevant change of perspective. The analysis of economic growth, in tandem with an attention towards environmental impact, has generally adopted nation-wide investigations able to identify the dynamics of the process on a macro level (Hou et al. 2020; Li et al. 2019; Martin and Saikawa, 2017; O'Neill et al. 2018). This approach has been questioned by several authors (Capasso et al. 2019), as DSs are large, complex and global in nature, and are also instantiated in local, territorially bounded contexts (Brenner, 1998). Recent results presented by (Mura et al. 2021) empirically prove that sub-national geographical scales carry additional and multifaceted information about sustainability transition (ST) pathways. Even within the same country, geographical areas vary widely in not only their levels of environmental impact and economic growth, but also in their income inequality, innovation activity and employment (Han et al. 2020; Breau et al. 2014; Glaeser et al. 2009). Therefore, in order to fully capture the implications for the society, scholars need a stronger focus on regional and local actions (Krausmann et al. 2017; Bretschger and Karydas, 2019; La Torre et al. 2019; Sasse and Trutnevyte, 2020).

Combining these perspectives, we focus on the following interrelated research questions: *Which distribution across different DSs characterizes European regions? Which trend do socio-economic externalities show in relation to different DSs?*

From a methodological perspective, we focused on the industrial sector due to its high impact on the environment – as it generates about a third of the global greenhouse gases (GHG) emissions[1] (Fischedick et al., 2014) – and we applied unconditional growth model analyses (Tasca et al., 2009) to a new and unique dataset of European regions between 2008 and 2016. We then identified four DSs, characterised by different relationships between economic growth and environmental impact – which we label as *green growth, green de-growth, black growth* and *black de-growth.*

Our results map the distribution of European regions across the four DSs proposed. Interestingly, although EU regions spread across all four scenarios, more than half of the regions encompass a green growth pathway. Moreover, we described the differences that occur among the proposed scenarios in terms of socio-economic externalities related to competence development, industrial investments, and well-being of European citizens (Cuiyun and Chazhong, 2020; Hallegatte et al., 2018; Hallegatte and Rozenberg, 2017; Ravallion et al., 2000). Our findings open up policy questions about the optimal economic structure that a society needs to trigger significant changes, considering also the related externalities, like level of education, employment and investments.

We provide four contributions to existing literature. Firstly, we integrate extant evidence in the green growth literature (Capasso et al., 2019), by conceptualising four different DSs and empirically exploring their development across EU. Secondly, we consider the relevance of the spatial dimension, when analysing development scenarios by moving beyond national-level data and analysing the four DSs at the regional level (Bretschger and Karydas, 2019). Thirdly, we explore differences in socio-economic factors that occur across the different scenarios proposed (Krausmann et al. 2017). Finally, we contribute to the de-growth literature (La Torre et al., 2019), by focusing on the concept of well-being and by introducing a more comprehensive operationalisation that integrates employment level and risk of poverty into this construct.

2. Methods

The goal of our work is to provide a framework to help EU regions (i) visualize their positioning along the complex and long-term environmental transitional process and (ii) understand the socio-economic implications of their positioning. In order to reach such goal, we developed a comprehensive dataset, including CO_2 equivalent (CO_2e) emissions and socio-economic data for EU regions. Based on two parameters, i.e. CO_2e and Gross Value Added (GVA), we clustered the regions into four DSs and we, then, applied a statistical model to evaluate the externalities of transitions outlined.

Our analyses are based on a panel dataset of 2,529 observations, derived from a sample of 279 European regions observed along a nine-year period from 2008 to 2016. The regions were defined at the NUTS (Nomenclature of Territorial Units for Statistics) 2 level, based on EUROSTAT territorial subdivision, for which we collected environmental and socio-economic data. NUTS are defined using administrative borders (where possible) and population thresholds, with the aim of describing the territory through socio-economic data. They are organized in different levels, from 0 (corresponding to Country borders) to 3 (corresponding to, e.g., Italian "provinces"). NUTS 2, in particular, coincides with different geographical units, depending on the national framework, but overlaps with Regioni in Italy, Communidades autónomas in Spain, or the Regierungsbezirke/nonadministrative aggregations in Germany (Eurostat, 2015).

2.1. Variables and data collection

The model encompasses a framework for evaluating the concurrent changes of Greenhouse Gases (GHG) emissions, GVA from the industrial sector, and socio-economic variables. We used the following data sources to populate the input database for the model: European Emission Trading System (EU ETS) (European Commission, 2003) for industrial emissions values and EUROSTAT for socio-economic variables. The former reports GHG emissions data at the industrial plant level, covering 11 high-energy intensity sectors and about 45% of the total EU emissions. GHG emissions data are reported in terms of carbon dioxide equivalent emissions (CO_2e), i.e., based on their global warming potential compared to CO_2. Primary data were aggregated at the NUTS 2 level to obtain the emission value of ETS-industries in the region. Regarding EUROSTAT, we used GVA as a measure of the industrial sector's economic growth (based on NACE Rev. 2, Statistical classification of economic activities in the European Community). This measure can be reasonably regarded as deriving from the same source as the CO_2e emissions dimension, thereby providing a direct comparison.

In addition, we considered several socio-economic statistics to assess the externalities of industrial transition scenarios. The selected variables were grouped into three main areas: competences, investments, and well-being.

Competences. Scientists and Engineers data were collected from the EU Labour Force Survey and made available from Eurostat at NUTS 2 level. *Scientists and Engineers* encompasses personnel who possess scientific or technological training, create scientific knowledge and engineering principles, and operate as high-level administrators and executives. They often represent the core of R&D and innovation at the industrial level. Meanwhile, we collected *Tertiary Education* data based on the various education levels of the International Standard Classification of Education[2], in this case, at level 5–6, as a percentage of the population aged 25–64 years.

Investments. Intramural expenditure in Research and Development (R&D) reflects the amount of spending on research and experimental development—including knowledge capital, culture and society and the use of this capital to design new applications—in terms of the percentage

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[1] The industry accounts for 32% of the total direct and indirect GHG emissions, while the other sectors are distributed as follows: 24.3% for Agriculture, Forestry and Other Land Use (AFOLU), 18.4% for buildings, 14.3% for transport, 11% Energy.

[2] ISCED 2011.

of Gross Domestic Product (OECD, 2002). *Industrial Gross Fixed Capital Formation (GFCF)* encompasses the acquisition of tangible assets, particular machinery and equipment, vehicles, dwellings and other buildings, as performed by resident companies in the area.

Well-being. Many different conceptualizations of well-being have been proposed by researchers, given the multidimensional nature of the construct. In our work, we refer to employment and poverty. *Industrial Sector Employment* (thousands of persons) was derived from the EU Labour Force Survey and reflects people's work conditions as relevant dimension for guaranteeing economic well-being (McGillivray, 2007). The *Risk of Poverty* indicator is measured as the sum of persons who are at risk of poverty due to social transfer, material deprivation or low work intensity at family level and focus the attention on the social and living dimensions of well-being[3].

2.2. Clustering procedure

The first step involved defining the clustering framework, which entailed evaluating the gradients between the level of GHG emissions (i.e., CO_2e) and GVA, at the start and end points of the analysis. This led to a reference system based on the two dimensions defined (i.e., ΔCO_2e and ΔGVA), with the origin point of ΔCO_2e and ΔGVA set to zero. Thus, we arrived at four quadrants where ΔCO_2e and ΔGVA have different signs. We defined each cluster based on a two-block label: the first depending on the sign of ΔCO_2e ("Green" where the GHG emissions decreased during the period of analysis; "Black" where GHG emissions increased) and ΔGVA ("Growth" or "De-growth", respectively signaling a positive or negative gradient of GVA). We focused on the quadrant of green growth in order to further delineate decoupling (Deutch, 2017; Krausmann et al. 2017) (i.e., negative ΔCO_2e and positive ΔGVA) into two forms: relative decoupling, where the negative ΔCO_2e is lower (in absolute terms) than ΔGVA; and absolute decoupling, where the negative ΔCO_2e is higher (in absolute terms) than ΔGVA. With our scheme we, thus, retrace and adapt the elasticity model proposed by Tapio (2005) to characterise the decoupling states between carbon emissions and economic growth, first moving the focus from economic to environmental component and, second, integrating it with the notions of *relative* and *absolute* decoupling within the green growth quadrant. Based on the defined rules, we then clustered the EU regions into five groups and proceeded with the following analyses. Fig. 1 reports the four development scenarios.

2.3. Analysis of variance (ANOVA) and unconditional growth modelling

In order to study externalities related to different DSs, we performed analyses of variance (ANOVA) by comparing the mean values of each variable in our dataset across clusters. This analysis allows us to capture statistically significant differences of the socio-economic dimensions under investigation over time and among the four DSs. The ANOVA was conducted independently for each year of the period of analysis. Additionally, we conducted the Scheffe's post hoc test.

We then proceeded with the unconditional growth modeling in order to describe temporal patterns in our data, as time represents a fundamental predictor of evolutionary phenomena (Singer and Willett, 2005). This technique allowed us to evaluate the significance of the intercept (i.e., starting point) and the slope (i.e., growth rate) of our socio-economic variables in relation to the five clusters (Walls et al., 2007). Unconditional growth modelling accounts for both the fixed (i.e., the expected trajectories for the overall sample) and random (i.e., the estimated variability of each observation compared to the group variable) effects. The general equation representing the model is as follows:

$$y_{tj} = \pi_{0j} + \pi_{1j}\mathrm{time}_{tj} + e_{tj} \quad t = 1, \ldots, T_j; j = 1, \ldots, N_k$$

Where t represents the time; j the cluster; y_{tj} the socio-economic variables at time t for cluster j; π_{0j} and π_{1j} the intercept and the slope for each cluster, respectively; time_{tj} the numerical measure of time at time t for each observation (NUTS 2) and group variable (cluster) (for our specific analysis, it is equal to 2008–2016); and finally, e_{tj} the time- and cluster-specific residual, assumed to be normally distributed with a zero mean and homoscedastic variance.

The level-2 equations are

$$\pi_{0j} = \beta_0 + r_{0j}$$

$$\pi_{1j} = \beta_1 + r_{1j}$$

where β_0 and β_1 are the intercept and slope common to all clusters (i.e., fixed effects), representing the means of the intercepts and slopes of the growth trajectories for all the NUTS 2 regions; r_{0j} and r_{1j} (i.e. random effects) represent the deviation of the intercept and slope of each observation around their group-specific mean trajectories.

Finally, in order to evaluate the differences across clusters we calculated the intraclass correlation coefficients (ICC). This allowed to compare the relative magnitude of variance components between different clusters at the initial status (i.e. intercept) and over time (slope). Specifically, the intercept describes the proportion of the total variance attributable to the differences across clusters at the initial status, whereas the slope evaluates the proportion of variance due to differences across clusters in their rates of change.

Overall, these analyses identified four transition scenarios and allowed us to study socio-economic variables comparing them across the different scenarios.

3. Results

3.1. The four development scenarios across european regions

Fig. 2 shows the distribution of European regions across the identified scenarios. The first two scenarios have a reduction of CO_2e emissions as their common characteristic. For this reason, we label them as "green". *Green de-growth* ($\Delta CO_2e < 0$ and $\Delta GVA<0$) comprises 45 regions, with an average CO_2e reduction of 31.6% and an average GVA reduction of 11.4%. *Green growth* ($\Delta CO_2e < 0$ and $\Delta GVA>0$) comprises 120 regions, with an average CO_2 reduction of 32.5% and an average increase in economic growth of 21.6%. Within this group, we also separate between alternative scenarios: relative decoupling and absolute decoupling. Relative decoupling is defined as a reduction of the CO_2e percentage that is lower than the increase in the percentage of GVA, while absolute decoupling is defined as a reduction in the CO_2e percentage that is greater than the increase in the percentage of GVA (Deutch, 2017; Krausmann et al. 2017). The model shows that 38 regions are in a relative decoupling scenario, with an average CO_2e reduction of 13.6% and an average GVA increase of 37.5%. On the other hand, 82 regions belong to the absolute decoupling scenario, with an average CO_2e reduction of 41.3% and an average GVA increase of 14.3%. The other two scenarios show an increase in CO_2e emissions; thus, we label them as "black". *Black de-growth* ($\Delta CO2e > 0$ and $\Delta GVA<0$) includes 11 regions, with an average increase of CO_2e emissions of 65.2%, and an average GVA decrease of about 12.7%. *Black growth* ($\Delta CO_2e > 0$ and $\Delta GVA>0$) comprises 39 regions that show an increase in CO_2e emissions (+59.2%) alongside an increase in economic performance (+24.9% in GVA).

3.2. Evolution of socio-economic externalities over time

All variables, except *Tertiary Education*, display significant values of ANOVA analysis, in several years (see Supplementary materials 1,

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[3] Other conceptualizations included the absence of diseases and infirmity, psychological aspects, personal growth, etc. (Cooke et al. 2016).

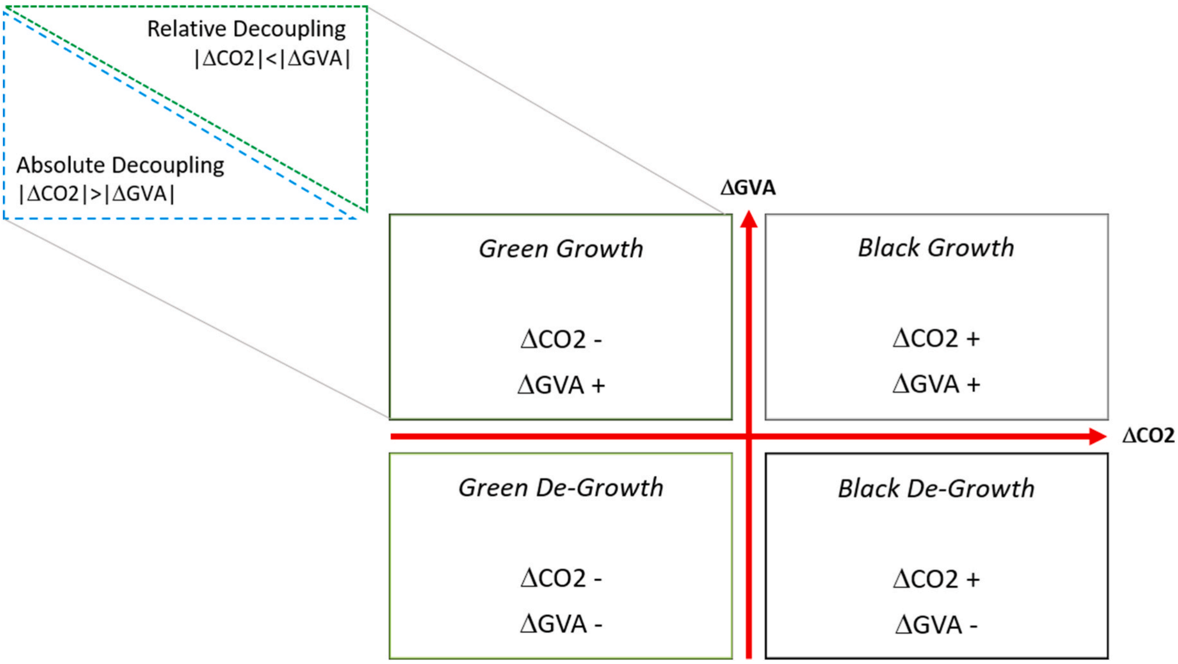


Fig. 1. Conceptual framework: the four DSs.

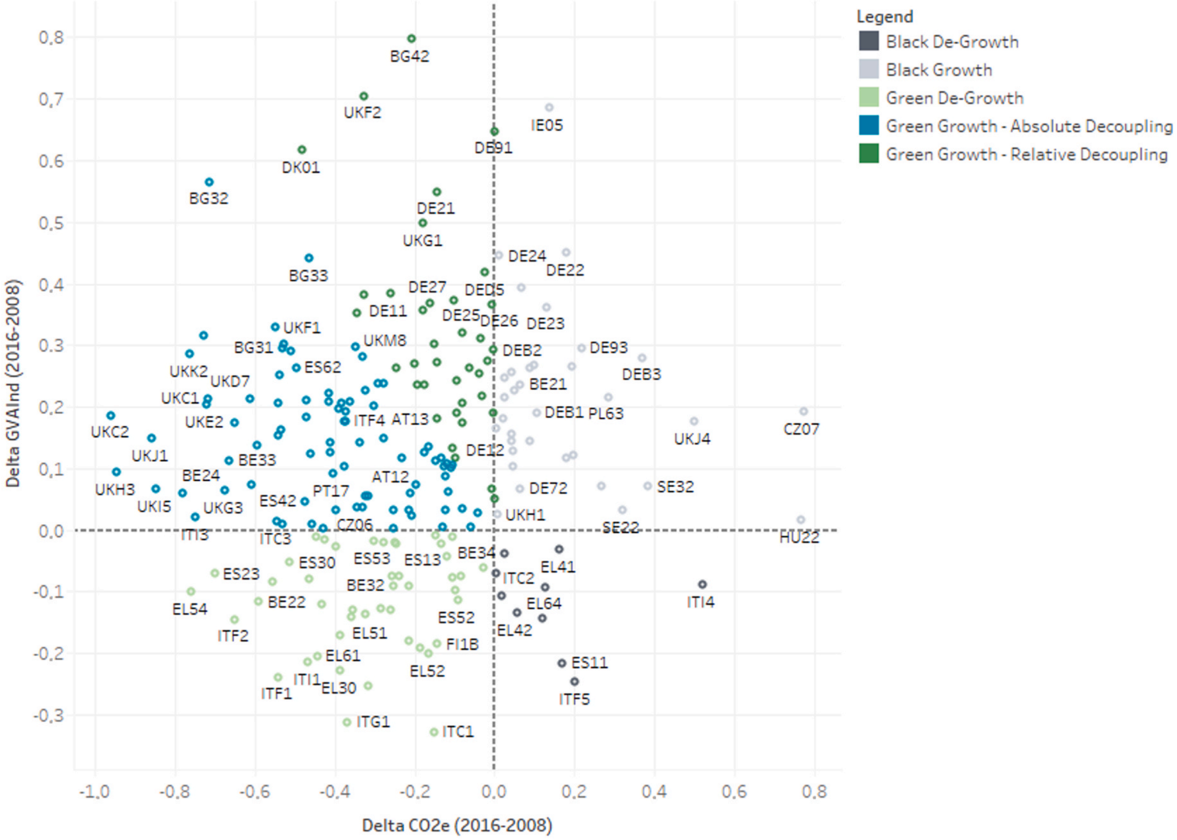


Fig. 2. Distribution of European regions across the DSs.

Table 1, for complete results). Therefore, differences emerge across clusters. To further explore these differences, we conducted Scheffe's test (see Supplementary materials 2, for complete results).

In order to account for the effect of time in our analysis, we thus proceeded with unconditional growth modelling, for both fixed and random effects. The significance of the fixed effects indicates differences between individual trajectories and the estimated mean for the whole EU, in terms of starting point (intercept) and variation over time (slope). All variables present significant differences in both intercept and slope, except for *Industry Gross Fixed Capital Formation* and *Industry*

Employment, which present significant values for the intercept only. The random effects estimate whether the individual trajectories of the clusters significantly differ from the overall one. None of the variables reports significant values (see Supplementary materials 1, Table 2, for complete results). For this reason, we calculated the ICCs to explore the proportion of the total variance across clusters related to their initial status and their rate of change. Our results show that the variability among clusters resides more in their initial status, i.e. intercept, rather than in their rate of change, i.e. slope, except for *Tertiary Education* and *Industrial GFCF*. The residual part of the covariance is, nevertheless, above 75% of the total and this would suggest that future developments of the study should explore covariates explaining residuals (see Supplementary materials 1, Table 3, for complete results).

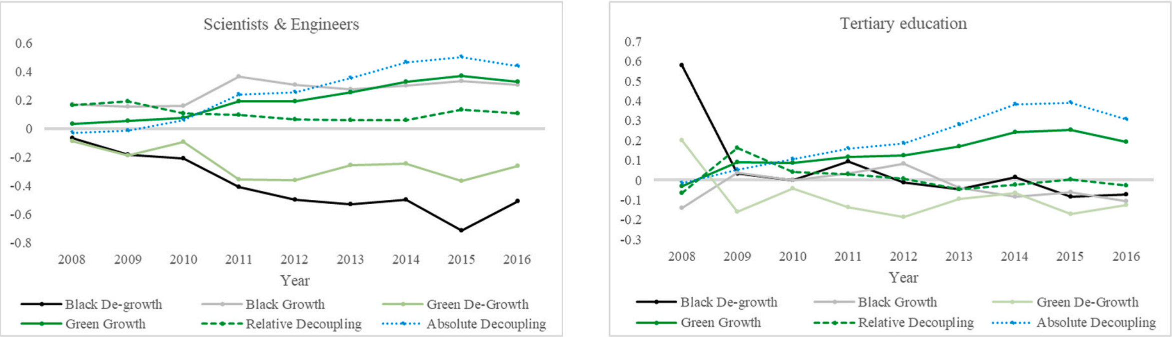
3.3. Socio-economic externalities across sustainable development scenarios

Based on the ANOVA and unconditional growth modelling, Figs. 3–5 show, for each SD considered, the trends in socio-economic externalities generated along the three macro categories of indicators: competences, investments and well-being. In appendix, we report the details of the socio-economic externalities across European regions.

Competences. Fig. 3 plots two components related to competence development: *Scientists & Engineers*, which captures the technological dimension of competences (Fig. 3a), and *Tertiary Education* (Fig. 3b), which refers to the development of both technical and social competences. Over time, both green and black de-growth reached values below the mean and showed decreasing trends with regard to a technologically skilled labour force, with black de-growth registering the biggest loss of skill (between −0.07 in 2008 and -0.51 in 2016). Green growth and black growth, instead, were characterized by above-average values and a gradually increasing trend in the development of scientists and engineers, with a minimum value of 0.03 in 2008 and 0.33 in 2016. Absolute decoupling showed the best trend, starting with a value of −0.03 in 2008 and ending with a value of 0.44 in 2016. Moreover, the relative decoupling scenario showed an intermediate trend relative to all the other scenarios, with an average level of technological competences of 0.11. The situation is different for the rate of tertiary education graduates. In this case, all the scenarios tend to have values that were below the mean or slightly above average over time, with an average in the time period of −0.02. The only exception is the scenario of green growth, which showed a better and increasing trend (from −0.03 in 2008 to 0.19 in 2016) thanks to regions in absolute decoupling, with a maximum value of 0.39. It is interesting to note that, in terms of developing social competences through tertiary education, the worst trend was registered by green de-growth regions, with an average value of −0.09 in the period 2008–2016. Black growth regions, on the one hand, displayed high levels of scientists and engineers, but low levels of tertiary education.

Investments. Fig. 4 plots the two components related to investments: *Intra-mural R&D* (Fig. 4a), which captures the intangible dimension of investments, and *Industry Gross Fixed Capital Formation* (Fig. 4b), which mainly refers to the tangible dimension. In terms of investments, the black de-growth scenario was the worst performer in both dimensions (with an average value of −0.66 and −0.63 for *Intra-mural R&D* and *Industry Gross Fixed Capital Formation*, respectively). Its trends were quite constant over time and significantly distant from those of the other scenarios. On the opposite side, the relative decoupling dimension of the green growth scenario was the best performer, with values above the mean and increasing trends in both dimensions (with average values around 0.5 in both). The highest discrepancy in respect to the other scenarios can be observed for the *Industry Gross Fixed Capital Formation*, where the value in 2008 and in 2016 were 0.83 and 1.25 points higher in respect to the black de-growth scenario. The trends for the absolute decoupling category were in the middle range for both dimensions; the trend was rather constant for intra R&D (with an average value of −0.02), but decreasing for the *Industry Gross Fixed Capital Formation* (from 0.01 in 2008 to −0.15 in 2016). Regarding the green de-growth category, we observed a slight decrease over time in both dimensions, with values ranging from −0.16 to −0.19 for intra R&D and from 0.04 to −0.25 for industry gross fixed capital formation.

Well-being. Fig. 5 plots two components related to well-being: *Industry Employment* (Fig. 5a) and *Risk of Poverty* (Fig. 5b). As far as industry employment, black de-growth showed very low values with an average value of −0.86 in the nine years considered. This category follows a very dissimilar evolution in respect to the other scenarios, where the values are slightly below or above the mean. In all the cases, however, the trend is rather constant over time. The relative decoupling dimension of green growth displayed the highest values (with a maximum of 0.42), followed by black growth (0.10), absolute decoupling (−0.01) and finally green de-growth (−0.18). As far as the dynamic over time, all the scenarios showed a constant or slightly decreasing trend, except for relative decoupling, which is characterized by an overall increasing evolution of 0.16 points. As far as the *Risk of Poverty* factor is concerned, the evolution over time is above the mean for regions characterized by a black de-growth transition (with a minimum value of 0.35 and a maximum value of 1.12). From 2008 to 2016, these regions registered a 0.25-point increase in the risk of poverty. While the green de-growth scenario presented lower values on this factor, it still showed an average value of 0.26 points—a problematic situation in terms of poverty. As far as the green growth scenario, regions in relative decoupling showed the best performance, both in terms of industry employment and risk of poverty. However, the difference with respect to the other scenarios was more pronounced in *Industry Employment*. In the case of *Risk of Poverty*, its values were quite similar to regions in a black growth transition. Likewise, absolute decoupling displayed an intermediate trend with an average value of −0.03 in the period 2008–2016.



a   b

Fig. 3. Competences: Scientists & engineering and tertiary education.

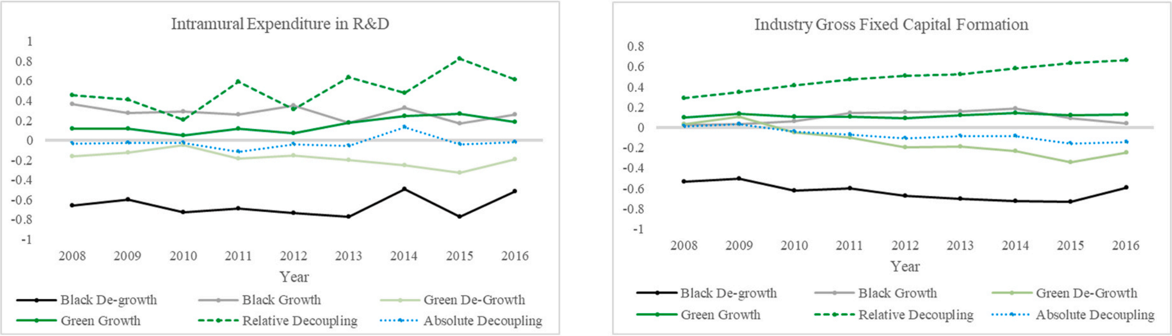


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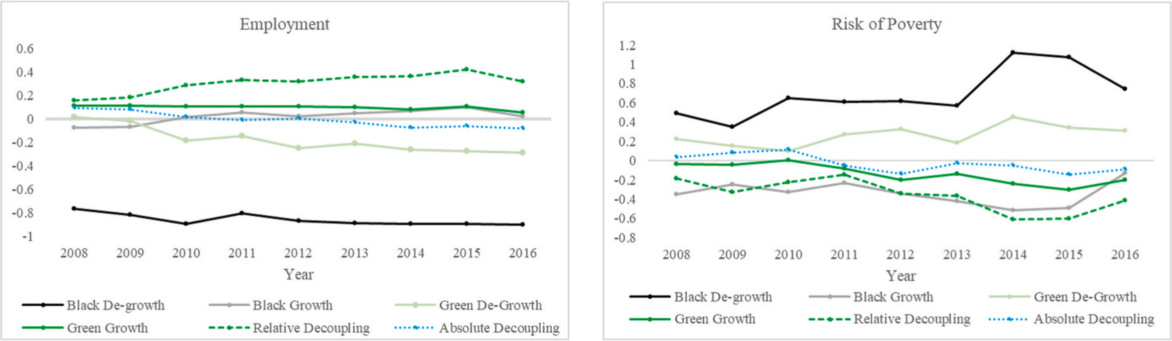
Fig. 4. Investments: Intramural R&D and industry gross fixed capital formation.



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b

Fig. 5. Well-being: Industry employment and risk of poverty.

4. Conclusions

4.1. *Discussion of main results*

There is a common understanding that macroeconomic processes—such as the financial system, labour markets, income distribution, and innovation—need to be considered in their environmental context (Cairns and Martinet, 2021; Hardt and O'Neill, 2017; La Torre et al. 2019). Our paper responds to that call by striving to develop better analytical frameworks for understanding economy-environment interactions on a macro-scale, as well as provide tools to manage the transition towards a sustainable economy.

Our analyses investigated the distribution of four different sustainable development scenarios in the industrial sector in Europe and econometrically explored their related socio-economic externalities. Additionally, the analyses conducted at the NUTS 2 level allowed us to hone in on existing interactions among environmental performance, economic results and social outcomes capturing shades of the phenomena at regional scale (Bretschger and Karydas, 2019; Hassink et al. 2019).

Our results identified two scenarios featuring increased emissions. Black growth and de-growth are occurring among European regions, but they should be avoided if Europe is committed to reaching the emission targets proposed by the EU Green Deal (European Commission, 2019). Both scenarios showed an increase in emissions, but diverse performances in terms of economic growth and social outcomes. Black de-growth showed the lowest employment rate and the highest risk of poverty, as well as the lowest levels of R&D investments, gross fixed capital formation, and competences. This scenario includes only 11 regions, some of which have switched from industrial production to public administration, with increased energy demand for households and urban areas (e.g., Bruxelles in Belgium). Other regions acted as hubs for power and heat generation, resulting in higher emissions alongside a lower rate of employment and wealth generation (e.g., Lazio in Italy and Galicia in Spain).

Conversely, black growth regions, representing the traditional growth model, deeply interlinked with environmental pollution and resource consumption, manifested reduced poverty alongside higher employment rates, R&D investments, and gross fixed capital formation. They also displayed high levels of scientist and engineers, but low levels of tertiary education. This scenario could signal a “cash cows” strategy, where companies operating in mature industries—having paid-off their carbon-intensive production systems—are trying to maximize the financial value of their investments. This situation emerges quite neatly in Hamburg (Germany), but also in Devon and Kent in the UK. The latter examples demonstrate that, even within the same country, geographical areas vary widely in not only their levels of environmental impact and economic growth, but also their socio-economic externalities. However, this scenario could prove to be dangerous, in particular during the current COVID-19 outbreak, as policymakers could remove environmental constraints in order to generate a faster, but wilder, economic recovery. The US provided an example of this in March 2020, when the Trump administration (Associated Press, 2020) decided to soften the threshold on CO_2 emissions for the automotive industry, introduced under the Obama administration, by lowering the annual reduction from 5% to 1.5%.

Coherently with previous studies in the field (EAA, 2019; Le Quéré et al. 2019; Madaleno and Moutinho, 2018; Villoria-Sáez et al. 2016), our results show that most EU regions are reducing CO_2e emissions, which suggests that developed countries are on a pathway towards decarbonization. However, this apparently positive result needs to be carefully considered and explored in greater detail, as there are emerging trade-offs that need to be properly managed (Parrique et al., 2019).

The green de-growth scenario is characterized by lower industrial employment, a higher risk of poverty, lower investments in innovation and fixed capital formation, and a lower rate of skilled labour force in terms of scientists, engineers, and tertiary education graduates. In these cases, reductions in CO_2e emissions seem to be driven mainly by a poor economic performance. Therefore, in this context, decarbonization does not represent an achieved policy target so much as a side-effect of the weakening of the economic structure. Examples of this scenario include the regions of Düsseldorf in Germany and Helsinki in Finland. Considering features displayed by this scenario in a broader perspective, the conditions underlying it may be resulting either from the end of an economic cycle or the onset of a global crisis, as repeatedly occurred in recent history, from petrol crisis in early '70s (Moomaw and Unruh, 1997) to COVID-19, and they should be turned into opportunities to boost low-carbon innovations by transition-oriented policies (Markard and Rosenbloom, 2020).

The green growth scenario, embodying the ideal from the economic and environmental perspective, shows more positive results in terms of social outcomes. However, the different means of decoupling CO_2e emissions from economic growth has produced two sub-scenarios. In relative decoupling, industrial employment and risk of poverty show the best results compared to all the other scenarios analysed. In addition, this scenario shows the highest results for investments in R&D and gross fixed capital formation. Finally, this scenario exhibits an intermediate value in terms of competences. In this context, more investments are made in terms of plants, labour force, machinery and R&D in order to foster incremental innovations—mainly of the technological and production type in order to make production processes more efficient (Severo et al. 2017). The modest environmental benefits are connected to the use of more efficient technologies or the switch to renewable energy sources (Suo et al. 2017), obtained thanks to investments in R&D and equipment. These scenario, more than others, expresses the complexity of ST study: even if positively performing, in terms of decoupling of CO_2e emissions from economic growth, in fact, it encompasses regions where a gradual transition is taking place, but time seem not mature for and abrupt and fundamental shifts of the system, as required for ST. Examples of this scenario include the South Yorkshire and Leicestershire regions in the UK, and Stuttgart in Germany (Rowlatt, 2020).

Compared to relative decoupling and black growth, absolute decoupling shows the worst values in industrial employment and the risk of poverty. Furthermore, investments in R&D and gross fixed capital formation are lower than relative decoupling and black growth, but comparable to the green de-growth scenario. Meanwhile, this scenario features the highest level of competences—both in terms of technical skills (measured by the number of scientists and engineers) and broader competences (reflected in high levels of tertiary education) (Ashton et al. 2017; Bowen et al. 2012). These competences might stimulate two transition pathways: moving production offshore and new service-oriented business models.

On the one hand, a combination of managerial skills and Keynesian-type short-term profit emphasis (Lavoie, 2014) led firms to outsource production processes to more cost-effective geographical locations. Concurrently, these areas exhibited limited investments in research, innovation and equipment. One example is the Midlands in the UK, which outsourced most of its productions to developing countries such as India or China (Hardt et al. 2017; Steinberger et al. 2013). On the other hand, these skills supported either the design of innovative business models focused on servitization and the sharing economy, or a switch from manufacturing to services; in either case, firms reaped greater financial returns alongside lower environmental impact and resource use (Mura et al. 2020). This is the case of Outer London, Berkshire, Buckinghamshire and Oxfordshire (Chang and De Búrca, 2016).

Of course, these solutions do not solve environmental issues. Outsourcing production systems only reduces local emissions, while displacing them to other geographical areas. Additionally, our data showed an overall reduction of CO_2e emissions of 4.6% per year in the absolute decoupling scenario: a value that is much lower than the proposed reduction target of 14% (Masson-Delmotte et al. 2018) if we want to keep the carbon budget of 420 Gt available on a global scale (Jackson and Victor, 2019). Finally, the introduction of innovative business models focused on services rather than manufacturing processes contributed to a reduction of industry employment and an increase in the risk of poverty. In conclusion, even absolute decoupling may be insufficient, and technology alone cannot trigger the significant changes required. Instead, we need to radically rethink the economic structure of society. We need to develop different skill sets that move beyond profit-maximization logics and give equal attention to environmental and social outcomes. This includes a structural change in how goods are produced and consumed, as well as the ability to develop changing work patterns and different business models (Giampietro, 2019; Hardt and O'Neill, 2017).

4.2. Contributions and directions for future research

With our paper we advance our knowledge on two main streams of research literature: the green growth, by conceptualising and analysing other DSs, and the degrowth literature, by operationalising the concept of well-being.

First, we contribute to the *green growth literature* by elaborating on the framework proposed by Capasso et al. (2019). In their work, the authors suggest that factors for the study of green growth may be grouped into the three dimensions of (i) spatial scales (i.e., different level of analysis, from local to global) (ii) policy rationales (i.e., which address different types of failures inhibiting sustainability transitions), and (iii) facilitating conditions for green growth (i.e., presence of institutions, technologies, capabilities and resources). Starting from this contribution, we elaborated the framework along two main directions. On the one hand, instead of focusing exclusively on the green growth scenario, we enlarge the scope of the framework, by including the discussion of different types of DS such as green degrowth, black growth and black degrowth. We enrich the conversation by conceptualising DSs, mapping their distribution across EU regions and exploring the distinctive patterns of socio-economic variables along time. On the other hand, we advanced the investigation of the spatial scales and the facilitating conditions for DSs through a quantitative approach. In terms of space, we moved beyond the mere national level of investigation and we empirically tested socio-economic externalities along different DSs at a more fine-grained level of analysis, providing insights at the regional level (Bretschger and Karydas, 2019). In terms of facilitating conditions, we operationalised skills and capabilities proposed by Capasso et al. (2019), taking into consideration the competences of the private sector in terms of technical and tertiary education, investments in research, development and plants, and integrating the concept of well-being, deeply rooted into the degrowth literature (Kallis, 2011).

Second, considering well-being as an element of concern poses the issue of defining a measurement framework for it. In this sense, we contribute to the *degrowth literature*, where the concept of well-being has always been in the agenda of the characterising factor for DSs. Well-being is regarded as a key factor for sustainability (Kjell, 2011) and the desirable trade-off, together with environmental preservation, for abandoning the strive towards economic growth in favour of post-growth economy (Hardt et al., 2021; Heikkinen, 2015). Nevertheless, the lens for its evaluation has been mainly qualitative and inadequate in capturing its heterogeneous nuances and different components, focusing exclusively on employment or consumption modes (Bilancini and D'Alessandro, 2012; Heikkinen, 2015). With our work, we introduce a more comprehensive approach, by operationalising well-being not only through employment, but also with the inclusion of a composite indicator, capturing the risk of poverty, which supports the living conditions of the population. This approach not only adds value to the academic conversation, integrating social indicators to the evaluation of the interaction of macroeconomy and environment (La Torre et al., 2019), but also offers an additional instrument for evaluating the impacts of policies belonging to the Just Transition framework[4] (i.e. policies oriented to the transition towards a low-carbon economy where adverse impacts for labour force and communities are minimised).

Although these contributions, our study presents some limitations that open interesting research directions to be addressed by future works. While we use rich longitudinal data on socio-economic externalities, the use of EU-ETS data as the exclusive source for CO_2e emission data could be a limitation. Indeed, this leads to focus on particular industrial sectors (energy intensive sectors) and specific contaminants (GHGs). Nonetheless, the present analysis may still offer valuable insights in relation to meeting the ambitious international target of limiting global warming at 1.5 °C. Further studies could exploit satellite data (e.g., Copernicus Atmosphere Monitoring Service) to evaluate different contaminants (e.g., nitrogen oxides) and sources of contaminations (e.g., traffic, household heating systems).

With our work, we develop a dataset allowing analysis on environmental and socio-economic variables at a fine geographical scale, i.e. NUTS 2, allowing to capture the differences at sub-national level and the pathways of such variables over time. This approach, although innovative and promising for future development, inevitably presents a limitation related to data availability, which is not equally distributed along time and across countries in Europe, thus generating missing values in the dataset. To mitigate this issue, we perform a multiple imputation technique based on chained equations (MICE). MICE results are extremely effective in our case, since they generate less biased values in the case of panel data (Allison, 2002). In any case, future studies could develop analyses based on different sources of information, more complete time-series, or aggregated data at different NUTS levels.

Finally, we used Intraclass Correlation Coefficients as the final fit measure for our model, as they support the interpretation of our results. Future studies could further elaborate the model, for example by including additional covariates, such as specificities related to the different industrial sectors or different governance schemes within the EU countries, in order to facilitate and expand further statistical tests.

Credit author statement

Matteo Mura: conceptualization; project administration; methodology; writing – original draft; writing – review & editing; supervision Mariolina Longo: conceptualization; project administration; methodology; writing – original draft; writing – review & editing; supervision Sara Zanni: methodology; formal analysis; data curation; visualization; writing – original draft Laura Toschi: conceptualization; writing – original draft; writing – review & editing.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.117327.

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