SPES
Sustainability performances, evidence & scenarios

SPES Focus on WP 3

Beyond the numbers: what composite indices reveal – and conceal – about trade-offs and synergies in sustainability transitions

April 2025

Funded by the European Union

Funded by European Union's Horizon Europe Programme under Grant Agreement No. 101094551

Authors

François Combarnous - Bordeaux University, Bordeaux School of Economics

André Meunié - Bordeaux University, Bordeaux School of Economics

Eric Rougier - Team leader and researcher of the SPES project, Bordeaux University, Bordeaux School of Economics

Contributors and peer reviewers

Mario Biggeri,University of Florence; András Gábos, TARKI Social Research Institute; Luca Lodi, University of Florence; Pedro Salas-Rojo, London School of Economics and Political Science.

Acknowledgements

The authors would like to thank all SPES partners for their inputs provided in several SPES meetings and communications.

Cite as

Combarnous, F., Meunié, A., Rougier, E., (2025*) Beyond the numbers: what composite indices reveal – and conceal – about trade-offs and synergies in sustainability transitions*. SPES Focus on WP3, SPES project – Sustainability Performances, Evidence and Scenarios. Florence: University of Florence. Available at: https://www.sustainabilityperformances.eu/publications-deliverables

Disclaimer

This SPES Focus for the project SPES has been prepared by the Bordeaux School of Economics of the University of Bordeaux as part of Task 3.1 “Mapping individual indicators and composite indices that might be relevant for measuring transition performances” / Work Package 3. This task has allowed SPES research partners to provide an overview of (i) indicator selection practices of existing measurement frameworks and of (ii) indicators that might be relevant to be included in a new dashboard structured according to the pillars of sustainable human development and are suitable to serve as individual items for a composite index.

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

Funded by the European Union under Grant Agreement No. 101094551. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Agency. Neither the European Union nor the granting authority can be held responsible for them.

SPES Sustainability performances, evidence & scenarios

Table of Contents

Abstract

Composite indicators measure complex processes like the sustainability transition across the pillars of the Sustainable Development Goals: Planet, Prosperity, People, Partnership, and Peace. Their popularity stems from their simplicity and comparability, but their proliferation raises concerns about ambiguity, overlap, and limited utility in addressing the systemic nature of sustainability transitions. We show that while diverse composite indices provide multiple perspectives, they often emphasize narrow dimensions, creating measurement gaps and complicating comparisons.

These measures also obscure key interactions, such as trade-offs (e.g., economic growth vs. equity), synergies, and independence among dimensions. Using Principal Component Analysis, this paper analyses six composite indices globally and in the EU27, finding that sustainability transitions involve systemic trade-offs and synergies. For instance, in the EU27, economic growth and social inclusion are negatively correlated with environmental sustainability. The authors recommend refining the selection of composite indices, improving systemic analysis, and developing interaction-sensitive indicators to capture trade-offs and synergies, ensuring more coherent and effective sustainability monitoring. Lastly, the observed variation in sustainability dynamics between global and regional samples suggests that tailored strategies are necessary.

1. Introduction

Over the past decades, the development of composite indices (CIs) and dashboards has expanded significantly to evaluate and monitor various complex dynamic processes. A query on Scopus by Greco et al. (2019) retrieved nearly 600 composite indicators in 2016, marking a nearly fivefold increase compared to 2006. Many of these indicators aim to encapsulate progress across the dimensions of the sustainability transition, frequently aligning with the five pillars of the Sustainable Development Goals (SDGs): Planet, Prosperity, People, Partnership, and Peace. Typically, scores across these dimensions are aggregated into an overall score, facilitating comparisons across countries, regions, and cities. Recent research by Gábos et al. (2023) identified 44 composite sustainability transition indicators (STIs) in use, each designed for sufficiently broad samples of countries.

This growing prevalence underscores the critical role of STIs in measuring, monitoring, and comparing nations' progress toward sustainability. However, while these indices provide a convenient numerical representation of sustainability efforts, they also obscure important complexities. As the title of this paper suggests, we move beyond the numbers to examine what these indices reveal—and conceal—about sustainability transitions. In particular, two key challenges must be addressed to ensure their relevance.

First, the abundance and popularity of STIs reflect not only their communicative simplicity but also the multidimensionality of sustainability itself. The variation in scope and aggregation methods among STIs (Gábos et al., 2023) illustrates diverse, sometimes conflicting, interpretations of what sustainability entails, and first of all the opposition between weak and strong versions). This diversity can create ambiguity about the requirements for a successful transition, necessitating a systematic evaluation of what each STI measures. Specifically, determining whether these indicators collectively provide a comprehensive picture of sustainability or merely fragmented insights is essential.

Second, STIs inherently represent aggregate achievements, which limits their capacity to capture interactions—both synergies and trade-offs—between different dimensions of the transition. Sustainability is widely recognized as a systemic process (IPCC, 1992, 2023; Grin et al., 2010; Köhler et al., 2019; Moallemi et al., 2022), characterized by interdependencies between its various components. Progress in one dimension often influences, and is influenced by, others. For instance, increases in carbon taxes have demonstrated how decarbonization efforts can inadvertently exacerbate inequalities for individuals reliant on private transportation or living in remote areas that may eventually backfire against transition policies. While STIs may imply such interactions through aggregated outcomes, they are not designed to reveal them more explicitly.

This paper aims to address these two challenges. First, we examine a diverse set of STIs to determine whether they reflect correlated or independent aggregate perspectives on sustainable development. Using the SPES conceptual framework (Biggeri et al., 2023), which aligns with the SDG pillars, we systematically analyze the capacity of 11 STIs identified by Gábos et al. (2023) to comprehensively represent all these pillars of sustainability transitions. Our findings confirm Gábos et al. (2023)'s observation that each STI offers a partial perspective, emphasizing the need for integrated analysis to achieve a fuller understanding of the transition. Most STIs focus on specific combinations of the SDG/SPES pillars rather than providing holistic coverage. Analyzing the linear correlations among the eleven STIs in our study, we find that only about half are positive and significant at the 5% level—contrary to the expectation that all indicators would capture the same overall progress toward the SDGs. Even more striking, 7% of the correlations are negative and significant.

Next, we leverage the diversity and complementarity of the STIs analyzed by Gábos et al. (2023) to investigate cross-dimensional correlations. Specifically, we focus on our selection of six STIs addressing one-to-one interactions between the Planet, Prosperity, People, and Partnership pillars. These STIs collectively encompass all transition dimensions and bilateral interfaces. By using multidimensional statistical methods for analyzing their correlations, we identify patterns of synergy, trade-off, or independence between dimensions, offering insights into how progress in one area supports or hinders advancements in others.

In our global analysis of 164 countries, we found that progress on the Prosperity, People, and Partnership pillars was largely independent of advancements in the Planet pillar, reflecting diverse pathways to sustainability. However, regional patterns revealed more nuanced dynamics. In lower-income countries with limited engagement in sustainability transitions, synergies between these dimensions were more pronounced. Conversely, in higher-income nations with more advanced sustainability efforts, trade-offs became apparent, particularly between environmental sustainability and economic or social objectives.

Within the EU27, our analysis identified a strong synergy between Prosperity, social equity, and democratic governance. However, this cluster showed a negative correlation with environmental sustainability, highlighting a trade-off between sustainable economic growth and inclusive social development. Progress on the Planet-People interface, representing the just transition, remained largely independent of other dimensions, mirroring global trends.

There is broad consensus on the need to strengthen sustainability monitoring and it is often adovated that future efforts should prioritize refining composite indicators (CIs). Our findings emphasize that sustainability transitions are inherently systemic, requiring a holistic approach to interdimensional interactions to avoid fragmented or counterproductive strategies. This has two main policy consequences. While CIs remain valuable for tracking progress, they must be applied with caution, as their current design struggles to capture complex interdependencies. Second, targeted statistical analyses can help bridge these gaps: the proliferation of sustainability composite indicators (STIs) presents an opportunity to improve the monitoring of interdependencies, leveraging both their widespread use and inherent limitations to advance sustainability analysis.

The rest of this paper is structured as follows: Section 2 reviews the potential and challenges of using STIs to monitor sustainability transitions. Section 3 evaluates the performance of sustainability STIs in covering various transition dimensions and addresses ambiguity issues. Section 4 outlines our methodology for mapping interdimensional relationships across six STIs. Sections 5 and 6 present results for global and EU27 samples, respectively, while Section 7 discusses policy implications and concludes.

2. Monitoring sustainability transitions with composite indicators: Main challenges

Composite indicators offer a valuable means of summarizing complex and multifaceted processes, such as the sustainability transition. By design, they aggregate advancements across multiple dimensions—typically environmental, social, and economic—into a single measure easily comparable across countries and over time. Concerns about internal consistency and sensitivity have been well-documented, from foundational analyses (Freudenberg, 2003) to more recent reviews (Palencia-Esteban et al., 2023). Many of these limitations stem from the weighting and aggregation methodologies employed (Greco et al., 2019). Some come also from the normalization step, as emphasized by Palencia-Esteban et al. (2023) specifically for STIs.[1]

Challenges relating to external validity, that is the capacity of CIs to accurately monitor the interconnected and multidimensional nature of sustainability transitions also are critical as we will see in this paper. Indeed, CIs are subject to significant limitations when attempting to highlight the underlying mechanisms that drive these aggregated outcomes. Composite indicators typically aggregate sub-dimensions into a single score using weighted sums or other mathematical operations. While this simplifies complex datasets, it inherently restricts the insights these indicators can provide. For example, additive or multiplicative transformations obscure whether progress in one dimension is achieved at the expense of another (trade-offs) or whether improvements are mutually reinforcing (synergies). A high score in economic growth, for instance, may offset poor performance in environmental sustainability, leading to an aggregate result that masks tensions between these two domains.

This issue is especially pronounced when components are aggregated using a weighted arithmetic average, the most commonly employed method. Arithmetic averaging assumes that the components of a CI are mutually preferentially independent—that is, no synergy or conflict exists among them (Freudenberg, 2003). This assumption is unrealistic in the context of sustainability, where interactions between dimensions are often significant (Gan et al., 2017). Additionally, this method presumes perfect or partial substitutability between dimensions, allowing strong performance in one area to compensate for weak performance in another. In sustainability contexts, this substitutability is problematic, as it ignores the hierarchical and interdependent relationships among dimensions. For instance, environmental degradation imposes constraints on social and economic systems, exacerbating vulnerabilities and heightening the risk of systemic tipping points (Rockström et al., 2009; Steffen et al., 2015).

Using a weighted geometric average – a multiplicative approach – reduces the problem of perfect substitutability to some extent. By penalizing low-scoring dimensions, this method indeed aligns with the concept of "strong sustainability," which posits that natural capital cannot be replaced by other forms of capital (Beliakov et al., 2007). Geometric aggregation emphasizes the importance of

[1] Obviously, questions of standardization could be added to the list of procedures required for any multidimensional analysis, particularly when using "additive" composite indicators. However, our approach is precisely unaffected by this problem. Indeed, in PCA, the initialization stage consists in standardizing all the continuous quantitative variables considered in the analysis, in order to directly neutralize problems linked to the different units of measurement and variances of the various variables.

balanced performance across dimensions, reinforcing the idea that sustainability requires success in all relevant areas. However, even this approach falls short in capturing the interrelations between dimensions. It is no better suited than arithmetic methods for identifying patterns of synergy, trade-off, or independence across sustainability indicators.

Moreover, the geometric mean collapses to zero with numers close to zero which imposes to find alternative ways of aggregating while preserving (at least partly) interrelations between dimensions (Biggeri and Mauro, 2018; Biggeri et al, 2019). Additive and multiplicative STIs provide an important but limited perspective on multidimensional progress. While they offer an explicitly comprehensive view of sustainability, they remain implicitly relational or systemic, often functioning as "black boxes." When trade-offs or synergies arise between two dimensions—such as when progress in one area hinders or bolsters another—the aggregated score provides no visibility into these relatedness and dynamics.

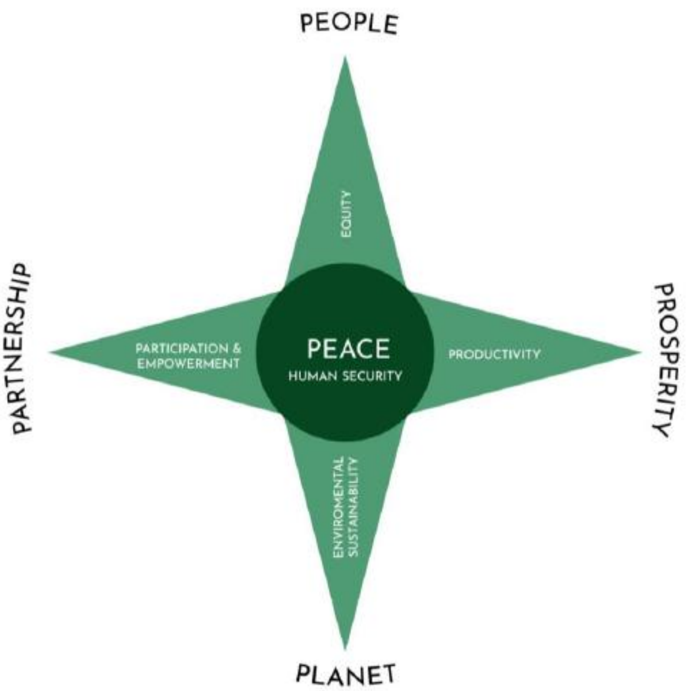
Developing truly systemic indicators capable of capturing such interdependencies remains a significant challenge in sustainability measurement. Yet, given the critical political and practical implications of trade-offs in sustainability transitions, there is a pressing need to complement STIs with methodologies that can explicitly highlight these relationships by leveraging existing indicators. Advanced multidimensional statistical analyses, for example, can help map independence, synergies, and trade-offs between the different pillars of sustainability transitions by identifying patterns of orthogonality, correlation, or anti-correlation across STIs or their subcomponents. This paper adopts such an approach, aiming to enhance the interpretive power of STIs by uncovering relational dynamics that are otherwise obscured.

However, using advanced multidimensional statistical analyses for identifying trade-offs or synergies also imposes to be very cautious with the sample selection. Principal component analysis (PCA) is a relative analysis, the position of variables or countries in a multidimensional correlation plan delivered by the analysis is relative, not absolute. This means that each country/variable’s position might change as the size of the sample changes. In other words, trade-offs might be visible or invisible, depending on what country/variable is included in the analysis. Monitoring trade-offs and synergies through PCA analysis of STIs therefore requires to stick on the same sample and the same set of data, from one period to the other and forbids to compare positions from one year/analysis to the others. Yet, patterns of multidimensional correlation can be compared across years/analyses if the set of countries and variables are the same.

3. Comprehensiveness and measurement ambiguity

While keeping in mind the methodological limitations of STIs, we now want to map exactly what they (or a sample of them) really represent, that is what dimensions of the sustainability transition they really document and how. The assumption here is that not all STIs proposed by the literature or international expert organizations cover the same set of dimensions of the transition. This might be due to data limitations or theoretical and ideological priors governing the selection of dimensions and choice of components.[2] These choices are not always made explicit and clear in technical documents. Yet, they shape the content of STIs differently, although large overlaps also exist between them.

Figure 1. *The 5 pillars of Sustainable Human Development*



Source: Biggeri et al. (2023)

Figure 1 reproduced from Biggeri et al (2023) represents the different dimensions of the sustainability transitions that are consensually associated by the literature to cover the different facets of the process: Planet, Prosperity, People, Partnership and Peace to fit to the SDGs

[2] This may also pertain from differentiation strategies dictated by competition between organizations or publication bias.

terminology.[3] What the figure suggests is that all these five dimensions are interrelated. To be sufficiently sustained in the medium and long run, positive developments on the "Planet" dimension need to be backed by sustained livelihoods on the "Prosperity" dimension, improved equity on the "People" dimension and collective support and political engagement on the "Partnership" one. All these developments coalesce into a peaceful sustainable transition.

Confronting this conceptual mapping of the comprehensiveness and relatedness of the transition process to the information structure of a large set of STIs shows that the latter generally cover only subparts (often very narrow) of the transition map. As suggested by the systematic review of 44 STIs summarized in Gábos et al (2023)'s Table 1, there are very few STIs that capture all the dimensions of the Figure 1's framework. Only one quarter of those 44 STIs actually cover four pillars and slightly less than half cover less than three pillars. The same conclusion holds when we focus on the shortlist of 15 STIs established by Gábos et al (2023) for their ability to effectively capture the Planet, Prosperity, People, Partnership and Peace SDGs with a sufficiently good country and time coverage.[4] All 15 STIs are not well balanced or equally informed over all pillars. Most of them measure attainments located at the interface of two or three pillars, some with different focal points.

Table 1. *Descriptive statistics of STIs*

Variable	Minimum	Maximum	Mean	Variation coefficient
Beyond GDP_2020b	47,900	90,400	72,907	0,127
Competitive Sustainability Index_2022	26,800	73,700	52,070	0,249
Green Growth Index_2022	48,900	75,400	65,774	0,090
Just Transition Score_2022	63,500	86,000	78,522	0,074
Legatum Prosperity Index_2023	65,600	84,600	75,185	0,075
Planetary pressures–adjusted HDI_2022	0,645	0,819	0,749	0,062
Social Progress Index_2024	75,200	90,400	83,622	0,049
Sustainable Development Goals Index_2023	72,900	86,400	80,248	0,038
Sustainable Development Index_2022	0,122	0,733	0,495	0,362
Sustainable Society Index_2020	4,234	6,817	5,812	0,095
Transitions Performance Index_2020	59,338	78,361	67,553	0,070

Source: authors' calculations based on the most recent data available on the respective websites of the institutions/organizations that produced the indicators.

In order to provide a more robust assessment of the measurement ambiguity or noise generated by the proliferation of STIs, we also conducted linear correlation analysis between indicators of the shortlist. We had to downsize the set of STIs used as four of the fifteen selected indicators could

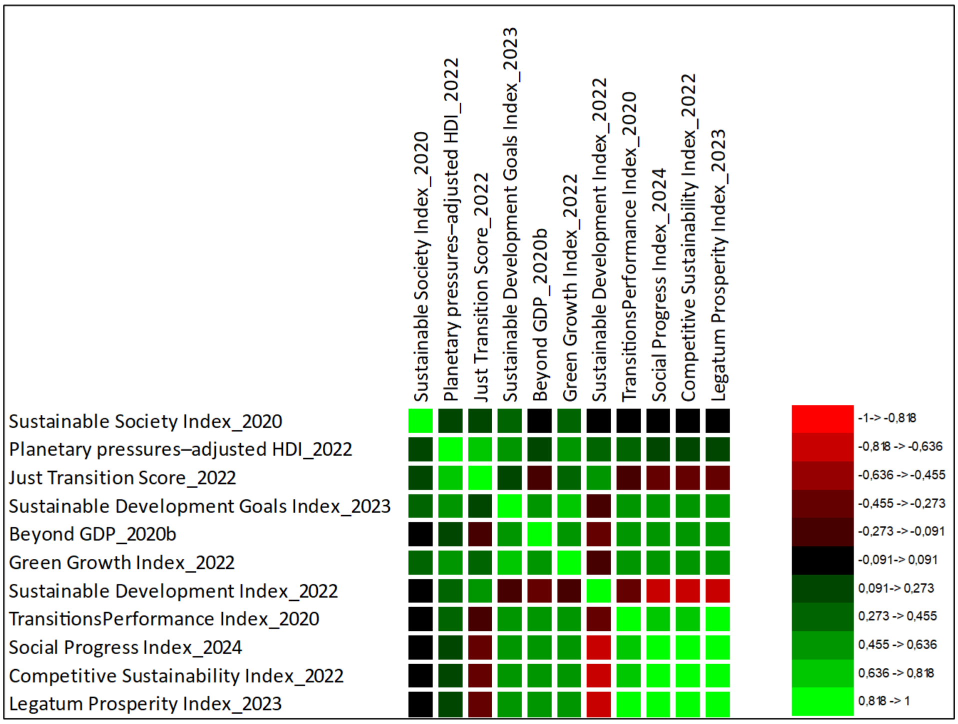
[3] They also frame the SPES project.

[4] They include the coherence with Sustainable Human Development and SPES frameworks, the degree of complexity and completeness of the theoretical framework, the inclusion of the indicator system in European and international policies and in EU Joint Research Center audit, the reliability of the publishing organization, the clarity of data sources, the time and country coverage and the availability of regional data.

not be considered in the analysis for different reasons.5 We thus ended up with the reduced set of 11 STIs that could be fully informed for all 27 EU countries at a date recent enough to make the observations comparable (2020-23).[6] Correlation analysis was carried out on the EU27 sample because some of the eleven indicators are only very little or not at all informed for countries outside EU27. Still, we assume similar results for all countries in the world. The descriptive statistics of these eleven STIs reported in Table 1 show that two of them are particularly dispersed compared to the others: the Competitive Sustainability Index and the Sustainable Development Index.

If we now look at the linear correlations between the eleven STIs as reported in the Figure 2, it appears that barely half of the linear correlations per pair of variables are positive and significant at 5% level, while one could have expected that all indicators would propose different measurements of the same overall phenomenon of progress towards the SDGs[7]. Even more surprising, 7% of the linear correlations are negative and significant. More specifically, a block of three STIs are strongly positively correlated and explain about 90% of the common variance (Social Progress Index, Legatum Prosperity Index and Competitive Sustainability Index). On the other side, the Sustainable Development Index, appear to be significantly anti-correlated to this first block and also to the Transitions Performance Index.

Figure 2. *The linear correlation matrix*



Source: authors' calculations based on the most recent data available on the respective websites of the institutions/organizations that produced the indicators.

[5] The ASviS Composite Index and the Sustainable Human Development Index had no sufficiently recent data (latest data for 2016 and 2013 respectively), and the former had no synthetic measure but only provides a dashboard of 18 separate SDGs. On the other hand, the Genuine Progress Indicator had no generalizable measure allowing comparisons in space, and the OECD Better Life Index website did not provide precise synthetic values and did not communicate on the treatment of components (weights, treatment of ordinal variables).

[6] Only one missing value, that of the Sustainable Development Index for Estonia, is estimated at the nearest neighbour (Lithuania) for multidimensional measures or for classification techniques.

[7] Rank correlation analyses lead to the same conclusions.

When applying classification techniques (k-means clustering on variables) to the 11 variables, we obtain a classification in three internally consistent and externally differentiated groups. The first and larger one brings together indicators – the Beyond GDP, Green Growth Index, Just Transition Score, Legatum Prosperity Index, Social Progress Index, Sustainable Development Goals and Transitions Performance Index – that are predominantly loaded by good performances in economic and human wellbeing indicators, and only marginally by good performances referring to environmental wellbeing. The second group includes STIs (the Competitive Sustainability Index, the Planetary Pressures-Adjusted HDI and the Sustainable Society Index) that prove more balanced between the economic, human and environmental wellbeing dimensions. The last group is a singleton made of the Sustainable Development Index indicator which is far 'greener' than the others, and it is anticorrelated to STIs composing the two other groups.

These correlation and classification analyses therefore confirm that not all the eleven STIs actually measure the same thing or are equally informative of the same underlying reality. Only half of them is significantly and strongly positively correlated, therefore providing different but substitutable summary pictures of a supposedly unique underlying transition reality. The others actually measure very different things, that is are informative of different underlying transition realities. Consequently, STIs should not be taken indistinctly one for the other, without a clear understanding of the reality each one accounts for. As Gábos et al (2023) emphasizes, the vast majority of the composite indicators available are based on measurements referring to at least two dimensions and most of them associate different measures for one single dimension.

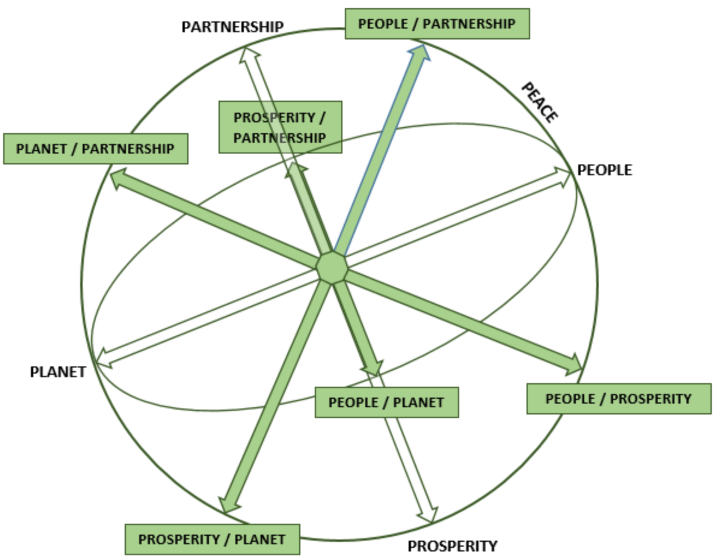
More interesting, most of the 11 STIs actually measure attainments "at the interface" of two pillars, thus providing a synthetic picture of attainments in a specific and partial subsystem of the transition process. This means that the system illustrated by Figure 1 may be fully covered up by putting together those STIs providing complementary pictures of the whole system. This also means that it is possible to map how these subsystems of attainment correlate on a multidimensional plan. By mapping the multidimensional statistical correlations between STIs with different and complementary focal points, we think we can spotlight the relatedness of the transition system described in Figure 1 and identify trade-offs and synergies between the different attainment interfaces.

4. Mapping relatedness across transition pillars: Our approach

The sustainability literature has emphasized hundreds of local trade-offs, that is positive changes in one dimension of the transition that leads to negative changes in another. In this section, we focus on highly-dimensional trade-offs and synergies, those occurring between the aggregate achievements in the five dimensions (Planet, Prosperity, People, Partnership, Peace) of the just transition that are captured by STIs.

The elements at our disposal for carrying out this approach are, on the one hand, the set of composite transition indicators selected by the WP3 (Gábos et al, 2023) and, on the other hand, the conceptual framework of the 4+1 pillars of transition proposed by Biggeri et al. (2023) and represented in the Figure 1. As explained above, the 15 STIs selected by Gábos et al (2023) do not cover similar subsets of the sustainability transition process, and they provide no guidance on synergies and trade-offs on their own. As illustrated in Figure 3, the whole set of possible one-to-one interfaces involved in the Figure 1 can be covered by picking up the STI that best covers each one of the six possible interfaces between Prosperity, Planet, People and Partnership. Noteworthy, we deliberately leave aside the Peace pillar for two reasons. First, security or peace *per se* are actually poorly documented in the shortlisted STIs. Second, we consider that the "peace" dimension actually encompasses all the other pillars, as both a condition and a consequence of parallel progress in all them. Peace is nonetheless added as a characterization variable in the analysis.

Figure 3. *The six possible interfaces between the 4 + 1 pillars of transition*



Source: authors

Additional constraints were imposed on the choice of these composite indices, so that the structure of the database is well suited for processing factor analysis and comparisons over time. More specifically, we have selected the STIs (i) the best suited to accurately measure progress at the interfaces of each of the pillar pairs considered, (ii) covering the largest possible statistical population, and (iii) enabling us to collect two distinct measurements over time, closest to 2020 and a decade earlier. These six STIs are described in the table 2. They allow compiling a complete and informed database at two points in time for 164 countries worldwide[8]. Obviously, such a database cannot get rid of overlaps between indicators, some of them sometimes using variables that are identical or similar in their construction or what they aim at measuring. So as to keep these overlap effects to a strict minimum, we chose to reduce the LPI and ND-GAIN indicators to their strictly relevant components, thereby eliminating the potential overlap with other interfaces. Importantly, overlap issues are not supposed to blur the results of factor analysis, which precisely focuses its attention on all possible interrelations between the variables put into the analysis.

Table 2. *The 6 selected composite indicators and the interface they cover*

PEACE Global Peace Index (GPI)	PEOPLE / PARTNERSHIP	**Human Freedom Index (HFI)**
	PROSPERITY / PARTNERSHIP	**Legatum Prosperity Index (LPI)***
	PLANET / PARTNERSHIP	**Global Adaptation Initiative Country Index (ND-GAIN)***
	PROSPERITY / PEOPLE	**Inequality-adjusted HDI (IA-HDI)**
	PLANET / PEOPLE	**Just Transition Score (JTS)**
	PLANET / PROSPERITY	**Sustainable Development Index (SDI)**

Source: authors

***Note**: * Index recalculated from its subcomponents to narrow the focus on the interface we aimed to consider; see detailed indices definitions and sources in Table A.1 in the appendix. GPI is not used for analysis but as an additional variables to check for correlations post-analysis. Our rationale is that Peace is both a condition and consequence of sustainability transition.*

[8] Countries were excluded from the database if more than two of the six variables were missing. For the few countries where one or two variables were missing (16% and 5% of individuals respectively), the data were completed using the nearest neighbor technique, which proved to be the most appropriate for subsequent factorial analysis.

Through factor analysis (Principal Component Analysis), we can describe how the STIs covering each of the six possible interfaces of Figure 3 correlate on a multi-factor plan for a large population of countries. Synergies (trade-offs) between different two-dimensional achievements will be identified if CIs covering them are significantly correlated (anti-correlated) on one factor. Similarly, decoupling between two-dimensional attainments will be identified if some CIs are found to be orthogonal, that is if they stand on two different factors.

There are good reasons why we adopted this specific design rather than simply mapping correlations between variables or subcomponents of existing STIs focusing on single dimensions. The main one is that by selecting 6 STIs representing all the possible pairs of achievements with a minimum number of components, our approach conveniently balances the objectives of parsimony and complexity. As a matter of fact, the alternative approach consisting in mapping correlations between STIs' subcomponents focusing on single dimensions would impose to decompose STIs and arbitrarily pick up individual components for each individual dimensions. Yet, these indicators show complex structures designed to be internally consistent and have adopted different weighting and aggregation structures, some being compensatory indexes (HFI, LPI, ND-GAIN) while other are indexes incorporating penalties (IA-HDI, JTS, SDI). For the sake of parsimony (and generality), our methodology therefore deliberately preserves the integrity of STIs. Overall scores of all six STIs thus theoretically embody 'first order' synergies (or trade-offs) between the two pillars they are covering. Logically, the overall score will be higher (lower) when there is synergy (trade-off) between attainments in the two dimensions than when there is no synergy (trade-off). By decomposing aggregate scores, we would lose these 'first-order' interactions and complexity. But maybe more importantly, we also preserve these STIs for taking advantage of the complementarity between their differentiated focal points. We therefore had to preserve the full CIs for the sake of complexity too. Moreover, our method allows to identify 'second-order' synergies or trade-offs between these six 'first-order' attainments covering the entire set of bilateral interactions. We thus contend that our approach consisting in mapping six indicators of bi-dimensional achievements (comprising themselves implicit first-order synergies or trade-offs) provides a more complete picture of relatedness across transition attainments than the one we would have got by simply mapping four indicators of one-dimensional attainments.

5. Mapping relatedness across transition pillars: Global analysis

A global analysis was first conducted on the largest sample we could get for the six STIs. This global sample includes STIs' global scores measured in 2020 (or the closest available year) for 164 developed and developing countries. This first analysis is meant to describe the most global patterns of synergies, trade-offs and decoupling between the six one-to-one interfaces linking Planet, Prosperity, People and Partnership pillars.

A preliminary statistical analysis of each of the six selected STIs first shows that each individual distribution is relatively normal. Then, examination of pairwise linear correlations[9] reveals two distinct patterns. First, positive and significant linear correlations are observed between most pairs of indices. Second, non-linear relationships are also visible between the indices including the 'Planet' pillar (SDI, JTS) and those involving the 'Prosperity' and 'People' pillars (LPI or IHDI). In other words, the apparent pairwise relations between the selected STIs suggests that we are in presence of a set of coherent variables (significant linear/non-linear, rank and ordinal correlations), each clearly carrying its own multidimensional information. This setting is appropriate for implementing a factor analysis approach identifying the pattern of multidimensional correlations across all six pairs of pillars.

Principal component analysis (PCA) of our dataset generates the correlation circle reported in Figure 4.[10] The circle first shows that the three possible interfaces between Prosperity, People and Partnership pillars are all clustered on the right of the first factor, making it the main driver of differentiation between the countries in the sample from the point of view of the multidimensional phenomenon considered. Indeed, 62 % of the global variance is captured by this first factor that we label 'Inclusive Economic & Human Development' (IEHD). Rather expectedly, the position of the (non-contributory) supplementary variable 'No peace'[11] in the multidimensional plan suggests that IEHD is positively correlated with human security. Across the board, the countries overperforming in IEHD find strong synergies between the four pillars of People, Prosperity, Partnership and Peace. Lastly, Figure 4 also suggests a synergy between attainments on IEHD and on the 'Planet-Partnership' interface. This apparently puzzling result is explained by the strong focus put by the 'Planet-Partnership' on adaptation and political engagement into adaptation.[12]

Once this first and major source of cross-country differentiation is accounted for, a second factor capturing 23% of the global variance stands out of the analysis. As it is driven by synergetic attainments on the 'Planet-Prosperity' and 'Planet-People' interfaces, we call this second factor 'Social and Environmental Sustainability' (SES). Good performance in terms of sustainable growth ('Planet-Prosperity') is thus positively correlated with good performance in terms of reduction of environmental inequality ('Planet-People') in the global sample. In the same time, good performance on this SES cluster seems to be decoupled with performance in IEHD as one country's position on

---

[9] Robustness has been checked by a complementary analysis of rank and ordinal correlations, see Figure A.1 in the appendix.

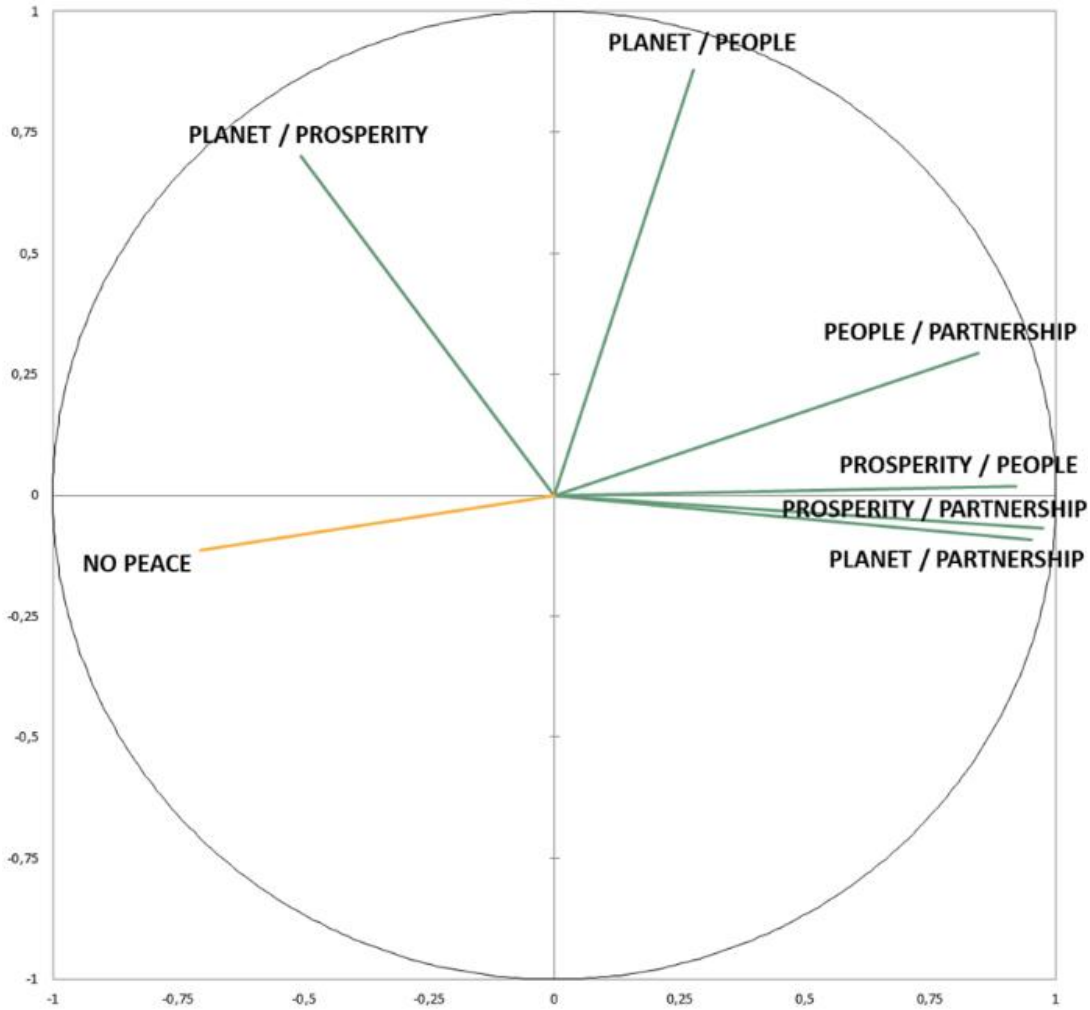
[10] More detailed results are reported in appendix Table A.3.

[11] This variable is measured by The Economist's « Global Peace Index » whose values are higher the lower the level of human security.

[12] We must also emphasize that ND-GAIN is by construction very "People" notably in its "Vulnerability" aspect and also very "Prosperity" (in its "Readiness" aspect) (see table A.1), which explains this correlation with the IEHD block. In other words, it is much less directly "Planet" than the other two indicators concerned with the environmental issue, but it is the one that best captures the "Planet / Partnership" interface.

the SES factor is independent of where its stands on the IEHD one. In other words, success on the SES objectives does not require to over- or under-perform on the IEHD ones, that is there is neither synergy nor trade-off to be observed, globally, between SES and IEHD in the most global sample.

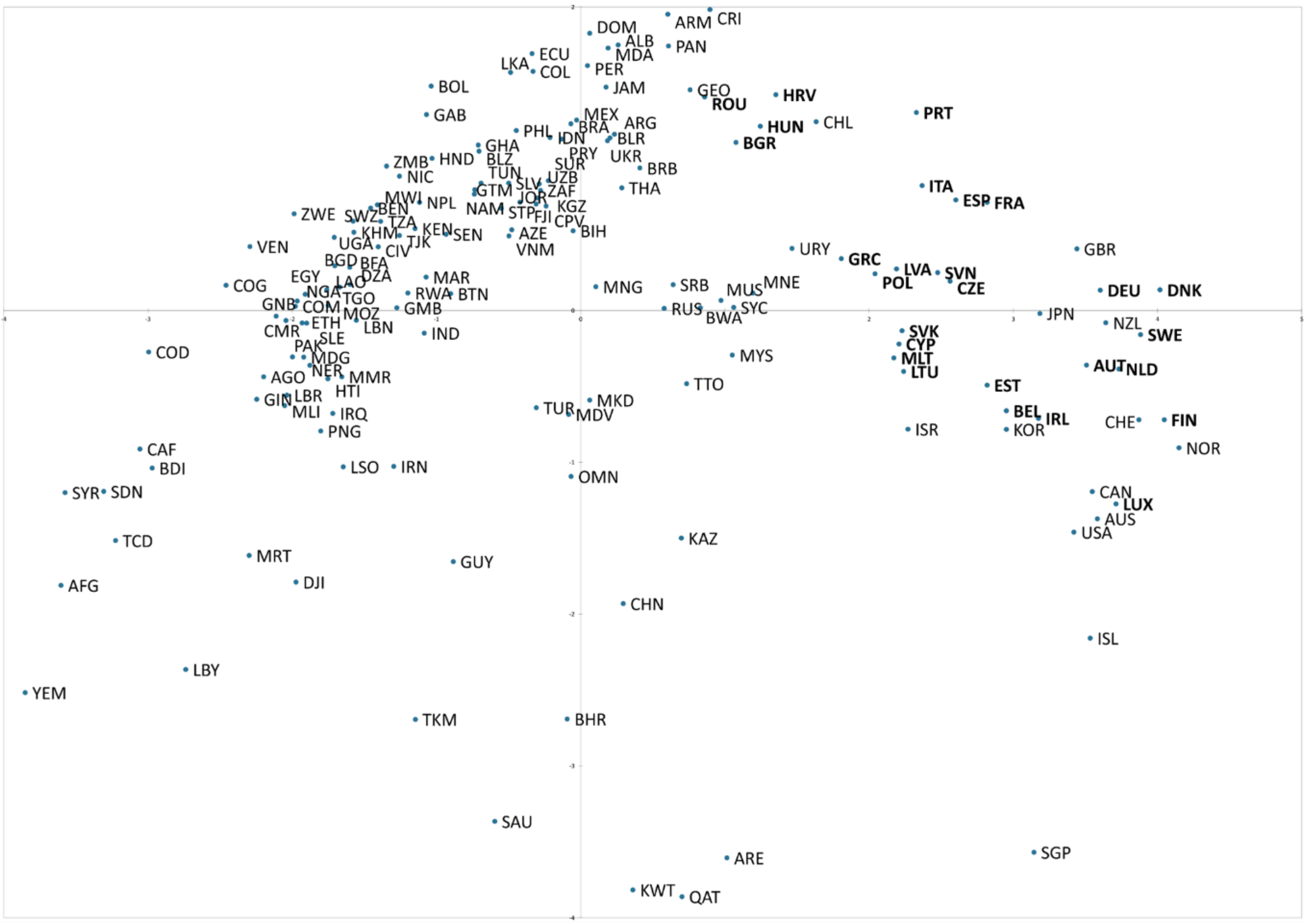
Figure 4. *Correlation circle of the first 2 components of PCA*



Source: authors' calculations

Note: *On this graph, the horizontal and vertical axes represent the computed principal components, i.e. the best linear combinations - independent of each other - of all the initial variables. They capture more than 85% of the total variance of these variables (62% + 23%). The more their projected vectors form an acute angle with each other, the more positively correlated one variable is with another. The more their projected vectors form a flat angle, the more they are anti-correlated. Finally, they are uncorrelated if their projected vectors form a more or less right angle with each other.*

Figure 5. *Scatter plot of countries on the first 2 components of PCA in 2020*



Source: authors' calculations

Note*: this graph shows the projections of country-individuals onto the two principal components described in Figure 4 that explain and describe the relative positions of individuals and the inter-individual distances on this graph; the sensitivity to sampling of the projections was tested using bootstrap techniques which support the robustness of the relative positions observable on this plane; EU27 countries are shown in bold characters.*

The country projection on these two first factors in Figure 5 brings useful additional insights into the general picture. First and obviously, there is a clear income per capita gradient behind achievements on the IEHD factor. Second, heterogeneity on SES is at its highest for middle income countries (MICs) and at its lowest among lower-income countries (LICs) and high-income countries (HICs). In fact, three different sub-patterns emerge from the data when looking at the different regions of the Figure 5's scatterplot. First, the positive slope on the left-hand side suggests that a synergy pattern seems to occur for the lower-income countries of the sample, with higher performance on IEHD combining with higher performance on SES. The opposite is true for the richest countries as shown on the right-hand side of the graph where higher performance on IEHD seems to combine with lower performance on SES, showing that sustainability dynamics consist in a far more complex picture than the Environmental Kuznets Curve. In the intermediate part of the graph where the bulk of middle-income countries are standing, average levels of IEHD achievement combine with extremely variable levels of SES suggesting that the decoupling between the two dimensions previously emphasized is driven by this category of countries including China, India or Brazil.

Table 3. *Characterization of group specificities in their transition to sustainability*

GROUP	COUNTRIES	MULTIDIMENSIONAL CHARACTERIZATION OF TRANSITION TO SUSTAINABILITY
Group 1	Australia, **Austria**, **Belgium**, Canada, **Cyprus**, **Czech Republic**, **Denmark**, **Estonia**, **Finland**, **France**, **Germany**, **Greece**, Iceland, **Ireland**, Israel, **Italy**, Japan, **Latvia**, **Lithuania**, **Luxembourg**, **Malta**, **Netherlands**, New Zealand, Norway, **Poland**, **Portugal**, Singapore, **Slovakia**, **Slovenia**, South Korea, **Spain**, **Sweden**, Switzerland, United Kingdom, United States	Fairly marked success in IEHD combined with relative weakness in SES *Significantly higher values for HFI, LPI, ND-GAIN, IA-HDI, JTS but significantly lower performance for SDI*
Group 2	Albania, Argentina, Armenia, Azerbaijan, Barbados, Belarus, Belize, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, **Bulgaria**, Cabo Verde, Chile, Colombia, Costa Rica, **Croatia**, Dominican Republic, Ecuador, El Salvador, Fiji, Gabon, Georgia, Ghana, Guatemala, Honduras, **Hungary**, Indonesia, Jamaica, Jordan, Kyrgyzstan, Malaysia, Mauritius, Mexico, Moldova, Mongolia, Montenegro, Namibia, North Macedonia, Panama, Paraguay, Peru, Philippines, **Romania**, Russia, Sao Tome and Principe, Serbia, Seychelles, South Africa, Sri Lanka, Suriname, Thailand, Trinidad and Tobago, Tunisia, Ukraine, Uruguay, Uzbekistan, Vietnam	Marked success in SES *Significantly higher values for HFI, JTS, SDI*
Group 3	Algeria, Angola, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo, Egypt, Ethiopia, Gambia, Guinea, Guinea Bissau, Haiti, India, Iraq, Ivory Coast, Kenya, Laos, Lebanon, Lesotho, Liberia, Madagascar, Malawi, Mali, Morocco, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Papua New Guinea, Rwanda, Senegal, Sierra Leone, Sudan, Swaziland, Syria, Tajikistan, Tanzania, Togo, Uganda, Venezuela, Zambia, Zimbabwe	Fairly marked weakness in IEHD *Significantly lower values for HFI, LPI, ND-GAIN and IA-HDI*
Group 4	Afghanistan, Bahrain, China, Djibouti, Guyana, Iran, Kazakhstan, Kuwait, Libya, Maldives, Mauritania, Oman, Qatar, Saudi Arabia, Turkmenistan, Turkey, United Arab Emirates, Yemen	Relative weakness in terms of IEHD combined with a marked weakness in terms of SES *Significantly lower values for HFI, JTS and SDI*

Source: authors; Note: EU27 countries are shown in bold characters

This cross-sectional analysis essentially provides a static picture of trade-offs and synergies as they emerge from the scores measured in 2020. It therefore says nothing about the dynamics that have been concretely at work over the 2010 decade, which is somewhat frustrating when analyzing such dynamic process as transition. Adopting a more dynamic perspective within the limitations of the PCA involves reconstructing in the plan derived from the factor analysis in 2020 the 164 countries' individual trajectories between 2010 and 2020 through the supplementary individual technique. The method consists in projecting its 2010 scores for the six STIs onto the factorial axes obtained for 2020 (given by Figure 5). When doing this, it happens that only 50% of countries recorded positive developments in both IEHD and SES dimensions over the decade, the 50% others being equally distributed between those that have combined IEHD progress with a decline in SES, and those that have experienced the opposite trend.

Based on the six initial composite indicators, we finally carried out a k-means classification procedure in order to identify sets of countries that are similar in the way they are achieving their transition to sustainability. The optimal classification in four groups of countries[13] is reported in Table 3[14]. Consistently with our previous comments, the European and advanced economies all cluster in a group characterized by a combination of marked success in IEHD and relative weakness in SES. A handful of East-European former socialist countries nonetheless came out as exception to this rule and seem closer to Higher Middle-Income countries in a group featuring marked success in SES independently of performances on IEHD. The third group gathering the poorest countries of our sample severely underperforms in terms of IEHD without showing a marked pattern on SES. The last group, comprising China and a lot of Central Asian or Gulf countries somewhat underperforms in terms of IEHD while underachieving even more massively in terms of SES.

The global analysis that was conducted on the largest sample of countries has therefore provided different noteworthy insights on the relatedness between the different pillars of the transition. First and foremost, there is no visible trade-offs appearing between the six interfaces of one-to-one synergies covering the five pillars of the just sustainability transition when the analysis is conducted on the largest and most heterogeneous sample of countries. Second, performances in Inclusive Economic & Human Development (IEHD), that is all possible interfaces between People, Prosperity and Partnership pillars, are found to be strongly synergetic. Third, achievements in 'Social and Environmental Sustainability' (SES) covering the Planet-Prosperity and Planet-People interfaces are orthogonal to the others, meaning that overperforming in SES does not require to overperform or to underperform in IEHD. Yet, going beyond global averages nonetheless points to different patterns of relation between IEHD and SES. For the countries the least advanced in the process of transition (which also happen to be the poorest), a good performance in IEHD tends to combine with a better performance in SES. The apparent synergy might facilitate further progress along their transition path. On the contrary, for the countries already advanced in their transition (which also happen to be the richest), better performance on IEHD seems to have been traded against setbacks in SES. It therefore seems that these economies might no longer be able to progress in one dimension without harming the other.

These results suggest that transition paths towards sustainability requir more stringent policies as the countries get richer, exacerbating potential conflicts between economic, social et ecological goals. The PCA is a powerful tool for assessing correlations between large number of variables on multidimensional plans. Yet, it should be emphasized that as the method is based on variance

---

[13] The selected partition results from the optimization of the ratio between inter-group and intra-group variance (Calinski-Harabasz index) and from the minimization of the similarity index between the groups (Davies-Bouldin index). Missing data have been replaced by the mean value of each variable in order to neutralize their impact on classification.

[14] Group means of initial composite indicators and PCA multidimensional components are shown in Table A.3 in the appendix.

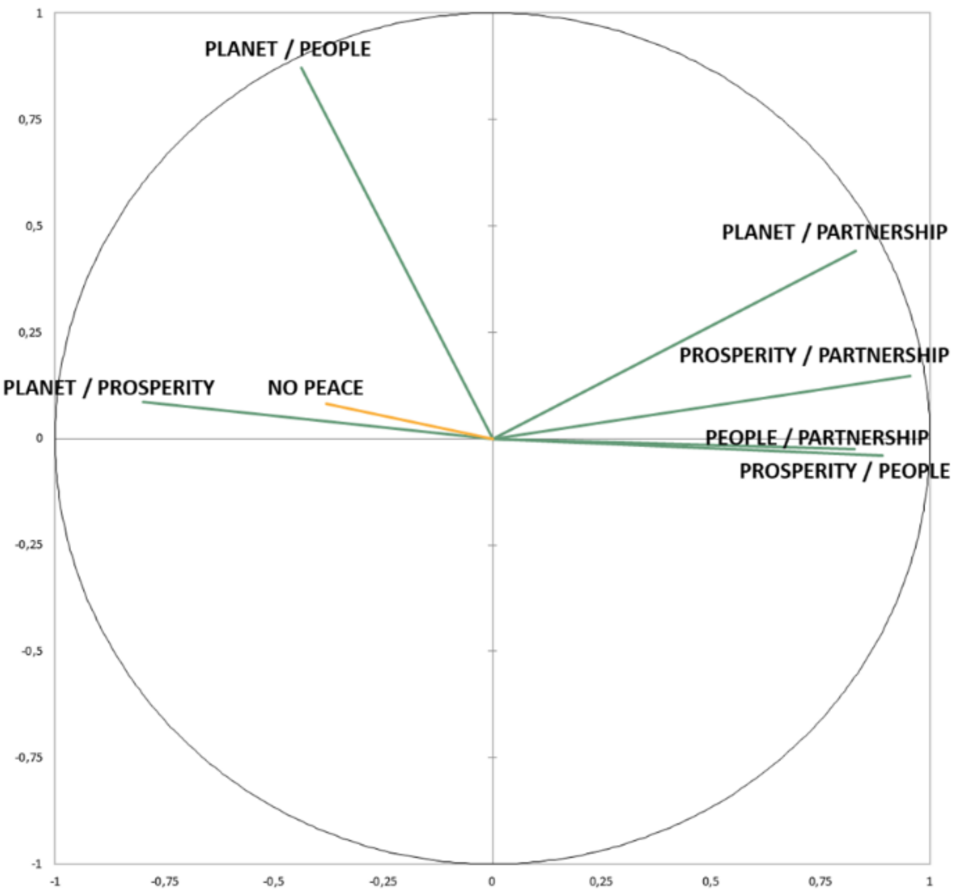
decomposition, the patterns of correlation it provides are relative to the sample composition and in no way absolute. This means that some of the results we just summed up may be invalid on other perimeters of country, notably if these countries are less heterogenous. In the next section, we therefore explore the patterns of multidimensional correlation that emerge from the similar analysis focusing on the EU27 countries. The expectations are that the way the six STIs fit together across the EU27 countries might slightly differ from what we just showed for the global sample. Conversely and importantly, identifying similar patterns on these two highly different samples might contribute to strengthening the reach and external validity of our findings.

6. Mapping transition tradeoffs and synergies: EU27 countries

As was shown in Figure 5 and Table 2, EU27 countries constitute a relatively homogeneous group in terms of the SDG performances in the global analysis. However, it is important to reproduce the previous analysis on the subsample of European countries to check whether the patterns revealed by the global analysis also hold in a set of more homogeneous countries. Indeed, what differentiates EU27 countries from others is not necessarily what differentiates EU27 countries from each other. Our analysis notably shows that, when the lens is tighter and focused on UE27 countries only, new and interesting relations indeed emerge from the analysis. The main innovation is the apparition of a crucial trade-off which was only partially visible in the global analysis.

Following the same approach as for the global sample, we start by analyzing the shape of the distribution of the six composite indicators among EU27 countries and by measuring the pairwise correlations. Figure A.2 in appendix highlights significant – although rather weak – linear pairwise correlations between the various interfaces of SDG achievements. Here also, we are in presence of a statistical ground that is convenient for PCA implementation.

Figure 6. *Correlation circle of the first 2 components of PCA – EU27 countries*



Source: authors' calculations

The principal component analysis of the UE27 dataset generates the circle of correlations shown in figure 6.[15] As in the global analysis, the figure exhibits strong positive synergies between all the pairs of achievements making up for IEHD: 'Prosperity', 'People' and 'Partnership'. This means that accomplishment (or relative regression) in any one of these interfaces keeps on combining with accomplishment (or relative regression) in the two others in this sample. Here again, albeit less strictly, the 'Planet-Partnership' achievements also correlate with those above-mentioned, the explanation being the same as for the global analysis. Finally, there's a clear trade-off between attainments on the 'Planet-Prosperity' interface and those on the IEHD cluster. What's different for UE27 is thus that achievements on IEHD seem to have been realized at the cost of environmental sustainability (ES) achievements. When it comes to the 'Planet-People' achievements, they seem to remain globally decoupled from all the others, as in the global analysis, suggesting that socially sustainable development stands also as an autonomous dimension among the narrower and more homogeneous sample limited to UE27.

The PCA scatter plot for the EU27 countries (Figure A.3 in appendix) illustrates that different country-specific combinations of attainments emerge from data. The figure reveals a relative similarity of results between Northern European countries in its northeast quadrant, between Mediterranean European countries at the top of the graph, or also between Eastern-European countries on the left-hand side of the graph. This could be a sign of different transition trajectories at work across the continent. However, Figure A.4 in the appendix shows that if we widen the focus of observation by including major emerging countries and candidates for EU membership countries in the analysis, the EU 27 remains a very homogeneous group in terms of the multidimensional phenomena considered.

Table 4. *Distribution of EU27 countries in terms of their relative progress between 2010 and 2020*

RELATIVE PROGRESS ON IEHD 2010-2020 (AT THE COST OF SE ACHIEVEMENTS) **(PRINCIPAL COMPONENT 1)**	**RELATIVE PROGRESS IN FAIR TRANSITION 2010-2020 (PRINCIPAL COMPONENT 2)**		
	LOW	**AVERAGE**	**HIGH**
Low	FRA, HUN, MLT	AUT	CYP, ESP, FIN, GRC, ITA
Average	POL, SVN	BGR, DNK, NLD, SVK, SWE	BEL, LUX
High	DEU, IRL, LTU, LVA	CZE, EST, ROU	HRV

Source: authors

Lastly, the reconstruction of EU27 countries' trajectories during the last decade, using the same method as in the previous section (supplementary individual method) which is reported in Table 4 shows that almost all EU27 countries have experienced positive dynamics in both dimensions between 2010 and 2020. Although these developments are more or less marked from one country to another, no obvious polarization between potential top performers and other countries over the decade is nonetheless observable (see table 4 below).

[15] See table A.4 in appendix for detailed results.

7. Conclusions

Against the backdrop of the proliferation of composite indicators (CIs) seemingly reflecting the multidimensional nature of sustainability, our research reaffirms that they remain valuable tools for tracking progress toward sustainability but must be applied with caution.

Our paper shows that each CI embodies a unique perspective, which may be more or less ambitious or comprehensive. As other previous papers, we argue that while this diversity offers multiple lenses for analyzing sustainability, it also introduces measurement ambiguity: overlapping indicators can lead to redundancy, while divergent results complicate cross-comparisons (Böhringer & Jochem, 2007; Morse, 2013). Many CIs prioritize specific dimensions while neglecting others, limiting their effectiveness as holistic sustainability measures. Our analysis underscores the need for careful selection and interpretation of CIs to ensure alignment with intended objectives and clarity regarding their scope.

Another core limitation of CIs is their inability to explicitly account for interactions between dimensions. By design, they provide aggregate summaries that often obscure systemic relationships – such as trade-offs, synergies, or independence – between sustainability dimensions (Rockström et al., 2009; Steffen et al., 2015). For example, economic growth may conflict with environmental protection, or social equity might complement environmental initiatives. Yet, CIs are by design unable to explicitly point these relationships. We suggest that tailored statistical analyses can help address these shortcomings, but deeper conceptual and methodological advancements are needed. By juxtaposing and averaging dimensional scores, traditional CIs fail to fully highlight these nuances, which are crucial for understanding the complexity of sustainability transitions and fitting policies to this complexity. This challenge has been widely acknowledged in the literature, prompting calls for more integrative analytical approaches that consider sustainability as a dynamic and interconnected process (Parris and Kates, 2003; Köhler et al., 2019).

To address these measurement gaps, our study analyzed correlations among six CIs representing the interfaces between the SPES pillars (Planet, Prosperity, People, and Partnership). Using Principal Component Analysis (PCA), we identified patterns of trade-offs, synergies, and independence among these six interfaces. In the global sample of 164 countries, progress on the Prosperity, People, and Partnership pillars was largely independent of progress on the Planet pillar, reflecting varied pathways to sustainability. However, regional analyses revealed more nuanced relationships. For lower-income countries with limited engagement in the sustainability transition, synergies between these dimensions were more evident. In contrast, for higher-income nations with more advanced sustainability efforts, trade-offs emerged, particularly between environmental sustainability and economic or social goals.

Focusing on the EU27, our analysis highlighted a clear synergy between the prosperity, social equity, and democratic governance dimensions. However, this cluster was negatively correlated with environmental sustainability, indicating a trade-off between sustainable economic growth and inclusive social development. Achievements on the Planet-People interface, representing the just transition, remained largely independent of other dimensions, consistent with global patterns. These findings emphasize that sustainability transitions are inherently systemic processes, requiring explicit consideration of interdimensional interactions to avoid fragmented or counterproductive strategies.

Our analysis is based on a specific selection of indicators. Selecting others indicators might have led to other results. Yet, our selection was not arbitrary as they are the ones that cover the best one of the six possible pairs of sustainability transition dimensions incorporated in SDGs: Planet, Prosperity, People, Participation. Any other selection would therefore be less relevant for covering these intersections. Yes, one limitation with our method is that several STIs selected show tend to partially overlap, that is are not strictly orthogonal. In fact, this limitation reinforces our findings as despite overlaps (generating positive correlation between STIs) we could find patterns of statistical independence or negative associations between different pairs of attainments.

Moving forward, we propose several key recommendations to improve the use and development of CIs in sustainability monitoring.

First, concerning the selection and interpretation of CIs, policymakers and institutions should carefully choose indicators that align with their objectives and ensure comprehensive coverage of relevant dimensions. A clear understanding of what each CI measures, its gaps, and its complementarity with others is essential to avoid misinterpretations and unintended biases in decision-making. Enhanced coordination and harmonization of CI methodologies—akin to efforts seen in the field of well-being indicators (Stiglitz et al., 2009)—could facilitate meaningful comparisons and strengthen evidence-based policymaking.

Second, efforts should focus on developing relational indicators that reflect the complex interplay between sustainability dimensions. Indicators incorporating systems-thinking approaches (Grin et al., 2010; Köhler et al., 2019) could provide deeper insights into the interconnected nature of sustainability transitions. Unlike traditional indicators that assess progress in isolation, system-based indicators consider feedback loops, trade-offs, and synergies, allowing for a more dynamic and realistic representation of sustainability challenges. By emphasizing cross-sectoral linkages, these approaches can help identify unintended policy consequences, reveal hidden interdependencies, and support more integrated decision-making processes (Meadows, 1999). Our static analyses suggest that addressing these interactions more dynamically and systematically would be an important step forward.

Third, our findings illustrate the potential of PCA in identifying interdimensional patterns. However, PCA results are highly dependent on the sample and dataset used, reinforcing the need for robust methodological rigor. Researchers and policymakers should ensure that datasets remain consistent across time periods to maintain comparability and reliability. Trade-offs or synergies may appear or disappear with changes in the sample, underscoring the importance of sensitivity analyses and transparent methodological choices (Saltelli et al., 2008).

Finally, the observed variation in sustainability dynamics between global and regional samples suggests that tailored strategies are necessary. Policies for high-income nations should address trade-offs between economic growth and environmental goals, while those for lower-income countries might focus on leveraging synergies to accelerate progress. Recognizing that sustainability transitions are context-dependent aligns with recent calls for differentiated sustainability strategies (Scoones et al., 2020). By addressing these gaps, CIs can evolve into more powerful tools for advancing systemic sustainability transitions, fostering policies that are not only comprehensive but also responsive to real-world interdependencies.

References

Beliakov, G., Pradera, A., and T. Calvo (2007) *Aggregation Functions: A Guide for Practitioners*. Springer.

Biggeri M., Clark A. D., Ferrannini A. and V. Mauro (2019) Tracking the SDGs in an 'integrated' manner: A Proposal for a New Index to capture synergies and trade-offs between and within goals, *World Development*, 122, 628–647.

Biggeri M. and V. Mauro (2018) Towards a more 'Sustainable' Human Development Index: Integrating the environment and freedom, *Ecological Indicators*, 91, 220-231.

Biggeri, M., Ferrannini, A., Lodi, L., Cammeo, J., Francescutto, A. (2023) The "winds of change": the SPES framework on Sustainable Human Development. SPES Working paper no. 2.1, SPES project –Sustainability Performances, Evidence and Scenarios. Florence: University of Florence

Böhringer, C., and P.E.P. Jochem (2007) Measuring the immeasurable: A survey of sustainability indices, *Ecological Economics*, 63(1), 1-8.

Boulanger, P. M. (2008) Sustainable development indicators: A STIentific challenge, a democratic issue, *Sustainable Development*, 16(3), 130-139.

Freudenberg, M. (2003) Composite indicators of country performance: A critical assessment, OECD STIence,Technology and Industry Working Papers, 2003/16, OECD Publishing.

Gábos, A., Lelkes, O., Cammeo, J. (2023) Report on mapping indicators and composite indices relevant to measure transition performances. SPES Report no. 3.1, SPES project – Sustainability Performances, Evidence and Scenarios. Florence: University of Florence.

Gan, X., Fernandez, I.C. Guo, J., Wilson, M., Zhao, Y., Zhou, B., and J. Wub (2017) When to use what: Methods for weighting and aggregating sustainability indicators, *Ecological indicators*, 81, 491-502.

Greco, S., Ishizaka, A., Tasiou, M. and G. Torrisi (2019) On the Methodological Framework of Composite Indices: A Review of the Issues of Weighting, Aggregation, and Robustness, *Social Indicators Research,* 141, 61–94.

Grin, J., Rotmans, J., and J. Schot (2010) *Transitions to sustainable development: new directions in the study of long-term transformative change*, Routledge.

IPCC (1992) *Climate change: First assessment report, International Panel on Climate Change*, IPCC, Geneva, Switzerland.

IPCC (2023) *Climate Change 2023: Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Geneva, Switzerland.

Kaur, H., and P. Garg (2019) Urban sustainability assessment tools: A review, *Journal of Cleaner Production*, 210, 146-158.

Köhler J., Geels, F.W., Kern, *et al* (2019) An agenda for sustainability transitions research: State of the art and future directions, *Environmental innovation and societal transitions* 31, 1-32.

Lo-Iacono-Ferreira, V.G., Torregrosa-López, J.I., and S.F. Capuz-Rizo (2018) Use of life cycle assessment methodology in the analysis of ecological footprint assessment results to evaluate the environmental performance of universities, *Journal of Cleaner Production*, 170, 1356-1364.

Lo-Iacono-Ferreira, V. G., Garcia-Bernabeu, A., Hilario-Caballero, A. and J. Torregrosa-López (2022) Measuring urban sustainability performance through composite indicators for Spanish cities, *Journal of Cleaner Production*, 359.

Mazziotta, M., and A., Pareto (2022) Composite indices construction: The performance interval approach, *Social Indicators Research: An International and InterdiSTIplinary Journal for Quality-of-Life Measurement*, 161(2): 541-551.

Magrini, A., and F. A Giambona (2022) Composite Indicator to Assess Sustainability of Agriculture in European Union Countries, *Social Indicators Research: An International and InterdiSTIplinary Journal for Quality-of-Life Measurement* 163(3), 1003–1036.

Meadows, D. (1999) *Leverage points: Places to intervene in a system*, The Sustainability Institute.

Moallemi, E.A., Eker, S., Gao, L., Hadjikakou, M., Liu, Q., Kwakkel, J., Reed, P.M., Obersteiner, M., Guo, Z. and B., Brett (2022) Early systems change necessary for catalyzing long-term sustainability in a post-2030 agenda, One Earth, 5(7), 792–811.

Morse, S. (2013) *Indices and Indicators in Development: An Unhealthy Obsession with Numbers*, Routledge.

Munda, G., and M. Nardo (2005). Non-compensatory/non-linear composite indicators for ranking countries: A defensible setting. European Commission Joint Research Centre.

OECD (2008). *Handbook on Constructing Composite Indicators: Methodology and User Guide*, OECD Publishing.

Palencia-Esteban, A., Salas-Rojo, P., Brunori, P., Lodi, L. (2024). Assessing measurement challenges and sensitivity in transition performance indicators. SPES Focus - Work Package #3, SPES project – Sustainability Performances, Evidence and Scenarios. Florence: University of Florence.

Parris, T. M., and R. W. Kates (2003) Characterizing a sustainability transition: Goals, targets, trends, and driving forces, *PNAS*, 100 (14), 8068-8073.

Rockström, J., Steffen, W., Noone, K. *et al.* (2009). A safe operating space for humanity. *Nature* 461, 472–475. https://doi.org/10.1038/461472a

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., Saisana, M., and S. Tarantola (2008) *Global Sensitivity Analysis. The Primer*, John Wiley & sons.

Scoones, I., Stirling, A., Abrol, D., Atela, J., Charli-Joseph, L., Eakin, H., Ely, A., Olsson, P., Pereira, L., Priya, R., van Zwanenberg, P., and L. Yang (2020) Transformations to sustainability: combining structural, systemic and enabling approaches, *Current Opinion in Environmental Sustainability*, 42, 65-75.

Sébastien, L., and T. Bauler (2013) Use and influence of composite indicators for sustainable development at the EU-level, *Ecological Indicators*, 35, 3-12.

Steffen, W., Richardson, K., Rockström, J. et al. (2015) Planetary boundaries: guiding human development on a changing planet, *STIence*, 347, 6223.

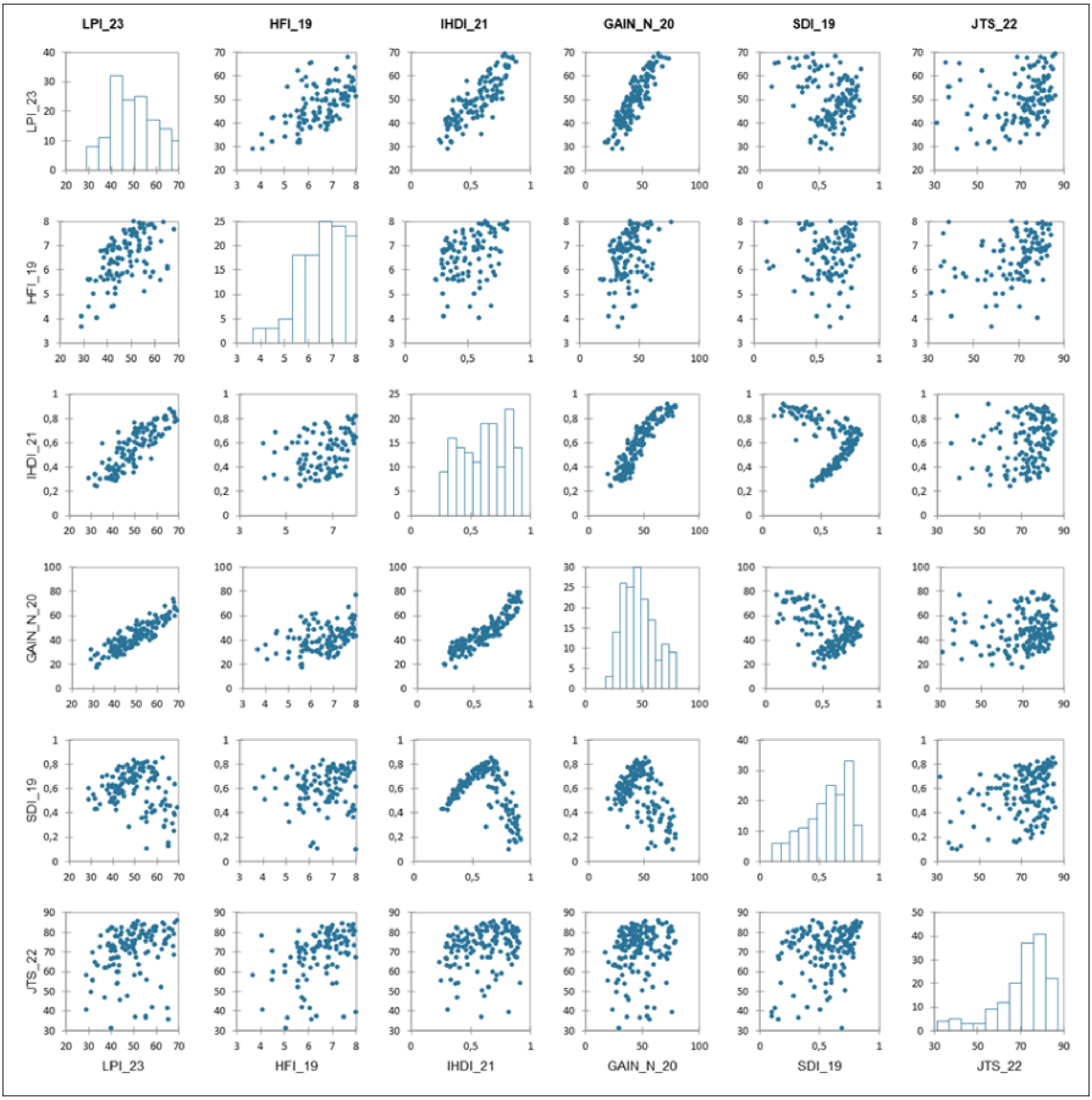
Appendix

***Table A.1** : selected composite indicators sources and description*

Human Freedom Index (HFI) Sources: various (World Justice Project, V-Dem Institute, Freedom House, University of Mariland, OECD, UNICEF, IMF, World Bank, World Economic Forum, etc.)	The Human Freedom Index presents the state of human freedom in the world based on a broad measure that encompasses personal, civil, and economic freedom. Human freedom is a social concept that recognizes the dignity of individuals and is defined here as negative liberty or the absence of coercive constraint. Because freedom is inherently valuable and plays a role in human progress, it is worth measuring carefully.
Legatum Prosperity Index (LPI)* Sources: various (BTI, Gallup, OECD, UN, WVS and many others)	The Legatum Prosperity Index™ is a framework that assesses countries on the promotion of their residents' flourishing, reflecting both economic and social wellbeing. It captures the richness of a truly prosperous life, moving beyond traditional macroeconomic measurements of a nation's prosperity, which rely solely on indicators of wealth such as average income per person (GDP per capita). **Here partial LPI (Governance, Social capital, Infrastructure & Market access, Economic quality)**
Global Adaptation Initiative Country Index (ND-GAIN)* Sources: various (Earth System Grid Federation, World Bank, FAOSTAT, WDI, World Resource Institute, AQASTAT, etc.)	The ND-GAIN Country Index is composed of two key dimensions of adaptation: vulnerability and readiness. Vulnerability measures a country's exposure, sensitivity and capacity to adapt to the negative effects of climate change. ND-GAIN measures overall vulnerability by considering six life-supporting sectors – food, water, health, ecosystem service, human habitat, and infrastructure. Readiness measures a country's ability to leverage investments and convert them to adaptation actions. ND-GAIN measures overall readiness by considering three components – economic readiness, governance readiness and social readiness. **Here partial ND-GAIN focusing on Participation and Environmental sustainability.**
Inequality-adjusted HDI (IA-HDI) Source: UNDP	The IHDI accounts for inequalities in HDI dimensions by "discounting" each dimension's average value according to its level of inequality. The IHDI value equals the HDI value when there is no inequality across people but falls below the HDI value as inequality rises. In this sense, the IHDI measures the level of human development when inequality is accounted for.
Just Transition Score (JTS) Sources: various (Our World in Data, Climate Watch, Eora Global Supply Chain Database)	The Just Transition Score combines the comprehensive, human-centered measurement of the Social Progress Index with data on countries' consumption-based per capita CO_2 emissions. The Just Transition Score measures countries' ratio of carbon emissions per capita to the Social Progress Index, it tells us how carbon efficient a country is at creating positive social outcomes. The ratio is scaled from 0 (worst performance) to 100 (best performance). Countries with the highest score are those that are most effectively tackling the climate crisis while delivering social progress for their people.
Sustainable Development Index (SDI) Sources: various (UNDP, UN International Resource Panel Global Material Flows database, Eora MRIO database	The Sustainable Development Index (SDI) measures the ecological efficiency of human development, recognizing that development must be achieved within planetary boundaries. It was created to update the Human Development Index (HDI) for the ecological realities of the Anthropocene. The SDI starts with each nation's human development score (life expectancy, education and income) and divides it by their ecological overshoot: the extent to which consumption-based CO2 emissions and material footprint exceed fair shares of planetary boundaries. Countries that achieve relatively high human development while remaining within or near planetary boundaries rise to the top.

Source: respective websites of the institutions/organizations that produced the indicators

Figure A.1 : distributions and pairwise linear correlations between selected composite indicators



Source: authors' calculations

Table A.2: *PCA main statistical results*

Eigenvalues:						
	F1	**F2**	**F3**	**F4**	**F5**	**F6**
Eigenvalue	3,749	1,363	0,492	0,262	0,084	0,051
Variability (%)	62,475	22,718	8,199	4,360	1,393	0,854
Cumulative %	62,475	85,194	93,393	97,753	99,146	100,000

	Factor loadings		**Contributions**		**Cos²**	
	F1	**F2**	**F1**	**F2**	**F1**	**F2**
LPI	0,974	-0,068	25,321	0,337	0,949	0,005
HFI	0,844	0,294	19,015	6,344	0,713	0,086
IA-HDI	0,920	0,018	22,600	0,024	0,847	0,000
ND-GAIN	0,952	-0,092	24,174	0,621	0,906	0,008
SDI	-0,506	0,700	6,842	35,983	0,256	0,490
JTS	0,277	0,879	2,047	56,692	0,077	0,773
GPI	-0,706	-0,113	0,000	0,000	0,498	0,013

Source: authors' calculations

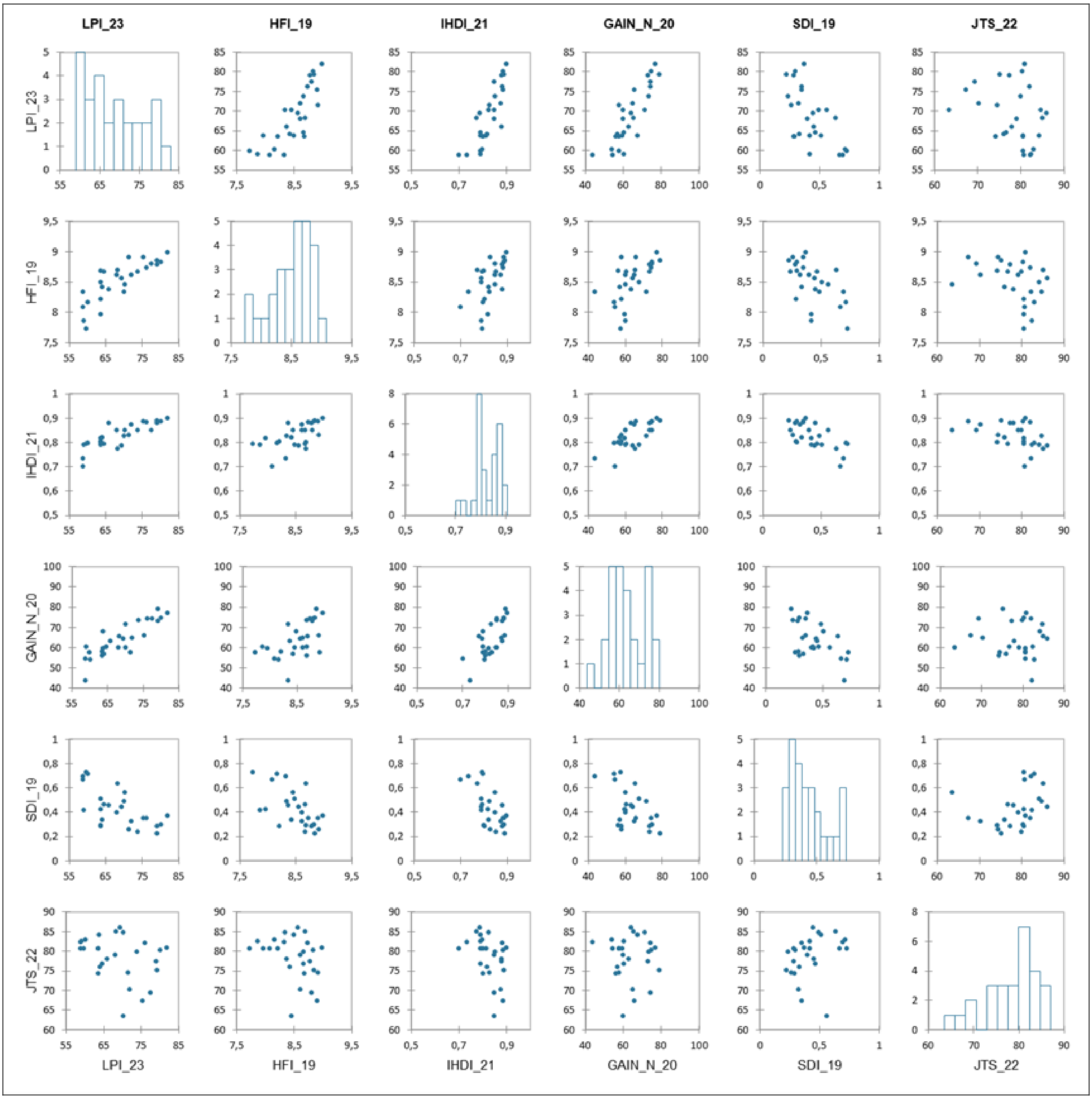
Table A.3: *group means of initial composite indicators and PCA multidimensional components*

Variables	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**All countries**
HFI	**8,599**	**7,474**	*6,122*	*5,745*	7,116
LPI	**71,877**	53,841	*41,155*	49,571	53,282
ND-GAIN	**68,418**	47,014	*33,179*	45,774	47,059
IA-HDI	**0,846**	0,631	*0,394*	0,602	0,601
JTS	**74,683**	**77,204**	69,788	*45,906*	70,697
SDI	*0,334*	**0,708**	0,591	*0,455*	0,564
IEHD (F1 coordinates)	**3,035**	0,102	*-1,854*	*-0,881*	0,000
SESD (F2 coordinates)	*-0,381*	**0,920**	-0,044	*-2,148*	0,000

Source: authors' calculations

Note *: bold characters identify means that are significantly higher, and italic characters indicate means that are significantly lower than the overall average for all countries.*

Figure A.2: distributions and pairwise linear correlations between selected composite indicators – EU27



Source: authors' calculations

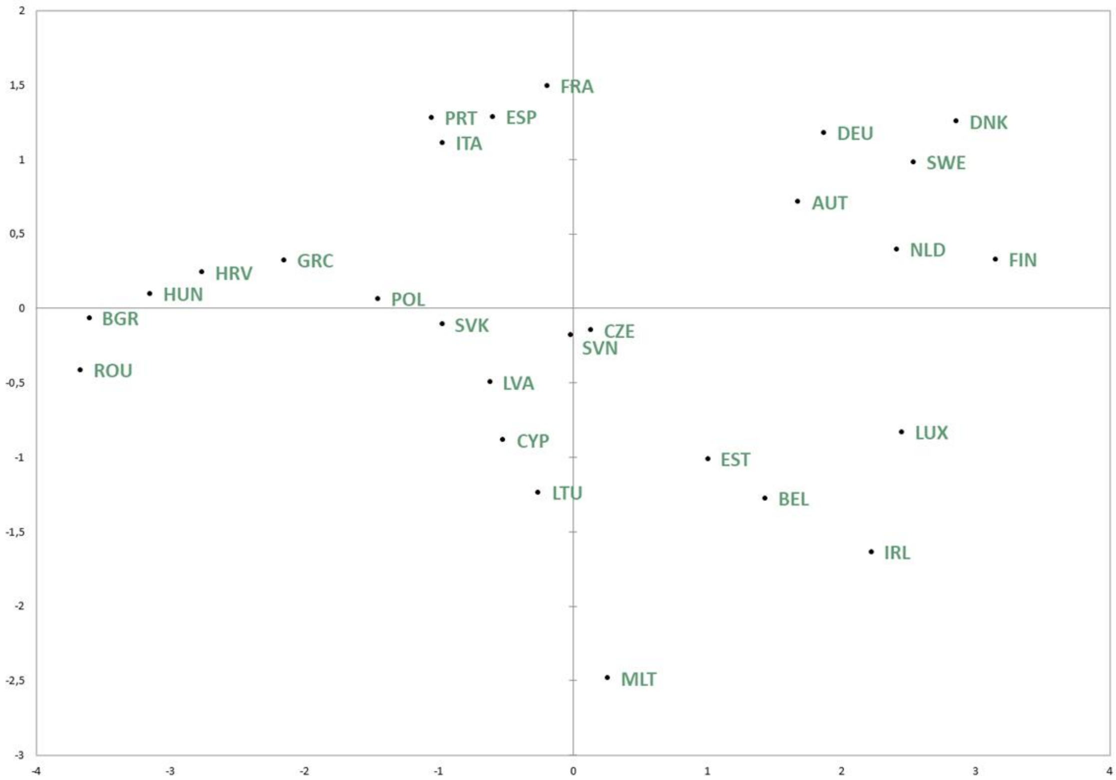
Table A.4: PCA main statistical results – EU27 countries

Eigenvalues:						
	F1	F2	F3	F4	F5	F6
Eigenvalue	3,910	0,987	0,448	0,433	0,172	0,050
Variability (%)	65,173	16,442	7,466	7,215	2,865	0,838
Cumulative %	65,173	81,616	89,081	96,296	99,162	100,000

	Factor loadings		Contributions		Cos²	
	F1	F2	F1	F2	F1	F2
LPI_23	0,954	0,147	23,277	2,203	0,910	0,022
HFI_19	0,829	-0,025	17,564	0,062	0,687	0,001
IHDI_21	0,892	-0,040	20,336	0,159	0,795	0,002
GAIN_N_20	0,830	0,441	17,610	19,707	0,689	0,194
SDI_19	-0,799	0,086	16,313	0,754	0,638	0,007
JTS_22	-0,438	0,872	4,900	77,114	0,192	0,761
GPI_20	-0,380	0,081	0,000	0,000	0,145	0,007

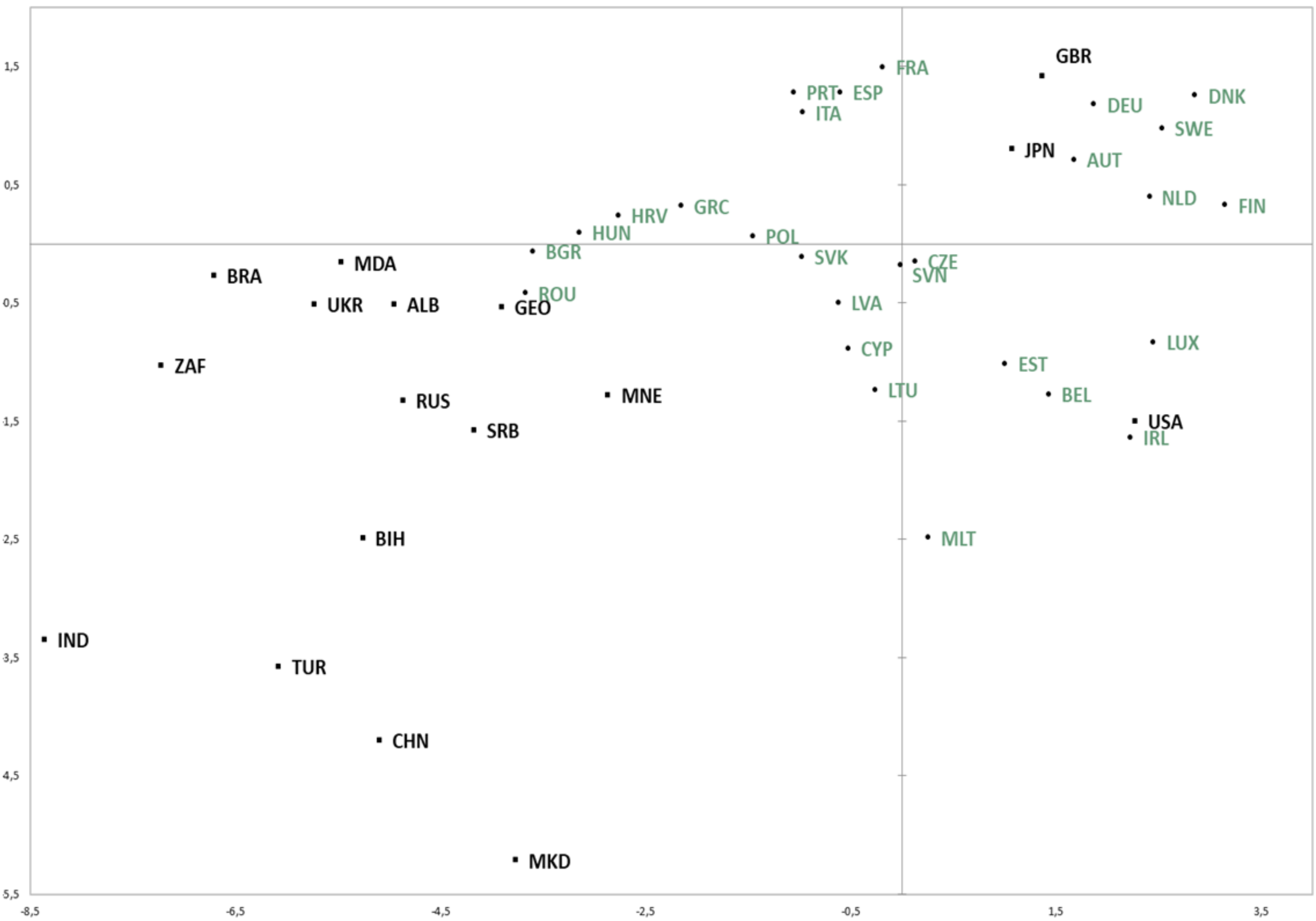
Source: authors' calculations

***Figure A.3**: countries scatter plot on the first 2 components of PCA – EU27 countries*



Source: authors' calculations

Figure A.4: *EU27 countries scatter plot on the first 2 components of PCA with major emerging countries and candidates for EU membership as supplementary individuals*



Source: authors' calculations

SPES Sustainability performances, evidence & scenarios

www.sustainabilityperformances.eu