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A Composite Indicator for Assessing Upscaled Energy Sufficiency and Sustainable Prosperity in the European Union

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ABSTRACT

The reliance on Gross Domestic Product (GDP) as a measure of economic success has been criticized for neglecting environmental and social dimensions of well-being. To address this limitation, this paper develops an adapted version of the Sustainable Prosperity Index (SPI), inspired by Jackson and Victor (2020) and applied to the European Union (EU). The study is motivated by the need for a holistic sustainability metric that explicitly incorporates energy sufficiency—an aspect often overlooked in beyond-GDP indices. Using a composite indicator approach, we construct the SPI by integrating economic, environmental, and social indicators, with a specific focus on energy sufficiency within four key high-energy consumption domains: food, transport, housing, and consumer goods. The SPI is computed for all EU countries under a Reference Scenario and multiple Sufficiency Scenarios to assess the potential impact of upscaled sufficiency measures on sustainability performance. Our results show that energy sufficiency measures can enhance EU countries' sustainability performance, with SPI improvements for the 5 analysed countries (Denmark, France, Germany, Italy, and Latvia) ranging between 1.2% and 2.3%. Countries with higher baseline resource consumption tend to experience the most pronounced gains. The findings highlight the potential of sufficiency-driven policies to complement decarbonization strategies by reducing overall energy demand.

KEYWORDS

Sustainable prosperity index, Composite indicator, Energy sufficiency, Energy policy, Beyond GDP, Lifestyle changes, European Union.

INTRODUCTION

In Europe, there is a current deficiency in comprehensive assessment tools that quantify the impact of individual energy sufficiency actions. The importance of individual behavioural actions is escalating, as they offer a broader perspective on potential shifts in energy consumption and the associated decrease in environmental impacts. This assigns a central role to sufficiency and its potential [1], [2].

The inadequacy of the Gross Domestic Product (GDP) in capturing social and environmental well-being is widely acknowledged. In 2009, the Commission on the

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Measurement of Economic Performance and Social Progress – led by Stiglitz, Sen, and Fitoussi – highlighted the limitations of GDP as the primary metric for assessing economic and social progress, advocating for broader measures [3]. This discussion catalysed various efforts to develop alternative indicators to better inform on the "comprehensive measurement of a country's overall state of economic and environmental health and social well-being" ([4]). Since its development in 1934 by Simon Kuznets and its subsequent adoption in policy frameworks after World War II, GDP has been largely criticized for failing to track the progress towards true sustainable development [5]. More recent critiques have led to the emergence of alternative frameworks, distinguishing between approaches that aim to "green" GDP [6] and those that propose entirely new indicators beyond economic growth.† This aligns with the argument by [8], who conducted an extensive literature review of alternatives to GDP, overcoming the crude measurement of income and material wealth.

Despite these improvements, the existing literature still grapples with the direct incorporation of energy sufficiency into comprehensive metrics. Indeed, several alternative measures have been proposed, yet they fall short in addressing sufficiency and its multi-level impact on economic, environmental, and social dimensions. For instance, [9] introduced a composite measure of economic welfare of a country's population, combining data on consumption, leisure, mortality, and inequality for a wide set of countries. However, the authors omit some factors such as the quality of natural environment. Moreover, the Better Life Index (BLI), developed by the Organisation for Economic Cooperation and Development (OECD) and firstly introduced by [10], does incorporate aspects such as work-life balance and life satisfaction, although it does not directly integrate sufficiency. The innovative Sustainable Wellbeing Index (SWI) proposed by [11] makes a step ahead to measure sustainable wellbeing in connection with the UN Sustainable Development Goals (SDGs). Despite combining the contributions of economic, natural capital/ecosystem services and social capital/community, the authors neglect the direct contribution of sufficiency towards sustainable prosperity. Other indices, such as the Sustainable Development Index (Hickel, 2020), integrate environmental sustainability, yet they fail to directly integrate the impact of demand shifts from behavioural lifestyle changes due to energy sufficiency measures. Only the recent work by [12] explicitly assesses optimal levels of "sufficiency" to monitor indicators included in beyond-GDP assessments for Asia, South-East Asia and Korea countries.

Remarkably, the European Environment Agency [13] stressed the quest for innovative strategies to ensure sustainable growth in Europe, advocating for lifestyles, communities, and societies that are willing to consume less, while enhancing well-being, equity and social cohesion. The Intergovernmental Panel on Climate Change highlights sufficiency as pivotal to reduce emissions, especially in buildings, by promoting smaller, compact structures, shared spaces, and co-housing to minimize resource use. Besides, it advocates for active transport, public means, as well as sustainable consumption patterns, such as eco-friendly diets, waste reduction, and durable products [14].

Similarly, [15] points out that "more attention should be given to measures that reflect a wider range of objective and subjective measures of well-being, as well as measures that better reflect the heterogeneity of peoples' experiences". By analysing 835 empirical works, Haberl *et al.* [16] advocate for an integration of sufficiency-oriented strategies to assess decoupling efforts in energy use, resource consumption, and emissions. Indeed, the decoupling concept – sustaining economic growth while reducing greenhouse gas (GHG) emissions – is key for climate policy. The United Nations' Decoupling Index (DI) [17], measures this process, by

† For more insights on the distinction between the concepts of "a-growth" and "de-growth", see Van den Bergh and Kallis [7].

distinguishing between absolute and relative decoupling.[‡] [18] later applied it to the EU28 case, assessing environmental impacts using the 16 EU Environmental Footprint indicators. Crucially, Kalimeris *et al.* [19] claim that non-GDP welfare indicators grow more slowly than GDP, introducing metrics like Material Intensity (MI) to explore the nexus between resource use and the economy. Finally, in their comprehensive review of the recent literature on beyond GDP metrics, Jansen *et al.* (2024) specify the promising approach of integrating elements of input-output analysis with stock-flow consistent models, to deliver overarching tools both for policy-makers and researchers [20].

Building upon such background, this paper addresses the research gap by proposing a comprehensive, multidimensional composite indicator [21] that moves beyond GDP. Investigating a narrow but unexplored field of research, this article aims to answer to its main research question of how the complex and multi-dimension assessment of sustainability into a unique beyond-GDP metric can isolate and summarise the specific effect of energy sufficiency lifestyle changes by individuals.

As part of the activities conducted during the EU-funded H2020 project FULFILL,[§] this article extends the Sustainable Prosperity Index (SPI) introduced by [22], underscoring the importance of energy savings and carbon emissions' reductions resulting from demand shifts due to sufficiency-oriented behavioural changes. The proposed metric aims to connect the economic, environmental, and social dimensions, designing simulated trajectories towards sustainable prosperity. This framework is applied to EU27 countries, by modelling a *Reference Scenario* (under baseline conditions) and a range of *Sufficiency Scenarios* driven by assumed Sufficiency shocks[**], which are applied to the selected indicators based on several hypotheses driven by the percentage uptake of lifestyle changes within EU countries.

The proposed SPI aims to offer a more comprehensive view of sustainability, with a focus on ensuring long-term prosperity for citizens, considering the Net-Zero GHG targets for 2050. By accounting for the diversity of indicators and the differing rates of penetration of sufficiency, the proposed SPI serves as an easy tool to enable fundamental insights on the potential for EU27 countries to enhance their decarbonization efforts via initiatives that support sustainable ways to produce and consume energy.

This paper is organized as follows. Section 2 presents a review of the literature on the topic. Section 3 investigates the employed methodological approach. Section 4 informs on sources of information for data collection and processing. Section 5 presents the main outputs of this research work, while Section 6 discusses the main findings and critical aspects of the paper. Section 7 concludes with final remarks.

LITERATURE REVIEW

The measurement of economic performance keeps changing over time. Many studies have suggested the adoption of a holistic view to assess the degree of wealth of a country. Therefore, there has been a wide literature studying methods and indicators for assessing the economic performance of countries, integrated with innovative solutions to add the environmental and social impact dimensions for a correct evaluation of sustainable prosperity.

[‡] *Absolute decoupling* occurs when resource use or environmental impact decreases, even as the economy continues to grow. On the other hand, *relative decoupling* occurs when resource use or environmental impact grows at a slower rate than economic growth. In other words, the economy becomes less resource-intensive or polluting per unit of output.

[**] In Input-Output (I/O) modelling, "shocks" refer to unexpected or significant changes in one or more economic variables or sectors, which then propagate through the entire economic system due to the interdependencies between sectors. Sufficiency shocks, in this context, are assumed to originate from simulated changes in consumer demand, to reflect a shift towards more sustainable or reduced consumption behaviours.

The efforts to redefine and innovate the way the progress of a country is measured date back to the previous century.

In 1972, William Nordhaus and James Tobin introduced the Measured Economic Welfare (MEW) index, to undermine the value of GDP as a proper measure of economic welfare [23]. The MEW took the measure of GDP, adding the value of leisure time and the amount of unpaid work in the economy, while detracting the value of environmental damage, hence accounting for negative externalities generated by increasing economic activity.

Key concepts, governmental and local actions, and project-based initiatives

Many applications were initiated, following the pivotal work by [3]. Hereby is a brief overview, at the best of authors' knowledge.

In 2010, the UK prime minister David Cameron launched a new program, outlining the concept of "inclusive wealth", aiming to set up a plan to transform the social setting of the country, creating new opportunities for sustainable prosperity to all Britain's forgotten communities. This concept was adopted in the landmark UK Levelling Up White Paper [24], inducing a 'system change' based on the reduction of regional inequalities. This resulted in the outline of 12 quantifiable national missions to be achieved by 2030.

Following this initiative by the UK Government, the Institute for Global Prosperity (IGP) established a novel definition of prosperity, engaging citizen social-scientists and community organizations in a pilot case in east London. Central to this effort is the Prosperity Index (PI) (PI),[††] an indicator developed by IGP, which identifies 15 headline factors that local people recognize as priorities to support prosperity and quality of life at the local level.

The Sustainable Development of Energy, Water and Environment Systems (SDEWES) Index offers a valuable tool for benchmarking city performance related to local energy systems across sustainability metrics. Encompassing 7 dimensions, 35 main indicators, and around 25 sub-indicators, the SDEWES Index assesses a city's progress towards sustainable development in areas like energy usage, water management, and environmental impact. This multi-faceted approach allows for comparisons between cities and facilitates the identification of strengths and weaknesses in sustainability efforts [25].

The New Zealand's Living Standards Framework [26] is the best-known example of a dashboard approach (the "LSF Dashboard"), a measurement tool which complements the LSF, which in turn represents the main flexible repository to gather all aspects that matter for the present and future New Zealand's wellbeing. The LSF acts on three levels: the individual and collective wellbeing (e.g. health, knowledge and skills, housing, environmental amenity, etc.), the Institutional and Governance framework (e.g. central and local government, firms, and markets, etc.) and further complementary aspects of wellbeing (e.g. natural environment, social cohesion, human capability, financial and physical capital).

In the EU, many initiatives have fostered the idea of sustainable and equitable growth. The Beyond Growth Conference [27] has this main objective of challenging the status-quo of current conventional policies, to generate policy recommendations aimed at establishing sustainable prosperity in Europe, based on a drastic change to the way of approaching economic, social, and environmental sustainability issues.

The European project WISE – Wellbeing, Inclusion, and Sustainability in Europe[‡‡] – aims at advancing studies on beyond traditional GDP-centric metrics, paving the way towards a new conceptual foundation. The "WISE triangle" identifies relevant dimensions for evaluating beyond-GDP existing indicators, based on Wellbeing, Inclusion, and Sustainability (WISE). Wellbeing pertains to the present state of wellbeing, inclusion relates to the distribution of

[††] Institute for Global Prosperity (IGP). The Prosperity Index. https://seriouslydifferent.org/what/prosperity-index

[‡‡] WISE Database. University of Leiden 2022 https://www.beyond-gdp.world/wise-database/wise-metrics

wellbeing, while sustainability points to the wellbeing of future generations. Noteworthily, metrics within the triangle are categorized based on their coverage of such dimensions, illustrating a nuanced understanding of societal progress. The 14 central beyond-GDP indicators are those that distinguish themselves to include all three relevant dimensions.

The Doughnut Economics initiative [§§] offers a new way to envision the societal transformation. Central to this initiative is the book [28], which quickly became an international bestseller due to its profound insights into redesigning economic systems and fostering sustainable growth for the future.

The G15+ collective has generated a dashboard of 51 indicators to assess the well-being of citizens in Quebec, surpassing GDP-centric evaluations.[***] This initiative aims to steer public policies towards a prosperous, inclusive, and sustainable society by offering a multifaceted perspective on societal progress. Endorsed by experts and supported by key institutions and organizations, this project underscores civil society's dedication to addressing the evolving needs of Quebec's population.

Key beyond-GDP indicators

Several studies reviewed the most relevant beyond-GDP indicators over time. A systematic review was recently performed by Agrawal and Sharma [29]. By means of a meta-literature analysis, the authors analyzed works published between 2012 and 2022, highlighting main articles, journals, influential authors, organizations, countries, keywords, and top trend topics.

Nevertheless, the work by Stiglitz *et al.* [3], as well as the one by Corlet Walker and Jackson [30], were primarily recognized as the starting point for reviewing the major state-of-the art beyond-GDP indicators.

Table 1 outlines the findings, followed by a brief discussion of each documented indicator, organized chronologically for analytical coherence.

Initially developed by the Pakistani economist Mahbub ul-Haq in the 1990s, the United Nations Development Programme – UNDP [31] developed the Human Development Index (HDI) for an easy-to-use comparison of average human well-being across countries, alongside with the GDP. It measures health (life expectancy at birth), education (mean and expected years of schooling), and per capita income indicators (GNI per capita), and thus, tries to capture the broad dimension of human development. It had the explicit target "to shift the focus of development economics from national income accounting to people-centered policies".

Conversely, the Sustainable Development Index (SDI) developed by Hickel [36] aims at overcoming the limitations of the HDI, which neglects the fact that “countries that score highest on the HDI also contribute most, in per capita terms, to climate change and other forms of ecological break-down”. Thus, the SDI includes the concept of nations’ ecological efficiency in delivering human development.

The Index of Sustainable Economic Welfare (ISEW) heavily contributed to undermine the concept of conventional GDP. The index was initially developed by the ecological economist Herman Daly and theologian John Cobb in the appendix of their 1990 book “For the Common Good” [38].

The Measured Economic Welfare (MEW) index dates to the work by William Nordhaus and James Tobin (1972), who undermined the value of GDP as a proper measure of economic welfare. The MEW took the measure of GDP, adding the value of leisure time and the amount of unpaid work in the economy, while detracting the value of environmental damage, hence accounting for negative externalities generated by increasing economic activity.

[§§] Doughnut Economics. 2023 https://doughnuteconomics.org/
[***] Indicators of Well-Being in Quebec. 2022 The Project – Les indicateurs du bien-être au Québec

Table 1. Review of indicators that go beyond GDP

Institution	Year	Reference	Indicator	Acronym
-	1972	Nordhaus & Tobin, (1972)	Measured Economic Welfare	MEW
UNDP	1990s	[31]	Human Development Index	HDI
-	1990	Cobb and Daly (1989)	Index of Sustainable Economic Welfare	ISEW
Redefining Progress	1995	[32]	Genuine Progress Indicator	GPI
New Economics Foundation	2006	[33]	Happy Planet Index	HPI
OECD	2011	[10]	Better Life Index	BLI
Canadian Index of Wellbeing Network	2011	[25]	Canadian Index of Wellbeing	CIW
UNEP	2012	[34]	Inclusive Wealth Index	IWI
World Economic Forum	2017	[35]	Inclusive Development Index	IDI
CUSP	2020	[22]	Environmental Burden Index	EBI
CUSP	2020	[22]	Sustainable Prosperity Index	SPI
SDI Project	2020	[36]	Sustainable Development Index	SDI
Legatum Institute	2021	[37]	Legatum Prosperity Index	LPI

The ISEW and the MEW were somehow precursors of the Genuine Progress Indicator (GPI), initially developed in 1995 by the U.S. no-profit organization Redefining Progress. The GPI started to be established as an alternative index to GDP, and began to be used both in Canada and the U.S. The GPI is composed by 26 indicators, encompassing the social and environmental dimensions which are not included in the GDP, such as pollution, volunteerism, crime, and climate change. Kubiszewski *et al.* [32] use estimates of GPI over the 1950-2003 period for 17 countries, to compare it with GDP. The authors argue that GPI attempts to adjust GDP for a range of factors (environmental, social, and economic) which are not sufficiently reflected in the GDP itself, enabling more effective comparisons between economic growth and well-being. Remarkably, GPI stems from the concept of sustainable income, which dates to the study by the economist John Hicks [39], later reviewed by Nordhaus [40].

The Happy Planet Index (HPI), provided in 2006 by the New Economics Foundation [33], emphasizes the role of life satisfaction, life expectancy, and ecological footprint per capita. The index aims to measure the extent to which countries use natural resources to achieve long and happy lives for their citizens, providing a compass to guide nations towards genuine progress. Remarkably, HPI indirectly incorporates for sufficiency, examining how efficiently countries use their natural resources to achieve sustainable well-being, through the inclusion of subjective life expectancy, life expectancy at birth, and ecological footprint per capita.

The Better Life Index (BLI) was created in 2011 by the Organisation for Economic Cooperation and Development (OECD) and is an interactive tool which consists of 11 topics of wellbeing, which are initially weighed equally. The rationale behind the Index was introduced by Boarini and d'Ercole [10], who discussed the shortcomings of GDP from the OECD perspective. The authors present the OECD approach for the BLI, a tool that provides a multi-dimensional assessment which allows for country-comparisons of well-being. The tool is now designed to enable users to prioritize among the 11 topics and monitor the performance of countries of interest. The dimensions include income, jobs, community, education, environment, governance, health, life satisfaction, safety, and work-life balance.

In 2012, the Inclusive Wealth Index (IWI) was proposed [34], which assesses the change in nations' wealth, by encompassing a comprehensive view of capital assets, including manufactured, human, and natural capital. It is a metric for inclusive wealth within countries, having the main advantage of integrating natural and social capital alongside economic wealth.

The Canadian Index of Wellbeing (CIW) was initially developed by the Canadian Index of Wellbeing Network, with the intention of monitoring the wellbeing of the Canadian population in environmental health, to assess well-being and going beyond the traditional economic indications of GDP. The CIW is composed of eight domains (Community Vitality, Democratic Engagement, Education, Environment, Healthy Populations, Leisure and Culture, Living Standards, Time Use), where each of them is further disentangled into 8 indicators [25]. Similar initiatives to CIW later led to national indexes tracking wellbeing (e.g. UK, Australia, Norway).

The Social Progress Index (SPI), developed in 2013 by the no-profit initiative "Social Progress Imperative", assesses social and environmental well-being across three broad dimensions: basic human needs, foundations of well-being, and opportunity [41].

The Inclusive Development Index (IDI) was introduced by the World Economic Forum [42], as part of the project of the WEF's System Initiative on the Future of Economic Progress. The indicator represents an annual assessment of 103 countries' economic performance, assessing how countries perform on 11 dimensions of economic progress in addition to GDP.

Jackson and Victor [22] – affiliated to the Centre for Understanding Sustainable Prosperity (CUSP) – elaborated two novel indicators going beyond GDP: the Environmental Burden Index (EBI), and the Sustainable Prosperity Index (SPI). The EBI describes the environmental impacts of economic activity which are absent from GDP, while the SPI incorporates a multi-level framework, including economic, environmental, and social levers into a unique composite index.

In 2021, the Legatum Institute launched the Legatum Prosperity Index. According to their approach [37], the index is an annual ranking of 167 countries on their levels of prosperity. It is based on multiple factors, including economic quality, business environment, governance, education, health, personal safety, social capital, and natural environment.

Common to the reviewed existing indices is that they frequently fail to adequately account for energy sufficiency, which is essential, in the authors' view, for a comprehensive assessment of sustainable development and prosperity.

Inclusion of energy sufficiency in beyond-GDP indicators

Bagheri et al. [43] introduce a novel multi-factor energy input-output (MF-EIO) model to support green growth in Canada by analyzing energy use, CO_2 emissions, and economic impacts. They use an MF-EIO model that incorporates eight multipliers and two green growth indices to evaluate the effects of changes in final demand on energy flows, emissions, and job creation. The two new indices developed are:

- Green Economic Growth Index (GEGI): this index assesses the extent to which different final non-energy demands threaten the environment through their CO_2 emissions due to a unit of economic expansion. It is calculated as the ratio of the CO_2 emission multiplier to the total output multiplier, and
- Green Job Growth Index (GJGI): this index measures the emissions intensity per energy job created from final non-energy and energy demands. It is calculated as the ratio of the

CO_2 emission multiplier to the energy job multiplier, indicating the CO_2 emissions per energy job created.

As a result, their analysis identifies economic activities that can stimulate green growth with minimal environmental impact, highlighting sectors with high renewable energy use and low CO_2 emissions. From this, the study concludes with policy guidelines to help promote green growth through targeted reforms and public expenditure strategies.

Millward-Hopkins et al. [44] present a model estimating the minimal energy required to provide decent living globally by 2050. It suggests that with advanced technologies and demand-side changes, it is possible to reduce global energy consumption to 1960 levels (which is considered sustainable) despite a larger population. The concept of sufficiency is then central to the paper. It involves reducing consumption to levels that meet basic needs without excess ("for decent living, but no more") which is materially more generous than what the opponents of consumption reduction assume. However, achieving the proposed energy reduction by 2050 requires a massive deployment of advanced technologies across all sectors in addition to demand-side changes: radical changes in consumption patterns are necessary. This means moving away from growth-oriented consumption to sufficiency-oriented consumption, even in high-income countries. The paper thus argues that these changes can provide a high quality of life for all, while significantly reducing energy use and ecological impact. It challenges the notion that environmental sustainability requires a return to primitive living, instead proposing a modern, low-energy, and high-living-standard global society.

> "*highly-efficient facilities for cooking, storing food and washing clothes; low-energy lighting throughout; 50 L of clean water supplied per day per person, with 15 L heated to a comfortable bathing temperature [..] air temperature of around 20 °C throughout the year, irrespective of geography; have a computer with access to global ICT networks; are linked to extensive transport networks providing ~5000–15,000 km of mobility per person each year via various modes [..] universal healthcare is available and [..] education for everyone between 5 and 19 years old.' And at the same time, it is possible that the amount of people's lives that must be spent working would be substantially reduced.*" Millward-Hopkins *et al.* (2020) p. 8

Of the indices in **Table 2**, none directly and explicitly include energy sufficiency as a component. However, some indirectly hint at aspects related to energy use or sustainability.

The other indices – HDI, IWI, SPI, IDI – primarily focus on economic factors, without directly addressing energy sufficiency. While the Environmental Burden Index (EBI) and Sustainable Prosperity Index (SPI) consider environmental impacts, they do not specifically isolate energy sufficiency as a separate component.

METHODS

This Section presents the method used for developing the composite beyond-GDP index.

Originally, inspiration was drawn from the *Sustainable Prosperity Index* (SPI) proposed by Jackson and Victor [22].[†††] Due to the flexibility related to its construction process and the

[†††] Our composite index stems from the approach used by the authors, who developed the *Environmental Burden Index* (EBI) and SPI based on a stock-flow consistent (SFC) macroeconomic simulation model for the case of Canada. Nevertheless, the SPI developed in this paper was adjusted to incorporate the impact of energy sufficiency and calibrating the relative data for the geographical scope of EU27 countries.

comprehensive aggregation of relevant economic, social, and environmental dimensions, the SPI was employed as the target beyond-GDP index analysed in the present paper.

The challenge was to tailor its computation to the case of EU countries, given the high level of heterogeneity, adding the complexity of assessing the impact of energy *Sufficiency Measures* (SMs) under specific scenario assumptions developed under the project FULFILL.[‡‡‡]

Table 2. Inclusion of energy sufficiency by analysed beyond-GDP indicators

Index	Acronym	Inclusion of energy sufficiency
Happy Planet Index	HPI	It includes ecological footprint, which is related to resource consumption and can be influenced by energy use. A lower ecological footprint often implies more sustainable practices, potentially including energy sufficiency. HPI also includes well-being, through the inclusion of subjective life expectancy, life expectancy at birth, and ecological footprint per capita.
Canadian Index of Wellbeing	CIW	It includes the domain "Environment," which assesses environmental quality and sustainability. While not specifically focused on energy, this domain could indirectly reflect the impacts of energy consumption on the environment. CIW also incorporates sufficiency through leisure and culture, time use, and democratic engagement.
Genuine Progress Indicator	GPI	It adjusts GDP by subtracting the costs of environmental damage, which can be linked to excessive energy consumption. GPI also includes non-market activities like volunteer work and housework. A higher GPI could indicate a more sustainable approach to resource use, including energy.
Better Life Index	BLI	It indirectly incorporates sufficiency among its 11 dimensions: individuals can prioritize aspects of their lives like health, work-life balance, and life satisfaction.
Social Progress Index	SPI	It includes basic individual well-being, such as health and safety, that indirectly could be associated with energy sufficiency.

Overall, the methodological approach followed a holistic procedure which entailed a continuous processing of information from multiple internal and external sources, ensuring the robustness, accuracy, and relevance of the final composite index, to effectively incorporate the impacts of sufficiency lifestyle changes in the calculation.

Several critical aspects have emerged in the construction of a composite beyond-GDP index. The primary concern entailed the selection of pertinent indicators related to economic, environmental, and social dimensions. In addition to this, the identification of scenario assumptions was approached. Thirdly, the normalisation of indicators became significant, to ensure consistency and enable meaningful comparisons among the input variables. Besides, the selection criteria for assigning weights to indicators within the composite index were addressed. Lastly, the final aggregation of input indicators and the construction of the SPI for the case of Europe to account for energy sufficiency was determined. Each of these issues is investigated in the following subsections.

[‡‡‡] EU H2020 FULFILL. Please consult https://cordis.europa.eu/project/id/101003656 and https://fulfill-sufficiency.eu/.

Selection of pertinent indicators

Initially, the scanning, comparison and selection of the pertinent measures and variables related to economic, environmental, and social dimensions was undertaken. This process was supported by preliminary data analysis, overlooking the evolution of time series variables between 2000 and 2020, highlighting differences across EU27 countries. This entailed a comprehensive review of the previous impact assessments conducted under the Input/Output (I/O) analysis[§§§] as well as the links with the literature gap review.

Regarding the final selection of pertinent input indicators, three major changes were executed to the Canadian SPI developed by Jackson and Victor [22]. Firstly, the indicator "*unsecured household debt-to-income ratio*" was ruled out. This exclusion was motivated by the complexity associated with interpreting this indicator in the context of assessing the impact of lifestyle changes on energy sufficiency. Specifically, the unsecured household debt-to-income ratio presents challenges in accurately reflecting how shifts towards more sustainable lifestyles and energy consumption patterns influence financial stability and debt levels. Secondly, GHG emissions were employed as the comprehensive indicator to substitute EBI for representing the environmental dimension of the SPI. Indeed, GHG emissions are a direct outcome of the I/O modelling framework developed by Golinucci et al. [45].[****] Lastly, the ratio of projected employment over projected population – to substitute unemployment rate – was constructed, mainly due to data availability on projected values of workforce under the considered scenario assumptions.

Table 3 summarizes the selected input indicators for SPI, covered dimensions, and sources.

Table 3. Selection of indicators for the composite beyond-GDP index

ID	Indicator	Label	Dimension	Source
1	GDP per capita	$GDP\_pc_{c,y}$	Economic	[45]
2	Employment to population ratio	$Emp/pop_{c,y}$	Economic	[45] & own processing
3	Debt to GDP ratio	$Debt/GDP_{c,y}$	Economic	Eurostat
4	Gini coefficient	$Gini_{c,y}$	Societal	OECD
5	Average annual hours worked per worker	$Avg\_hrs_{c,y}$	Societal	OECD
6	GHG emissions	$GHG_{c,y}$	Environmental	[45]

Noteworthily, following the insights by Jackson and Victor (2020), changes in indicators that are assumed to contribute positively to sustainability and prosperity were treated as positive contributions, while negative changes were treated as negative contributions.

Overall, the SPI allows to consider the performance across all economic, social, and environmental dimensions. This comprehensive consideration serves as the basis for the assignment of weights to each indicator (see the next subsection). By doing so, the shock and relative contribution of each indicator are accurately reflected into the proposed SPI.

[§§§] For more details regarding the assumptions and outcomes of the I/O analysis within FULFILL, please refer to the pertinent D6.2 report of the project (Golinucci *et al.*, 2024).

[****] The report by Golinucci *et al.* (2024) employs an input-output (I/O) modelling framework to conduct the impact evaluation of energy sufficiency measures on energy, economic and environmental output indicators under reference and sufficiency scenario assumptions. The modelling framework is fully adopted in the current paper.

Modelling energy sufficiency and identifying scenarios

A modelling framework was elaborated to include sufficiency scenario assumptions, as identified in FULFILL. This aspect is essential to establish a link between behavioural and lifestyle changes, and the road of EU countries towards sustainable prosperity. Indeed, the proposed SPI stands out from the others as it explicitly integrates several scenario assumptions aimed at including the impact of lifestyle changes from the perspective of energy sufficiency.

Originally, the investigation of sufficiency stemmed from a selection of 50 levers. These levers were evaluated through a qualitative selection process, based on scoring of several qualitative criteria such as impact, diversity, representativeness, and potential for quantification in the field of energy sufficiency. This preliminary process ended into identifying six selected *Sufficiency Measures* (SMs), namely: (*i*) reducing animal products in diets, (*ii*) shared housing, (*iii*) sharing products (e.g. washing machines), (*iv*) moderate car sizing, (*v*) increased biking, and (*vi*) reduced air travel.[††††]

Following this pre-selection, a unique target indicator was identified for each of the 6 assumed SMs[‡‡‡‡], leading to the elaboration of projections which assumed the evolution of the selected indicator over future years (2030, 2035, 2040, 2045 and 2050), in line with guidance policy targets and past trends. Finally, the aggregate quantification of sufficiency assumptions was done through a *bottom-up physical approach*, which eventually enabled the quantification of energy services' demand and related energy consumption per energy carrier.[§§§§]

To perform impact assessment, a *Reference Scenario* and a set of *Sufficiency Scenarios* were depicted. The main difference boils down to the variations that are hypothesized in final consumption patterns (assumed through shocks in demand via the above-cited bottom-up physical approach), as specified in the I/O framework described by Golinucci et al. [45]. Specifically, the *Reference Scenario* assumption outlines a transition process that excludes energy SMs[*****] but includes the decarbonization of the power sector and the electrification of certain final uses. A *Sufficiency Scenario*, instead, was defined as a set of inputs representing at least one sufficiency scenario assumption. Intuitively, the comprehensive *Sufficiency Scenario* depicts the modifications that occur when all 6 SMs are applied, in addition to the existing background changes. In contrast, the *Reference Scenario* only captures the baseline changes in the economic structure without the implementation of the 6 SMs.

Understanding this difference is crucial for gauging the additional impact of SMs on sustainable prosperity. By incorporating these scenarios, the SPI informs on the potential benefit (or drawback) of adopting sufficiency lifestyle changes beyond the improvements (or worsening) already projected in the *Reference Scenario* (see **Figure 1**).

As shown in **Figure 1**, the set of scenarios where sufficiency scenario assumptions are present (*Sufficiency Scenarios*) differ from the one where SMs are absent (*Reference Scenario*). Therefore, the impact of each measure is determined by the net variation of outcomes under the I/O model's results (Golinucci *et al.*, 2024). The difference between the impact under the *Reference* and *Sufficiency Scenario* indicates the effect of the sufficiency scenario assumption, which is quantitatively reflected through the observed output indicator.

For the scope of this paper, the following identified scenarios are investigated:

[††††] The details of the selection process are included in the extensive work by Gabert et al. [46].

[‡‡‡‡] The indicators employed for the six selected SMs were: (*i*) quantities of food consumed per person per day, diet type shares (e.g., omnivore, vegetarian); (*ii*) square meters per person saved through the adoption of shared housing; (*iii*) rate of washing machine ownership; (*iv*) share of new passenger car sales by segment; (*v*) proportion of trips and distances covered by bike; (*vi*) yearly passenger kilometers (p km) for air travel.

[§§§§] For additional details on the bottom-up physical approach, please refer to Jacobs and Taillard [47].

[*****] From now on, sufficiency measures are referred as SMs. For more details on their characterisation, please refer to the Data Section.

- *Reference Scenario*. It represents the assumed baseline condition of growth for the EU economy, based on background information on electricity, car, and heating system mixes.
- *Sufficiency Scenario, all measures*. In this case, the simultaneous impact of all 6 assumed SMs is considered. These include sufficiency lifestyles in the domains of food (changing diets), mobility (flying less, moderate car sizing, and cycling more)[†††††], sharing spaces in houses (proxied by the reduction of the floor surface per capita in housing) and sharing products (exemplified by the shared use of washing machines).
- *Sufficiency Scenario, diets*. This assumption considers the dietary change by simulating a gradual and country-specific shift from omnivorous diets to vegetarian, vegan, and pescetarian mixes within the EU population.
- *Sufficiency Scenario, flying less*. This assumption considers the reduction in fuel consumption and thus, in air transport service, from both households and industrial activities, hence encompassing both leisure and business trips.

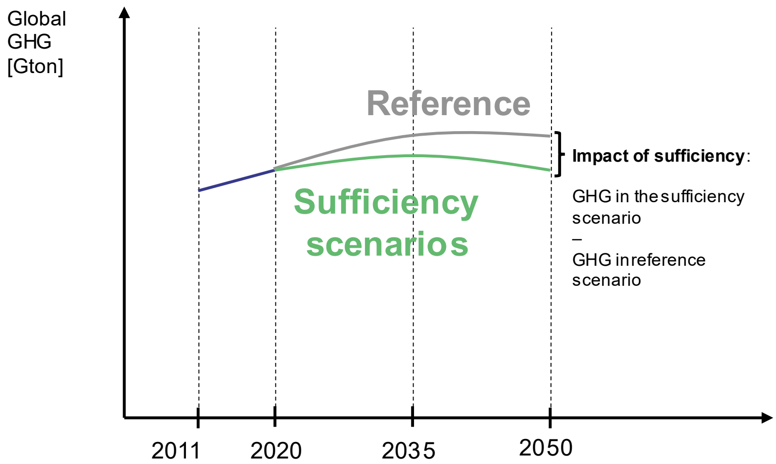

Figure 1. Representation of *Reference* and *Sufficiency Scenarios* in FULFILL. The example is here applied to the indicator "GHG emissions"

Overall, the inclusion of a *Reference* and a set of (three) *Sufficiency Scenarios* for the prospective analysis leads to the establishment of a more comprehensive view of potential for sustainable development, capturing both the baseline progress and the additional gains arising from adopting specific levers of energy SMs. This approach allows for a more nuanced analysis of policy impacts, supporting strategies that support sustainable prosperity in the EU.

Normalisation of indicators

Normalization is a critical step to ensure that all indicators are comparable and can be aggregated meaningfully (i.e. with the same units of measurement or unitless). This approach is beneficial for capturing the true dynamics and variations in each indicator.

To achieve this, the original levels of the indicators were transformed into their percentage changes (%), i.e. growth rates.[‡‡‡‡‡] This method allows to compare shocks to input variables

[†††††] The SM *moderate car sizing* simulates the attention to the purchase of cars by buyers, exemplified by modelling the purchase of different average weights of cars, considering current and projected diffusion of powertrains. The SM *cycling more* models the substitution of total kilometres driven by car to the benefit of kilometres cycled by individuals.

[‡‡‡‡‡] Note that, for the prospective analysis, a 5-year interval dimension was employed to compute relative percentage changes of the variables.

based on a common unit of measurement (i.e. rates of growth), to dynamically reflect the positive and negative contributions of each indicator to the composite index.

The percentage change of each variable x is calculated as follows:

$$perc\_change_x = \left(\frac{x_t - x_{t-5}}{x_{t-5}} \times 100\right)\% \quad (1)$$

Note that, in eq. (1), the percentage change for each indicator in year t is calculated with respect to its previous level observed 5 years before. By using percentage changes for each individual input indicator, the dynamic nature of shocks to each variable was more accurately captured, ensuring that the composite index remains responsive to real-world developments, tracking the evolution of the net effect of percentage shocks to selected indicators.

Weighting approach

Regarding the selection of weights, four primary methods commonly used can be identified in the literature:

1. *Equal weights*: assigning equal importance to all variables.
2. *Subjective/flexible weights*: assigning weights based on subjective judgment or adaptable criteria, depending on the goal of the assessment.
3. *Mathematical weights*: employing techniques like Principal Component Analysis (PCA) or factor loadings to compute weights mathematically.
4. *Expert weights*: engaging experts or consultants to determine weights through consultations.

The adoption of equal weights is the most commonly used weighing method in composite indicators [21].

For the SPI proposed in this paper, a *subjective/flexible weighting approach* was adopted, prioritizing an assignation of weights based on the authors' judgement on the contribution of each input variable with respect to sustainable prosperity in the EU. The final chosen approach was to assign the same weight to each of the three dimensions of sustainable prosperity, i.e. the economic, environmental, and societal dimensions. Thus, equal weights were assigned to all EU Member States (MS) to derive the main results for the adapted version of SPI within FULFILL, as shown in **Figure 2**.

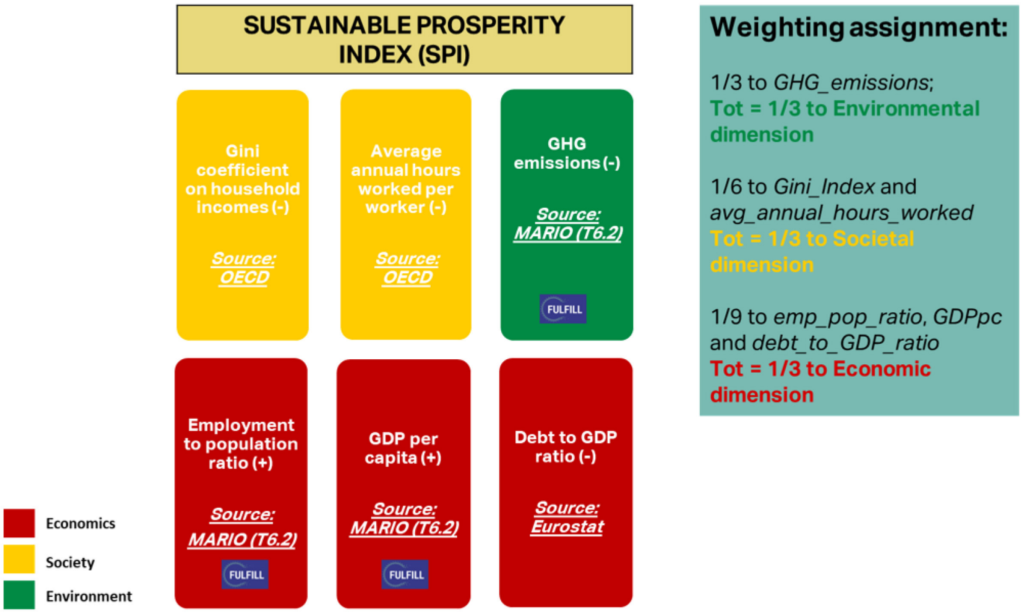

Figure 2. Weighting assignment based on equal-dimension weighting for SPI

Nevertheless, beyond the flexible/subjective weighting strategy based on equal-dimension weighting, a *sensitivity analysis* was conducted to assign weights more robustly and assess the impact on the computed SPI for both reference and the set of sufficiency scenario assumptions.

Sensitivity tests. In this paper, two types of sensitivity analysis were conducted, assessing the impact of further hypotheses and constraints on SPI scores.

- The first type assumes a change in the hypothesis of the weighting system, to account for EU countries' heterogeneity, extracting country-dependent weights.
- The second type assumes a cut-off on the GDP per capita scale, introducing a "sufficiency threshold" on per capita income level of the observed country.

The first type of sensitivity analysis is based on the detection of country-dependent weights, ensuring that weights reflect the relative importance of the variables across EU27 countries more accurately, reflecting country-specific trends. The following steps for weighting and computing the SPI were used in this first round of sensitivity analysis:

1. *Normalization*. For each country, the input variables – taken from 2020 to 2050 both for the reference and the set of sufficiency scenarios – are normalized using Min-Max normalization.
2. *Mean Calculation*. The mean value of each normalized variable is calculated for each country.
3. *Weight Calculation*. The mean values are then normalized by dividing each mean by the total sum of all means, ensuring that the weights sum up to 1.

The *Min-Max normalization* was used to transform input variables. This step scales the values of each variable to a range between 0 and 1, ensuring that variables are comparable among each other, independently on their unit of measurement. The formula for Min-Max normalization is the following:

$$x_{\text{norm}} = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \quad (2)$$

where x is the indicator value, $x_{\min}$ is the minimum value of the variable, and $x_{\max}$ is the maximum value of the variable.

Secondly, once the data were normalized, the mean value of each normalized variable is calculated for each country. These means represent the relative importance of each variable for that country in the given year.

Thirdly, the mean values are then normalized by dividing each mean by the total sum of all means. This normalization step ensures that the weights sum up to 1. These normalized means are used as weights, reflecting the relative importance of each variable based on the country's specific data. Mathematically, the weight for each variable ω_i is calculated as:

$$\omega_{i,c} = \frac{\text{mean}(x_{\text{norm},i,c})}{\sum_i \text{mean}(x_{\text{norm},i,c})} \quad (3)$$

where $x_{norm,i.c}$ is the normalized value of variable i for the specific country c.

Lastly, the SPI is computed for each country, using the country-specific calculated weights. This approach allows the SPI to adapt to the varying importance of different variables for each country, making the index more responsive to specific country contexts.

Therefore, the SPI calculated under the sensitivity analysis is calculated as follows:

$$SPI_{c,t} = \sum_{i,c}(\omega_{i,c} \times x_{\text{norm},i,c}) \quad (4)$$

By incorporating this robust weighting approach, the SPI accurately reflects the contributions of different variables to sustainable prosperity within each EU27 country.

The second type of sensitivity test is based on the intuition that while higher income generally correlates with better social and environmental indicators, this relationship may be reversed beyond a certain level of income. O'Neill *et al.* [48] indicate that nations with an income range between 7,000 USD to 12,000 USD per capita are among the best performers on social and ecological indicators. Research shows that beyond mid-range income levels, further increases can result into net negative social and ecological consequences ([32], [49], [50]). As reported by van den Bergh [51], the level of income at which the de-linking between GDP and (subjective) social welfare takes place is estimated at 15,000 USD, validating the 'threshold hypothesis'.

Thus, this paper introduces and tests the sufficiency threshold hypothesis, setting it at 20,000 EUR for GDP per capita, hypothesizing that additional income becomes unnecessary for achieving better SPI scores. Specifically, the analyzed countries are not punished for exceeding 20,000 USD but rather SPI scores are tested on the idea that income levels – over this threshold – do not further boost a country's SPI score.

To restore the equilibrium within the weighting system for SPI computation anytime the weight for GDP per capita falls to zero (i.e. anytime GDP per capita surpasses the sufficiency cut-off), the weights for the other indicators are re-balanced under the following scheme: *weight for GDP_pc: 0 (due to the sufficiency threshold hypothesis); weight for emp_pop_ratio: 1/6; weight for emissions: 1/3; weight for Gini_coefficient: 1/6; weight for Average_hours_worked: 1/6; weight for Government_debt_to_GDP_ratio: 1/6*.

Aggregation of indicators and computation of SPI

The input indicators were aggregated using a geometric mean approach, which helps to balance the contributions of each dimension and prevents compensatory effects where poor performance in one area is offset by high performance in another.

A weighed linear combination approach was employed, based on the weighting approach depicted in the previous subsection. Eventually, the net aggregate effect of weighed percentage changes of input indicators displays the overall positive or negative contribution towards sustainable prosperity. For reasons of results visualization, the SPI is plotted from a starting value of 100 in the initial year of analysis.

Mathematically, the weighed linear combination of chosen input indicators is defined as:

$$SPI_{c,t} = 1/9(\Delta\%\, GDPpc_{c,t}) + 1/9\left(\Delta\% \frac{Emp}{pop}_{c,t}\right) - 1/9\left(\Delta\% \frac{Debt}{GDP}_{c,t}\right) - 1/6\,(\Delta\%\, Gini_{c,t}) + \\ - 1/6\,(\Delta\%\, Avg_{hrs\,c,t}) - 1/3\,(\Delta\%\, GHG_{c,t}) \quad (5)$$

where *c* represents the observed EU country and *t* the observed year.

DATA

This section provides a detailed overview of the sources and processing methods used for the empirical analysis. It outlines the historical data collection from external sources such as OECD and Eurostat, covering indicators like the Gini coefficient, average annual hours worked, government debt to GDP ratio, GDP per capita, GHG emissions, and employment to population ratio. The methodology for projecting future values for these indicators under both the Reference and Sufficiency Scenarios is also explained. Additionally, the section describes the integration of output data from the FULFILL project [52], which includes projections for GDP per capita, employment to population ratio, and GHG emissions.

Notably, the proposed composite beyond-GDP index is calculated for the aggregate EU27 group, for each EU country. Initially it is computed in its historical values, and then for a set of scenario assumptions which integrate the potential impact of energy sufficiency. The process is innovative as it aims at depicting the assumed trajectory of the SPI under a *Reference Scenario*, and it adds the direct assessment of a selected number of relevant energy sufficiency measures

(SMs) and their overall impact on the SPI, allowing for the comparison and ranking of performance of EU countries, according to the proposed metric.

As hinted above, two main sources for data collection were consulted and processed:

- External sources of information (e.g. OECD, Eurostat), mainly concerning the construction of the composite index, as well as for the collection of pertinent indicators and their historical trends.
- Output information from the I/O analysis [45], mainly concerning the hypothesized trajectories of economic, environmental, and energy indicators, as well as for the representation of scenarios assumptions.

Each of these primary sources of information is described in the following subsections.

Data processing from external sources

An initial investigation of historical data of all six selected input indicators was conducted.

The following list details the information accessed through download and processing information from external sources of information, which fed the initial historical database (2000-2020) to compute the historical SPI.

- *Gini coefficient (or Gini index)* measuring income inequality (source: World Bank). The Gini coefficient measures inequality on a scale from 0 to 1, where higher values indicate higher inequality.
- *Average annual hours worked per worker* (source: OECD), which are measured in number of hours. They are calculated as the series of annual hours worked per person in total employment, in relation to data from mainly National Accounts concepts, and marginally from secretariat estimates from the European Labour Force Survey (LFS).
- *Government debt to GDP ratio* (source: Eurostat). This is defined as the General Government consolidated gross debt, as percentage of GDP.
- Historical data on *gross domestic product per capita* (USD at 2015 Purchasing Power Parities) were sourced by OECD.
- *GHG emissions* were directly sourced from Energy Statistics of EU Commission, DG Energy, Unit A4. Data are expressed in CO_2 eq., including CO_2, N_2O, CH_4, HFC, PFC, SF6, and NF3.
- Historical data on *employment to population ratio* were generated by integrating data for the total number of people employed between 15 and 64 with historical data of population. All data are from OECD.

<u>*Projections for 2020-2050.*</u> Future projected assumed values (up to 2050) for three of the six selected indicators – i.e., the Gini index, average annual hours worked, and debt to GDP ratio – had to be built separately. The issue was approached by following this strategy:

- As for the *Reference Scenario*, a simple approach based on linear regression (using Excel) was employed. Indeed, the identification of the linear trend of historical data for country-specific Gini index, average annual hours worked per worker, and government to GDP ratio was projected from 2020 up to 2050.
- As for the *Sufficiency Scenario, all measures*, the information on (*i*) past trends (2000-2020) and the (*ii*) assumed contribution of each SM to the SPI were considered, to generate assumed subjective correction factors. For instance, whatever the worsening in the past trend of the indicator was occurring, then the values of the indicator under the *Reference Scenario* were attenuated by 1% to generate the values under the *Sufficiency Scenario*. If, instead, whatever the improvement in the past trend of the indicator was occurring, then the values of the indicator under the *Reference Scenario* were attenuated by 5% to generate the values under the *Sufficiency Scenario*. This is specified in Equation (6), where *y* is the variable under investigation.

- As for the *Sufficiency Scenario, diets,* and *Sufficiency Scenario, flying less,* the same approach as above was adopted, by halving – in both cases – the subjective correction factors to 0.5% and 2.5%. This is specified in eq. (7).

$$y_{i+5,Suf} = \begin{cases} y_{i+5,\mathrm{Ref}} \times 0.99 \text{ if} y_{2050,\mathrm{Ref}} > y_{2020,\mathrm{Ref}} \\ y_{i+5,\mathrm{Ref}} \times 0.95 \text{ if} y_{2050,\mathrm{Ref}} < y_{2020,\mathrm{Ref}} \end{cases} \quad (6)$$

$$y_{i+5,Suf_{diets/flying}} = \begin{cases} y_{i+5,\mathrm{Ref}} \times 0.995 \text{ if} y_{2050,\mathrm{Ref}} > y_{2020,\mathrm{Ref}} \\ y_{i+5,\mathrm{Ref}} \times 0.975 \text{ if} y_{2050,\mathrm{Ref}} < y_{2020,\mathrm{Ref}} \end{cases} \quad (7)$$

where y stands for the variable, and i for the year.

Data processing from the project FULFILL

Conversely, the future values for Reference and Sufficiency scenarios (up to 2050) for the three indicators – GDP per capita, employment to population ratio and GHG emissions – were generated based on output projections from Golinucci *et al.* [45]. [§§§§§]

The necessary data for setting up the database for computing the projections of SPI were aggregated and processed in the following manner:

- Gross Domestic Product (GDP), measured in millions of EUR in constant values (2011). This indicator was transformed into the *GDP per capita*, by employing data on population projections (sourced by OECD).[******]
- *Greenhouse Gases Emissions* (GHG) in Global Warming Potential at 100 years (GWP100) (measured in tons of CO_2 eq). This figure includes CO_2, NOx, SO_2 emissions.
- Employment (measured in thousands of workers). This set of information was organized and then transformed into the indicator *employment to population ratio*, by using data on population projections (sourced by OECD).[††††††]

As hinted, the output data were generated under different hypothesized scenarios, with the aim of integrating information of shocks to sufficiency lifestyles and quantify their final effect on the composite beyond-GDP index.

At this stage, all necessary information was gathered and processed.

RESULTS

The adapted version of the SPI was calculated for each EU country, providing a full view of the progress towards sustainable prosperity of the EU continent, and tracking the contribution of energy sufficiency in this pathway.

Firstly, the analysis is focused on the computation of the SPI for each EU country based on historical data, covering the time frame 2000-2020. Then, projected SPI values until 2050 are produced, disentangling between the *Reference Scenario* and the set of *sufficiency scenario assumptions*. Noteworthily, the results are mainly displayed for the countries of analysis under the EU project FULFILL.[‡‡‡‡‡‡]

[§§§§§] All output data for projected Reference and Sufficiency scenarios are available in open-source at this repository: https://github.com/SESAM-Polimi/FULFILL_MARIO/tree/main.

[******] Measuring GDP with prices set at reference year 2011 entails tracking the "real" value of GDP, to measure the true volume growth, i.e. the GDP unaffected by shocks to inflation.

[††††††] To comply with inconsistently high levels of employment projected by MARIO for future years, a *down-scaling of data* was executed. This allowed to align projections with past trends of employment. This allowed to remove the bias introduced by the modelling exercise of MARIO, which omits the potential increase in marginal productivity of labour for future years.

[‡‡‡‡‡‡] The 5 FULFILL countries represent the partners of the EU H2020 FULFILL project, i.e. Denmark, France, Italy, Germany, and Latvia.

Historical SPI

Figure 3 displays the historical evolution of SPI for FULFILL countries and the EU27 joint group.

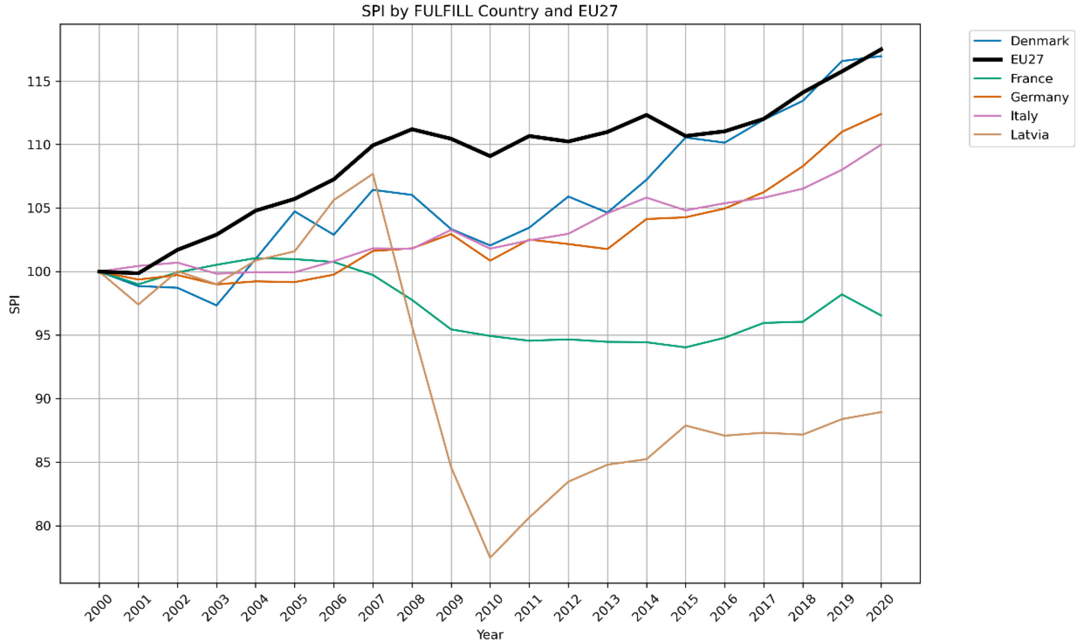

Figure 3. Ex-post computation of historical SPI for FULFILL countries and the EU27

The EU27 group's SPI displays a relevant upward trend, with minor slowdowns throughout the period. The global financial crisis had an evident impact (despite minor) on the SPI, which dipped to 109.08 in 2010, largely explained by the drop in GDP per capita and the sharp increase in the debt/GDP ratio in the EU, which outweighed the positive contribution to SPI represented by the decrease in GHG emissions (see **Figure 13**). The SPI experienced a slight dip to 110.23 in 2012 during the European sovereign debt crisis, reflecting the macroeconomic challenges faced by many EU countries. The SPI slacked to 110.66 in 2015, mostly driven by a significant fall in GDP per capita (-14.3% year-on-year – YoY). Before the COVID-19 pandemic, the SPI showed signs of recovery and stability, reaching 115.75 in 2019. In 2020, the SPI peaked to 117.48, showing that while there was a negative economic impact from the pandemic, the EU27 SPI increased mostly due to the strong fall in GHG emissions (-9.78% YoY).

Denmark's SPI showed high variability, remaining below the EU27's SPI until 2015, and then mirroring it from 2015 onwards. Denmark's SPI exhibits significant volatility mostly due to highly variable GHG emissions levels and the contribution of debt/GDP ratio. The SPI fell to 102.05 in 2010, and then recovered to its pre-crisis levels, catching up with EU27's SPI in 2015. In terms of inequality, Denmark displayed the lowest level of Gini Index among FULFILL countries, aver-aging 26.8 within the observed time frame.

France's SPI showed poor SPI performance throughout the time frame. Following an increase in SPI until 2004, during the following years France experienced a smooth decline in SPI, hitting its lowest value at 94.03 in 2015, mostly driven by a worsening in macroeconomic fundamentals and increasing Gini index. Afterwards, the French SPI recovered (reaching 98.2 in 2019) but then fell to 96.55 in 2020 (the 4th lowest SPI level across EU countries). Indeed, in 2020, the French GDP per capita dropped by 8% YoY, while the French debt/GDP ratio rose by 17.6% YoY.

Germany's SPI remained relatively stable until 2013, showing resilience to economic shocks. Afterwards, its SPI displayed a consistent growth, mostly driven by consistent efforts in abating GHG emissions.

Italy's SPI displays a smooth upward trend, mostly explained by progress in GHG emission re-duction, amidst a modest economic growth. The financial and sovereign debt crises led to slight fluctuations, with the SPI at 103.28 in 2009 and 102.97 in 2012. In 2020, despite the worsening in macroeconomic fundamentals (+15.4% YoY in debt/GDP ratio and -8.59% YoY in GDP per capita), the sharp decline in GHG emissions (-10% YoY) and average annual hours worked per worker (-9.76% YoY) outweighed the negative contribution to SPI due to the economic slow-down.

Latvia exhibited a significant outlier compared to the other countries. Its SPI sharply dropped to 84.62 in 2009 and 77.48 in 2010, following the global financial crisis. The fall was largely explained by a sudden hike in the debt/GDP ratio, which climbed from 8.4% in 2007 to 18.5% in 2008 and doubled in 2009 reaching 37%. Additionally, GDP per capita dropped from 23,346.9€ in 2008 to 20,351€ in 2009. Post-crisis, Latvia's SPI showed signs of recovery, approaching 88.94 in 2020, the 2nd lowest level across EU countries. This evidence could be attributed to structural factors, notably Latvia's declining and aging population, which reduced the available labor force, while driving up its sovereign debt.

Variability in sustainable prosperity was notably higher when examining other EU countries. While Denmark, Germany, and Italy demonstrated increasing SPI values throughout the period under review, other nations experienced more pronounced fluctuations. France and Latvia, for instance, displayed varying levels of resilience in maintaining social well-being amidst economic turbulence. This variability underscores the diverse impacts of global economic events on sustainable prosperity across EU MSs.

Projected SPI – Reference Scenario

Figure 4 provides an overview of the computed SPI for FULFILL countries and the EU27 group under the *Reference Scenario*.

The analysis of the SPI from 2020 to 2050 reveals significant trends influenced by various socio-economic and environmental factors. The chosen starting year of 2020 – notably impacted by the COVID-19 pandemic – led to substantial economic downturns, reductions in emissions, and interruptions in regular activities. This context is crucial for understanding the subsequent SPI growth projected for 2025 and beyond.

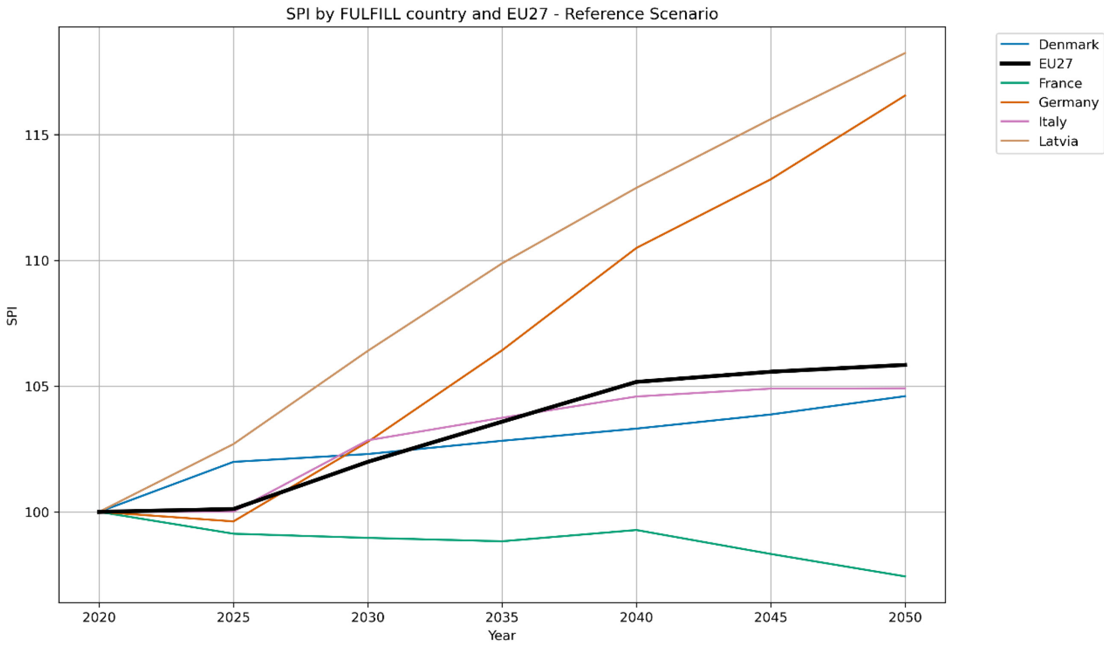

Figure 4. Projected SPI under the Reference Scenario for FULFILL countries and EU27

Starting with the EU27 group, the SPI rises only slightly to 100.11 by 2025. This can be attributed to recovery efforts post-pandemic, resumption of economic activities, and a correspondent resumption of GHG emissions. The GDP per capita is expected to rise by 8.45% in 2025, the employment/population ratio would increase by 8.22%, while GHG emissions would surge by 4.84% (see **Figure 14** in the Appendix).

The SPI would rise to 101.98 in 2030, driven by a further 7.05% increase in GDP per capita and continued improvements in employment and sustainability measures. By 2040, the index would reach 105.16, mostly driven by economic development, despite slightly increasing GHG emissions. In 2045 and 2050 the EU27's SPI would display a much weaker upward trend, bearing the environmental burden of significantly higher GHG emissions, reaching values of 105.57 and 105.84, respectively. Overall, the EU27 index remains positive, supported by improvements in economic and employment indicators (with lower average working hours per worker), although softening its growth due to variations in other factors such as emissions and slight increases in Gini index.

Denmark's SPI experiences a soft increase in SPI under the Reference Scenario, oscillating above and below the EU27 level. This smooth growth is activated by an 8.82% rebound in GDP per capita in 2025 (compared to 2020), a 8.85% increase in employment-population ratio, and a notable reduction in debt to GDP ratio. By 2030, the SPI slightly rises to 102.29, with a 4.54% rise in GDP per capita and a 4.59% increase in employment-population ratio, indicating a stabilization post initial recovery. Afterwards, the SPI would sustain a smooth rise, with values of 102.82 in 2035 and 103.31 in 2040, reflecting ongoing but more stable improvements in eco-nomic and employment indicators, despite slightly increasing GHG emissions and income inequality. By 2050, Denmark's SPI reaches 104.6, indicating consistent progress in sustainable development, driven by sustained improvements in GDP per capita and employment rates, coupled with reductions in debt-to-GDP ratio.

France's SPI displays a post-Covid recovery pattern which is significantly weaker compared to the other FULFILL countries. The French SPI falls to 99.13 by 2025, and continues to soften, reaching 98.96 in 2030, driven by a 5.09% rise in GDP per capita and a 5% increase in employment-population ratio, which fall short in outweighing the risks related to surging debt/GDP ratio. By 2040, the SPI would recover at 99.27, still well lower than the other FULFILL countries. In 2045, the SPI would display a notable dip to 98.32, possibly reflecting economic or policy adjustments, and a correspondent hike in GHG emissions. By 2050, France's SPI would fall further to 97.43, indicating threats to sustainability efforts.

Despite an initial worsening in SPI in 2025 – falling to 99.62 mostly due to the post-Covid re-bound of GHG emissions, Germany shows significant improvements in SPI performance. In 2030, the SPI would jump to 102.78, driven by a 5.69% rise in GDP per capita (compared to 2025) and a 5.54% increase in employment/population ratio, coupled with lower debt to GDP ratio. By 2035, the SPI jumps to 106.42, reflecting strong economic performance and sustainable innovations, with a 5.81% rise in GDP per capita and substantial reductions in debt-to-GDP ratio, emissions, and average working hours.

The upward trend continues afterwards, with Germany's SPI reaching 110.49 by 2040, supported by improvements in economic and employment indicators, despite slightly increasing income inequality. By 2050, the SPI stabilizes at 116.55, indicating a robust and sustained commitment to sustainable prosperity, driven by ongoing improvements in economic fundamentals, despite increasing GHG emissions occurring in 2045 and 2050.

Italy's SPI would rise slightly under the *Reference Scenario*, mostly oscillating around the EU27's level. In 2025, the SPI would reach 100.008, given a positive contribution from GDP per capita (+8.8% compared to 2020) and employment/population ratio (+8.79%), despite higher GHG emissions (+2.35%) and higher Gini coefficient (+1.8%). By 2030, the SPI reaches 102.84, reflecting substantial progress in sustainability, sustained by a notable 7.11% reduction in GHG emissions compared to 2025.

Over the subsequent decades, Italy's SPI growth would soften (mirroring the EU27's SPI), hitting values of 103.74 in 2035 and 104.58 in 2040. By 2050, the SPI reaches 104.91, indicating steady progress despite minor setbacks, supported by sustained improvements in GDP per capita and employment-population ratio, despite higher risks due to increasing GHG emissions, more pressure on the side of debt-to-GDP ratio, and higher income inequality.

Among FULFILL countries, Latvia exhibits the most remarkable hike in its SPI, rising to 102.69 by 2025. This growth is mostly driven by a 14.29% rise in GDP per capita over the observed time horizon, and a 13.62% increase in employment-population ratio, along with societal progress due to decreasing Gini index (-3.72%) and lower average working hours worked in the economy (-2.93%). By 2030, the SPI reaches 106.4, reflecting continued strong economic recovery and sustainability efforts.

Latvia would keep sustaining its high SPI, soaring to 112.88 in 2040 and 118.24 by 2050. These trends reflect Latvia's strong commitment to sustainable development and economic recovery post-pandemic, supported by sustained improvements in GDP per capita and employment-population ratio, alongside with reductions in income inequality, despite slightly rising GHG emissions.

As shown in **Figure 5**, by 2050, the *Reference Scenario*'s SPIs reveal significant variations, reflecting the diverse eco-nomic, social, and environmental trajectories across the regions.

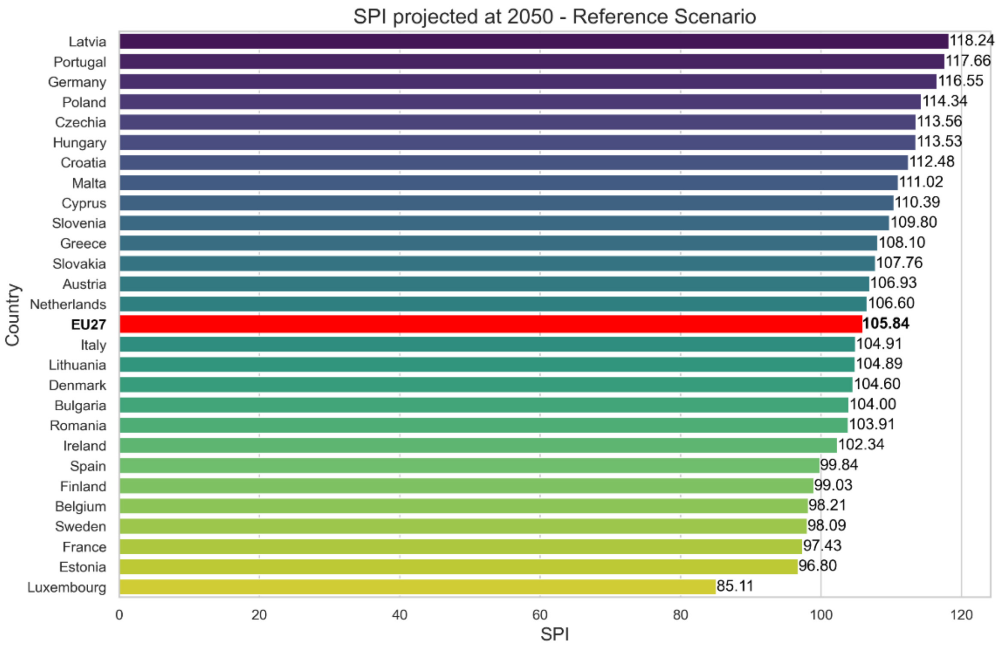

Figure 5. Projected SPI under the *Reference Scenario*, ranking of countries in 2050

Latvia, Portugal and Germany would emerge as the top performers with the highest SPI scores, hitting 118.24, 117.66, and 116.55, respectively. This suggests strong economic growth and significant improvements in sustainability measures. Over the whole observed period, Latvia's GDP per capita is expected to increase by an impressive 89.08% (behind only Croatia and Lithuania's GDP per capita growths), and its employment-population ratio is expected to rise by 82.37%, while Gini index would drop by 9.2%. Germany also shows robust performance with an overall projected GDP per capita increase of 44.6%.

Countries like Poland (SPI: 114.34), Czechia (SPI: 113.56), and Hungary (SPI: 113.53) show remarkable progress in 2050 under baseline conditions of economic growth. Over the selected time frame, Poland's GDP per capita is projected to grow by 71%, indicating substantial eco-nomic advancement, amid lower debt/GDP ratio (-29.7%) and higher employment/population ratio (+58.3%). Polish GHG emissions are expected to increase (+9.73%%), whereas income inequality would soften by 9.6%.

Luxembourg (SPI: 85.11), Estonia (SPI: 96.8) and France (SPI: 97.43) are at the lower end of the SPI spectrum in 2050 under the *Reference Scenario*. Luxembourg would suffer from a surge in GHG emissions (+62%) to support the growth in GDP per capita (+44.49%) and employment-to-population ratio (+40.23%). France would experience a moderate increase in GHG emissions (+9.89%) and a GDP per capita rise of 38.44%, financing growth by a substantial increase in the debt to GDP ratio (+52.1%), with added pressure on income distribution (+9.07% in Gini index). Estonia, while having a high increase in its GDP per capita (+71.36%), would struggle with a significant rise in GHG emissions (+40.94%).

Projected SPI – Sufficiency Scenario, all measures

The application of energy sufficiency measures (SMs) – as modelled within the FULFILL project – has transformative impacts on EU27 countries across four identified domains of sufficiency: diets, mobility, sharing products, and sharing spaces in housing.

Figure 6 shows the evolution of SPI derived from the *Sufficiency Scenario* projections for the period from 2020 to 2050.

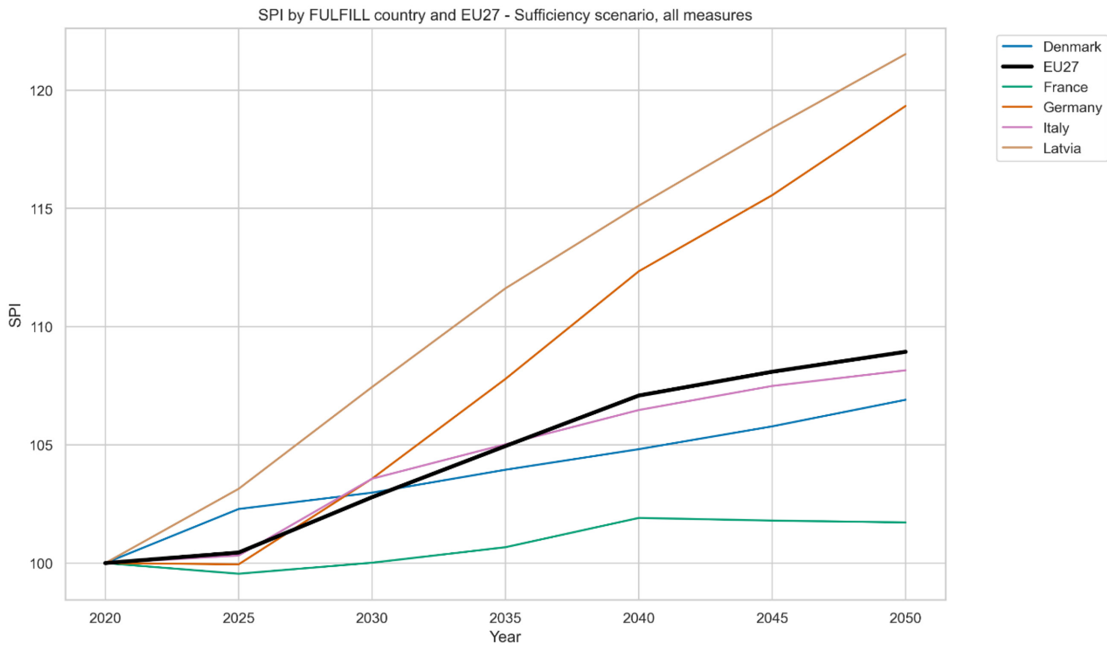

Figure 6. Projected SPI under the *Sufficiency Scenario* for FULFILL countries and EU27

Under the *Sufficiency Scenario*, the SPI for the EU27 would display values that, on average, would be 1.59% higher compared to the *Reference Scenario*'s resulting SPI. In 2050, GHG emissions under the *Sufficiency Scenario* would be 11.8% lower compared to the *Reference Scenario*, highlighting a significant improvement under the environmental performance. Economic indicators such as GDP per capita and employment/population ratio still grow, but less dramatically, indicating a balanced approach towards sustainability and prosperity.

For Denmark, the computed SPI under the *Sufficiency Scenario* is on average 1.25% higher compared to the *Reference Scenario*. Emissions control improves, with levels of GHG emissions in 2050 8.28% lower compared to the *Reference Scenario*. The GDP per capita would grow by 37.09%, which is 2.8% lower than in the *Reference Scenario*, but this is balanced by improved socio-economic outcomes, amidst slightly lower GHG emissions.

France would significantly benefit from sufficiency measures, compared to a case without them (*Reference Scenario*). In 2050, GHG emissions would be 14.67% lower than the

Reference Scenario, marking an improvement in the environmental performance, especially after 2040. While GDP per capita and employment/population ratio still see positive changes, the emphasis on reducing GHG emissions, improving public finances and equity would lead to a higher SPI, which would peak in 2040 at 101.91. In 2045 and 2050, the French SPI would remain in the positive area, stabilizing at 101.7. Overall, the French SPI would be on average 2.3% higher than the *Reference Scenario*'s values.

Germany's SPI under would mark levels which, on average, would be 1.41% higher compared to the *Reference Scenario*. This is due to better management of GHG emissions which, in 2050, would be 10.23% lower compared to the *Reference Scenario*. Despite a lower GDP per capita in 2050 compared to the reference case (-3.68%), most of the factors would contribute positively to the increase in SPI, despite slightly higher levels of income inequality.

Italy, in 2050, marks a higher SPI under the *Sufficiency Scenario* (SPI: 108.15), with a notable improvement in GHG emissions control (-11.53% compared to the *Reference Scenario*). GDP per capita and employment-population ratio grow healthily, but with a greater emphasis on sustainability and social equity. On average, the SPI is 1.6% above the *Reference Scenario*.

Latvia's SPI sees a relevant increase in the *Sufficiency Scenario*, with levels on average 1.7% higher than the reference one. Emissions would be better managed by 2050, with an overall reduction of 14.24% compared to the *Reference Scenario*. The decrease in the amount of average hours worked annually is pronounced (-24.65%), contributing to improved work-life balance and higher overall well-being.

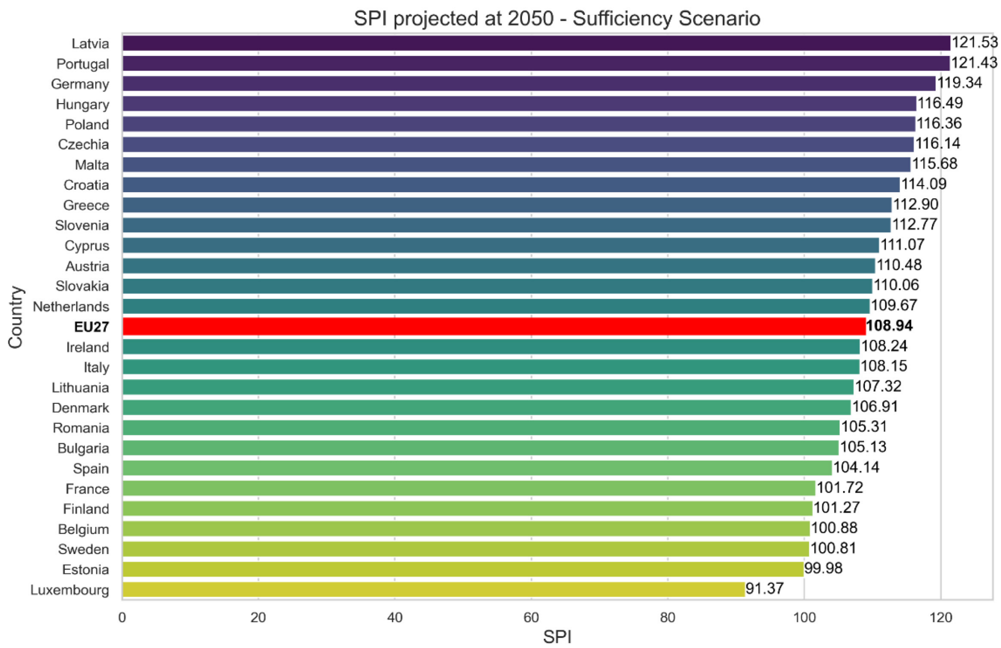

Figure 7. Projected SPI under the *Sufficiency Scenario, all measures*, ranking of countries

As shown in **Figure 7**, by 2050, the *Sufficiency Scenario*'s SPI would improve for all EU countries.

Under the *Sufficiency Scenario*, Latvia maintains the highest performance with a SPI of 121.53, showing a notable increase from the *Reference Scenario* (118.24). This would indicate Latvia's valuable role to achieve sufficiency goals by 2050. Moreover, Portugal and Germany would both maintain their position in the top 3 list of the ranking.

Interestingly, France would benefit the most across FULFILL countries from energy SMs, gaining three positions in the ranking and reaching an SPI of 101.72. Despite an improvement in its SPI, Italy would lose a position in the ranking (still lower than the EU27 average), with an SPI at 108.15 in 2050.

Comparison reference vs. sufficiency scenario, all measures. Overall, the comparison of results for SPI attributed both to the *Reference* and the *Sufficiency Scenario, all measures* for the FULFILL countries is reported in **Figure 8**.

Across FULFILL countries, the relative impact of Sufficiency Measures (SMs) on the SPI – compared to the *Reference Scenario* – would range, on average, between 1.25% and 2.3%. France would benefit the most from the implementation of energy SMs, whereas Denmark might benefit the least from the uptake of sufficiency lifestyle changes.

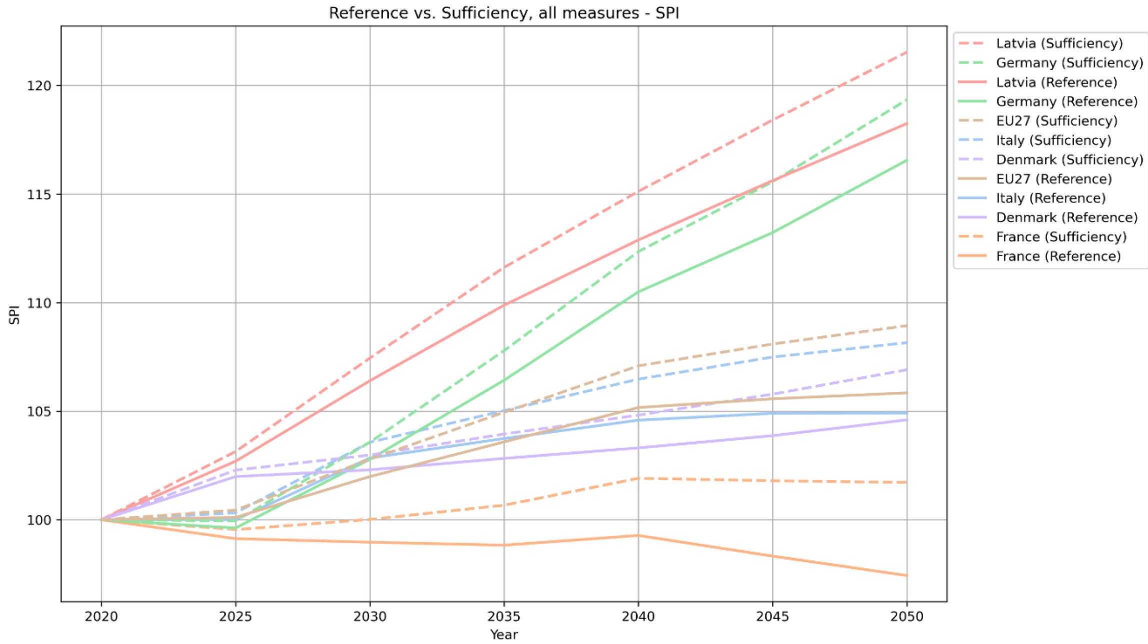

Figure 8. Comparison of *Reference* vs. *Sufficiency Scenarios* for FULFILL countries and EU27

Sensitivity analysis

Two types of sensitivity analyses are hereby reported.

The first type of sensitivity analysis proves the robustness of SPI scores by comparing results obtained under country-dependent weights which were extracted by a Min-Max normalization of input variables. This allowed to assess the impact on SPI by changing the weighting system, accounting for the heterogeneity of EU countries.

Moreover, the second type of sensitivity analysis assesses the impact on SPI from changes in the hypothesis on the GDP per capita scale, introducing a sufficiency threshold on per capita income which is country dependent.

The results are shown hereby.

Figure 9 reports the results of SPI under the *Reference Scenario*, adopting the dynamic attribution of weights. These results can be directly compared with those in **Figure 4** reporting the computation of SPI under constant weights.

The EU27's SPI computed with dynamic attribution of weights shows a slight increase from 102.77 in 2025 to 108.82 in 2050 (vs. 105.84 with constant weights), reflecting adjustments in indicator weights over time.

France's SPI, under the *Reference Scenario*, would decrease more sharply compared to the case of constant weights, declining to 96.72 in 2035, and then to 92.58 in 2050 (vs. 97.43 under constant weights).

The German SPI displays the most persistent growth, ranging from 104.5 in 2025 to 134.98 in 2050, indicating sustained improvements in sustainable prosperity metrics. These results significantly outperform the SPI computed under constant weights.

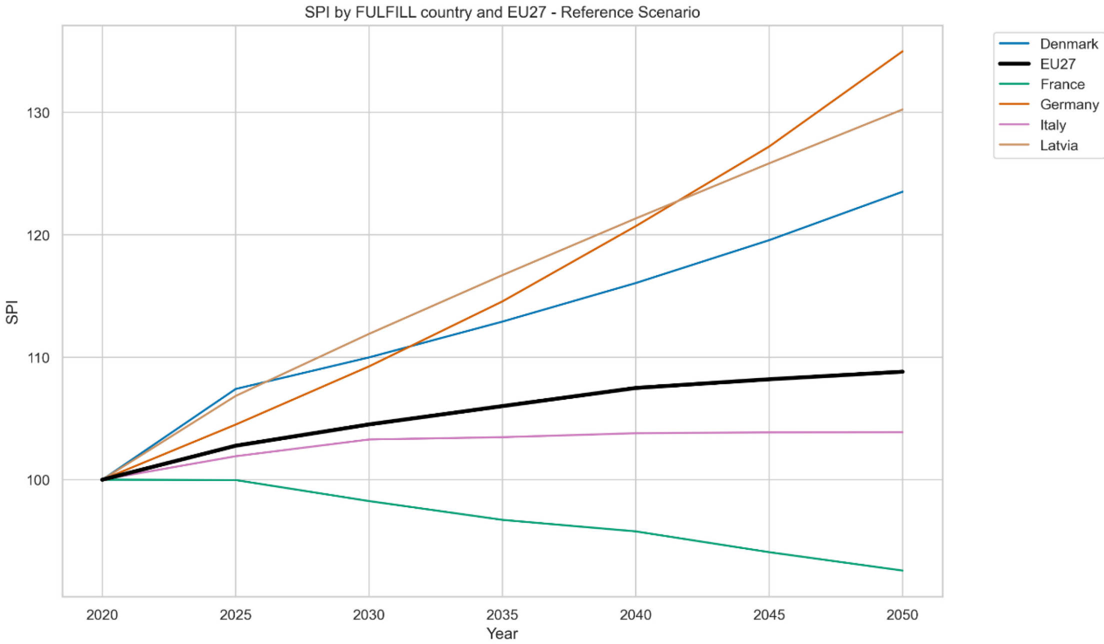

Figure 9. Projected SPI under the *Reference Scenario*. FULFILL countries and EU27. Sensitivity analysis of type 1

As for the case of SPI at constant weights, the Italian SPI closely mirrors the EU27's beyond-GDP metric. It shows minor fluctuations, stabilizing at 103.8 at the end of the observed period.

The Latvian SPI would keep showing an upward trend up to 2050, hitting a value of 130.23, slightly behind than the correspondent German SPI level.

Lastly, the Denmark's SPI sharply improves its performance compared to the case of constant weights, showing more pronounced growth. The index ranges from 107.4 in 2025 to 123.51 in 2050, strongly outperforming the 104.6 level obtained under the previous weighting system.

Overall, the choice between dynamic and constant attribution of weights affects the interpretation of SPI results for each country, under the *Reference Scenario*. Dynamic weights are more suitable to capture fluctuations and adaptability to changing sustainability priorities, while constant weights provide a stable baseline for assessing sustainable prosperity trends over time. Both approaches offer valuable insights into sustainable development efforts, reflecting either responsiveness to evolving challenges or stability in long-term performance metrics.

Figure 10 reports the results of SPI under the *Sufficiency Scenario*, stemming from the dynamic attribution of weights. These results can be directly compared with **Figure 6**, reporting the computation of SPI under constant weights under the impact of all SMs.

For the EU27, the SPI under the *Sufficiency Scenario* generally shows marginally higher SPI values compared to the *Reference Scenario*'s SPI with dynamic weights. The SPI ranges from 103.17 in 2025 to 110.9 in 2050. Denmark would experience an improvement in its SPI with dynamic weights, ranging from 107.74 in 2025 to 125.7 in 2050 (vs. 123.51 under the reference), showing effectiveness induced by SMs over time. This indicates that SMs would have an incremental impact, contributing positively to sustainable prosperity.

For France, Germany, Italy, and Latvia, the *Sufficiency Scenario* generally shows slightly high-er SPI values compared to the *Reference Scenario* throughout the forecast period. For these countries, both scenarios exhibit similar trends and patterns of fluctuation, suggesting that SMs slightly impact SPI compared to the reference case.

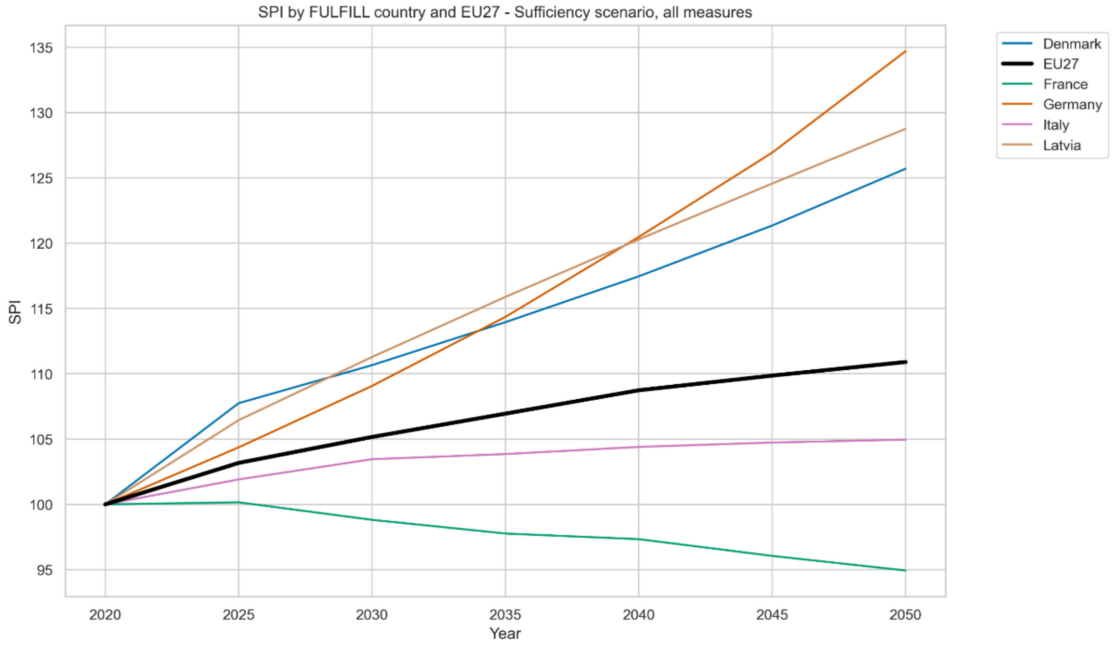

Figure 10. Projected SPI, *Sufficiency Scenario*. FULFILL countries and EU27. Sensitivity analysis of type 1

Overall, the SPI computed under the *Sufficiency Scenario* with dynamic weights generally show values that are marginally higher compared to the *Reference Scenario*, depending on the country. This comparison underscores the effectiveness of SMs in enhancing sustainable development across different contexts, highlighting the impacts on sustainable prosperity metrics over the forecast period.

Finally, SPI scores were evaluated by imposing a sufficiency threshold of 20,000 EUR on the GDP per capita scale (second type of sensitivity test). This threshold is assumed where additional income would turn out to be unnecessary for achieving higher values of SPI. For ease of visualization, only results for EU27 are reported. **Figure 11** displays the results.

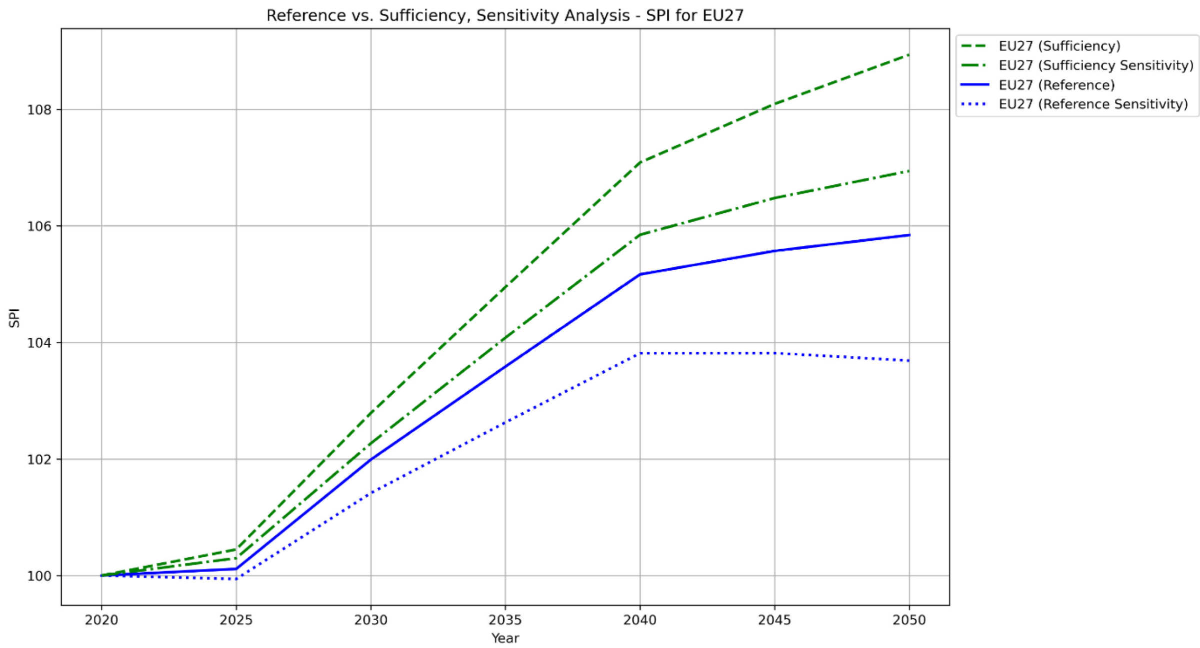

Figure 11. Comparison of scenarios for EU27's SPI under the (i) *Reference*, (ii) *Sufficiency*, (iii) *Reference with income threshold* and (iv) *Sufficiency with income threshold*. Sensitivity analysis of type 2

The SPI in the *Sufficiency Scenario* (without income threshold) displays the highest growth, reaching 108.93 by 2050, performing nearly 2 percentage points higher than the *Sufficiency Scenario* (with income threshold). This result is unexpected, showing that higher GDP per capita is somehow necessary – together with the adoption of SMs – for achieving higher SPI values. However, this outcome might be related to the reassignment of weights attributed within the SPI computation when the weight of GDP per capita drops to zero.

As expected, both *Reference Scenarios* (with and without income thresholds) display lower SPIs compared to the *Sufficiency Scenarios*, reflecting a positive impact of sufficiency measures (SMs) both with and without the adoption of the sensitivity analysis.

Eventually, this second type of sensitivity analysis helps to identify scenarios where countries can perform well socially and environmentally even without high levels of income, guiding energy and environmental policies to achieve sustainable development and prosperity.

DISCUSSION

As shown in **Figure 4**, under the *Reference Scenario*, the SPI for the EU27 increases up to 105.84 in 2050. This reflects some moderate improvements in socio-economic well-being and is accompanied by a significant increase in GHG emissions (from 4.74 billion tons to 5.39 billion tons CO_2 eq.), as well as by an increase in GDP per capita (from 27,609.26 EUR to 41,386.42 EUR). The Gini index, measuring inequality, also rises from 30.77 to 31.79%, indicating growing economic disparity.

Conversely, the *Sufficiency Scenario* shows a more socially desirable outcome for sustainable prosperity at the EU27 level. The SPI improves to 108.94 by 2050, reflecting enhanced overall well-being. Notably, GHG emissions in 2050 would remain nearly stable compared to 2020 – as displayed by the significant drops in **Figure 12** in years 2030, 2035 and 2040, mainly motivated by the policy goal of bringing to zero the carbon footprint of the power sector –, thus increasing minimally to 4.75 billion tons, which is a significant improvement over the *Reference Scenario*. GDP per capita increases to 39,736.37 EUR in 2050, more slowly than the *Reference Scenario*, thus signalling a more sustainable growth for the society, despite the smoother global growth rate over the simulated time horizon. The Gini index increases to 31.47%, creating slightly less pressure on income equality compared to the reference case.

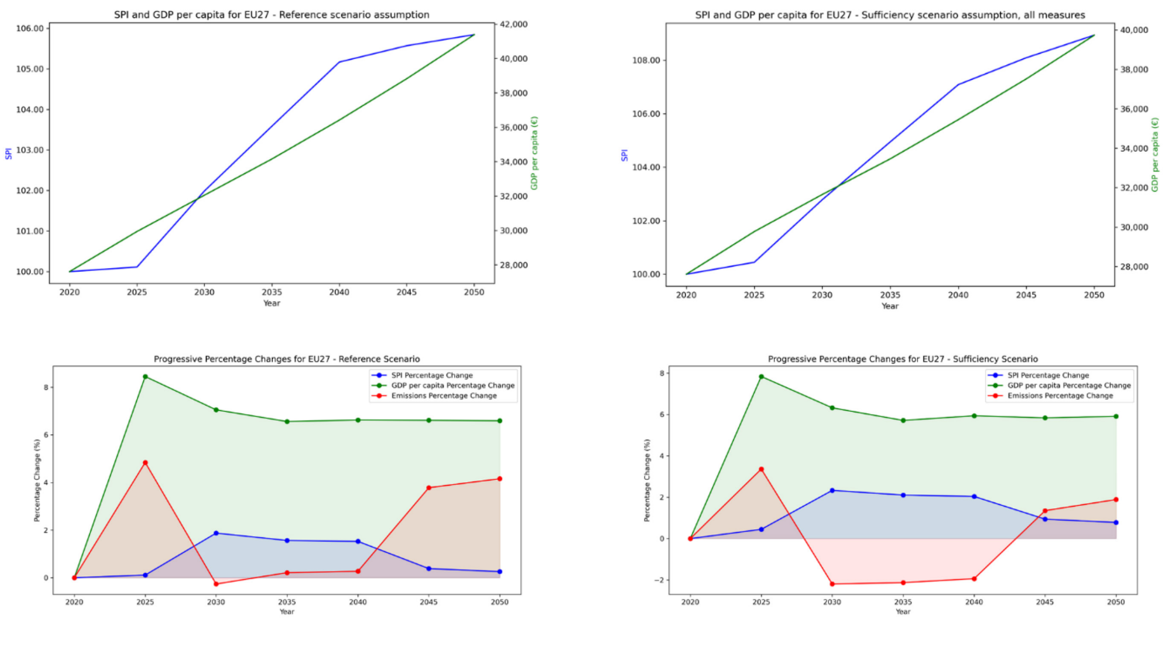

Figure 12. Comparison of GDP per capita and SPI levels for EU27 under the *Reference* and *Sufficiency Scenarios* (top panels); comparison of calibrated growth rates for SPI, GDP per capita and GHG emissions under the *Reference* and *Sufficiency Scenarios* (bottom panels)

Under the *Sufficiency Scenario*, all five FULFILL countries – Denmark, France, Germany, Italy, and Latvia – mark an improvement in their SPI scores compared to the reference case, reflecting advancements in sustainable prosperity. Indeed, the *Sufficiency Scenario* generally yields higher SPI improvements and better environmental outcomes compared to the *Reference Scenario*, showcasing the benefits of adopting sufficiency measures (SMs). France's SPI would benefit the most from the implementation of energy SMs, as its SPI would transition from 97.43 to 101.72 due to the adoption of sufficiency lifestyle changes.

Across all five countries, GDP per capita grows significantly from 2020 to 2050 in both scenarios. However, the increase is slightly lower under the *Sufficiency Scenario*, reflecting a trade-off between economic growth and sustainability measures. For instance, Denmark's GDP per capita in 2050 is 60,415.93 EUR under the *Sufficiency Scenario* compared to €62,157.58 in the *Reference Scenario*. This pattern is consistent across the other countries, with France, Germany, Italy, and Latvia all showing lower GDP per capita in the *Sufficiency* vs. the *Reference Scenario*.

A key benefit of the *Sufficiency Scenario* is the reduction in GHG emissions. In all five countries, the *Sufficiency Scenario* leads to lower emissions compared to the *Reference*, highlighting the environmental benefits of SMs. This is mirrored in France, Germany, Italy, and Latvia, where GHG emissions are significantly lower under the *Sufficiency Scenario*.

Income inequality – as measured by the Gini index – generally shows a slight reduction under the *Sufficiency Scenario* compared to the *Reference Scenario*. This suggests that SMs may help in achieving a more equitable distribution of income across the population. Similar trends are observed in France, Germany, Italy, and Latvia, where the Gini index is slightly lower under the *Sufficiency Scenario*.

To summarise, the *Reference Scenario* shows that while there is economic growth and some improvement in the SPI across the EU27 and selected countries, this comes at the cost of increased GHG emissions and rising income inequality. Economic advancements do not adequately convert into lasting prosperity, considering the environmental and societal aspects. In contrast, the *Sufficiency Scenario* demonstrates that a balanced approach emphasizing sustainability and equity can lead to better overall outcomes.

Although GDP per capita grows more modestly compared to the *Reference Scenario*, the gains in environmental performance and social equity underscore the benefits of SMs.

Efforts to develop measures that go beyond GDP often intertwine social and economic, and in some cases, environmental indicators, making it difficult to discern causes and effects due to their intricate interdependencies. These indicators are valuable for understanding overall well-being, but their complex nature poses challenges. A composite index, which aims to communicate a single value to policymakers and the public, is a tool designed to encapsulate these complex, multi-dimensional realities. However, it is crucial to acknowledge that the inherent goal of a composite index limits its suitability for investigating cause-and-effect relationships. While indices like the SPI excel at summarizing multi-dimensional realities, they may not be the optimal tools for causal inference.

The main benefits of composite indicators are several: easier to interpret than a collection of many singly issue indicators, can assess the development over time, aggregates a set of indicators without missing the underlying information and thereby improves the visibility and cognitive up take. These benefits of composite indicators are balanced by some drawbacks, like the challenges of misleading policy makers and other decision makers if misinterpreted, may lead to simplistic conclusions in a complex word that requires complex conclusion, the danger of misuses of composite indicators, by subject to political dispute, e.g. because of the selection of indicators and the weighting scheme, and the possibility that the composite indicator , if dimensions that are difficult to measure are not appropriately included **[21]**.

Composite indices like the SPI and CIW offer a holistic view of well-being by combining multiple indicators, however, this approach presents challenges. While these indices can inform policy by highlighting areas needing improvement and raise public awareness about various well-being dimensions, their complexity can lead to misinterpretations. Furthermore, assigning weights to indicators is inherently subjective and can significantly influence the overall score. The core despite arguable decision made in this research work was to assign equal weights (1/3 each) to the economic, social, and environmental dimensions, ensuring a coherent and balanced assessment throughout the analysis for the proposed composite index. Clearly, combining social and economic indicators can make it difficult to disentangle cause and effect, hindering the ability to identify what drives well-being improvements and design effective policies. This is akin to using energy consumption as a measure of well-being; energy is a mean to an end (like heating a home) and does not directly reflect well-being, similar to how GDP serves as a mean of transactions but does not directly fulfil needs. Composite indices excel at summarizing complex realities, but may not be ideal for pinpointing causal relationships ([25], [21], [53]).

CONCLUSIONS

This study contributes to the existing literature by proposing an adapted version of the *Sustainable Prosperity Index* (SPI), enlarging its application to the case of EU27 countries. By adopting a forward-looking approach based on calibrated future scenarios, the article contributes to the literature by assessing the extent to which energy sufficiency shocks contribute to sustainable prosperity for the EU continent. Additionally, it introduces and tests the concept of a sufficiency threshold (set at 20 k€, in this case) onto the proposed metric, offering a novel and flexible application on how to integrate diverse sufficiency options into beyond-GDP assessments.

Indeed, to assess sustainable prosperity across all EU27 countries, the dimension of energy sufficiency was integrated into the analysis. A novel metric was employed for this task, covering macroeconomic, environmental, and social dimensions, involving the projection of a *Reference Scenario* and a set of various *Sufficiency Scenarios* based on different levels of penetration of energy sufficiency into EU populations. Thus, beyond the main innovation of the study linked to its geographical scope (encompassing all EU27 countries), energy sufficiency measures were directly integrated into the SPI framework, representing a novel approach in advancing sustainability assessments. By projecting the designed scenarios, valuable insights into potential future trajectories of sustainable prosperity were generated.

The results show that for the EU27 group, the *Reference Scenario's* SPI displays a moderate increase, peaking around 2040, followed by a path of stabilization towards 2050. This pathway is driven by improvements in GDP per capita and employment-population ratio, despite increases in GHG emissions and in the Gini coefficient. Germany and Latvia stand out with the most significant improvements in SPI, reflecting their robust policies and innovations in sustainable practices. These countries benefit from substantial increases in GDP per capita and employment-population ratio, coupled with lower pressure on debt-to-GDP ratio. Additionally, Latvia experiences reduced income inequality and decreased average annual working hours, highlighting its balanced approach to sustainability. Denmark and Italy also demonstrate positive trends in SPI, though with more stability, indicating ongoing challenges and adjustments in their sustainability efforts. For France, the SPI shows several risks related to higher debt/GDP ratio, income inequality, and GHG emissions. These dynamics underscore the complexity of balancing economic growth with environmental sustainability and social equity.

Under the *Sufficiency Scenario*, the EU27 group generally achieves better environmental outcomes and the improvement in SPI. This scenario emphasizes a balanced approach, prioritizing environmental performance and social equity over rapid economic growth. France experiences higher SPI values, mostly driven by reduced emissions and enhanced social equity, highlighting the benefits of sufficiency measures in fostering a more inclusive society.

Overall, the *Sufficiency Scenario* leads to higher SPI values across all FULFILL countries compared to the *Reference Scenario*. The relative difference between the two scenarios ranges between 1.2% and 2.3% for FULFILL countries, with France benefiting the most from the implementation of energy SMs. Overall, the findings suggest the potential from the adoption of sufficiency measures to enhance sustainable prosperity by fostering a balanced and inclusive approach to development for the EU.

Despite its contribution, this study is not without limitations. Firstly, the adapted version of SPI proposed in this article does not account for the non-linearity of weights [22]. The use of equal dimension-based weights does not avoid subjectivity, while the assumption that all indicators contribute equally to the index could lead to misleading results. Besides, applying equal weights to percentage changes of variables disregards the differences in the absolute sizes of their changes. As a second issue, the choice of indicators in constructing the SPI can significantly affect the results. Different indicators might lead to diverse conclusions about the state and progress of sustainable prosperity. Despite comprehensive indicators were selected, the exclusion of other relevant socio-economic and environmental variables can bias the results.

Lastly, the authors acknowledge that the construction of the proposed version of SPI does not fully integrate all possible domains of energy sufficiency, as the modelling framework adopts a partial view of the effects that energy sufficiency may have on reduced energy consumption and environmental impact. This is particularly true when considering the multifaceted and complex nature of sufficiency practices, which might have indirect effects not only between countries but even within them. For this reason, the interpretation of results should be approached with caution, as this paper does not consider the potential rebound effects from energy sufficiency actions on savings and indirect effects on additional jobs and new value-added creation.

This study opens several avenues for future research. Researchers should refine SPI's weighting methodology, exploring non-linear or data-driven approaches to reduce subjectivity. Expanding indicator selection through participatory methods may enhance contextual accuracy. Besides, integrating energy sufficiency dynamics and assessing indirect effects like rebound impacts and socio-economic co-benefits would lead to more comprehensive sustainability assessments. A broader view of sufficiency, considering environmental impacts beyond just energy and GHGs, is essential for addressing the full scope of sustainability. Environmental sustainability includes factors like ecosystems, air pollution, and water accessibility, which should be integrated into future modelling frameworks.

In conclusion, this study offers novel insights into the multidimensional nature of sustainable prosperity across European countries, directly integrating energy sufficiency into the discussion. Projecting future scenarios is complex and uncertain depending on decision criteria and available data. Despite all, this study contributes to advancing the discussion on measuring sustainable development, providing valuable insights for policymakers and stakeholders, who need new solutions to monitor long-term prosperity in a rapidly changing world, while shedding light on the complex environmental and social impacts of economic development.

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NOMENCLATURE

Abbreviations

BLI	Better Life Index
CIW	Canadian Index of Wellbeing
CUSP	Centre for the Understanding of Sustainable Prosperity
DI	Decoupling Index
EU MS	European Member State
EBI	Environmental Burden Index
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GNI	Gross National Income
GPI	Genuine Progress Indicator
HDI	Human Development Index
HPI	Happy Planet Index
IDI	Inclusive Development Index
ISEW	Index of Sustainable Economic Welfare
MEW	Measured Economic Welfare
MI	Material Intensity
NGO	Non-governmental Organization
OECD	Organisation for Economic Cooperation and Development
PI	Prosperity Index
SDI	Sustainable Development Index
SDEWES	Sustainable Development of Energy, Water and Environment Systems
SM	Sufficiency Measure
SPI	Sustainable Prosperity Index
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNU-IHDP	United Nations University International Human Dimensions Programme on Global Enivronmental Change
WEF	World Economic Forum
WISE	Wellbeing, Inclusion, and Sustainability in Europe
YoY	Year on Year

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APPENDIX

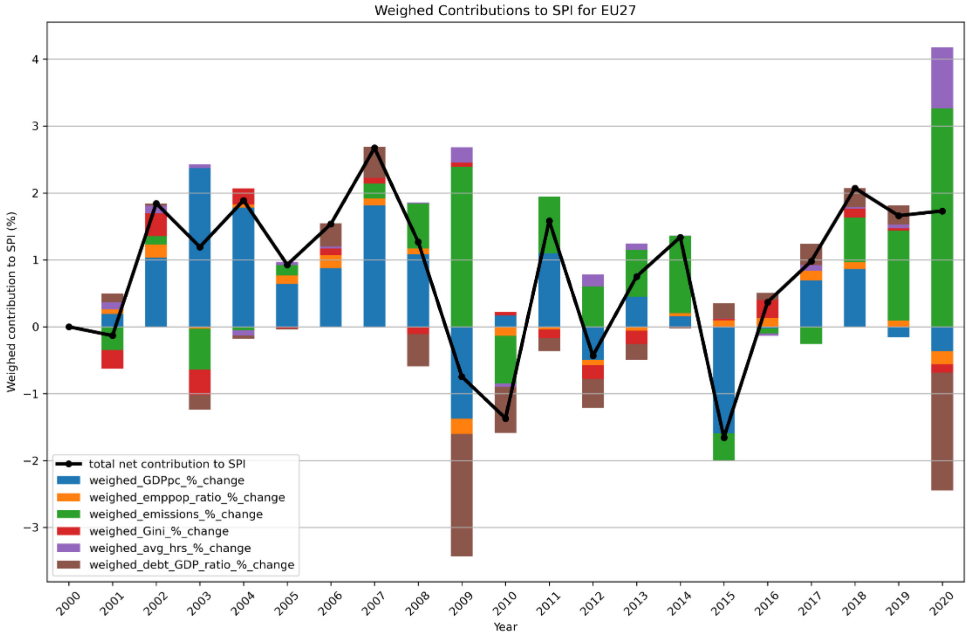

Figure 13. Decomposition of weighed effects for historical SPI – EU27 group

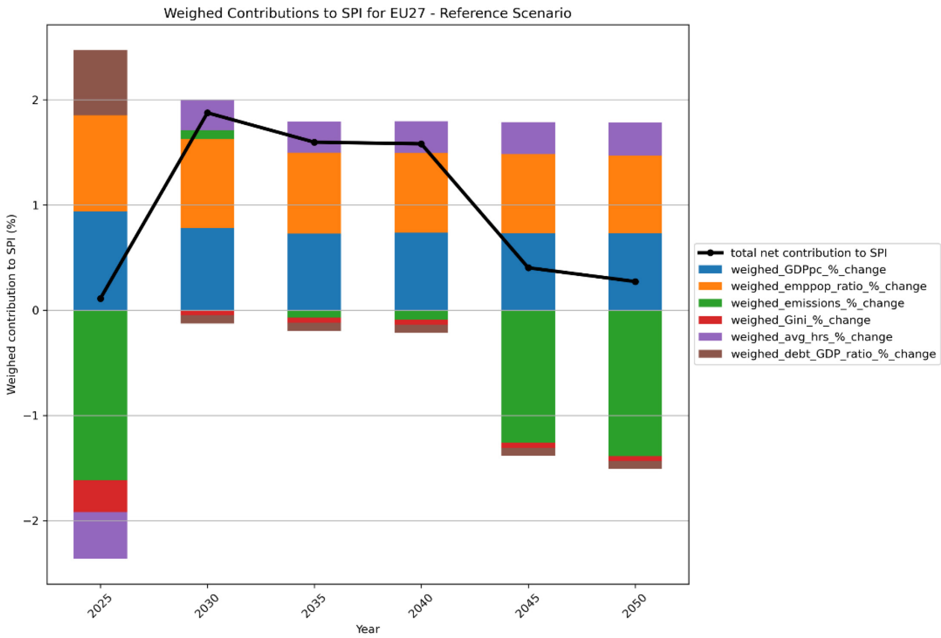

Figure 14. Decomposition of weighed contributions to the Reference Scenario's SPI – EU27 group

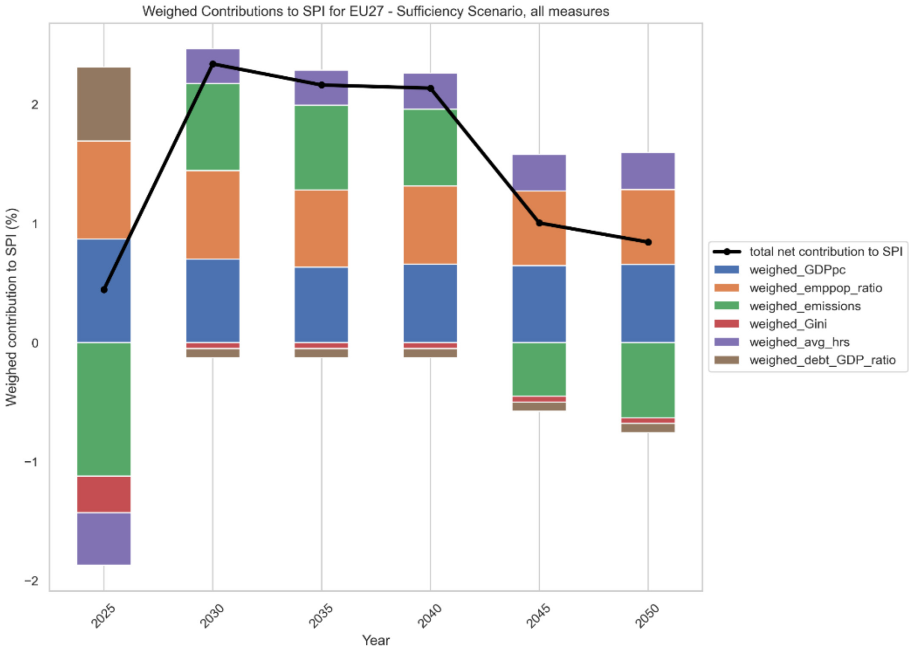

Figure 15. Decomposition of weighed contribution to Sufficiency Scenario's SPI – EU27 group

Sufficiency scenario, diets. **Figure 16** displays the outcomes of SPI for FULFILL countries resulting from the representation of the *Sufficiency Scenario, diets*.

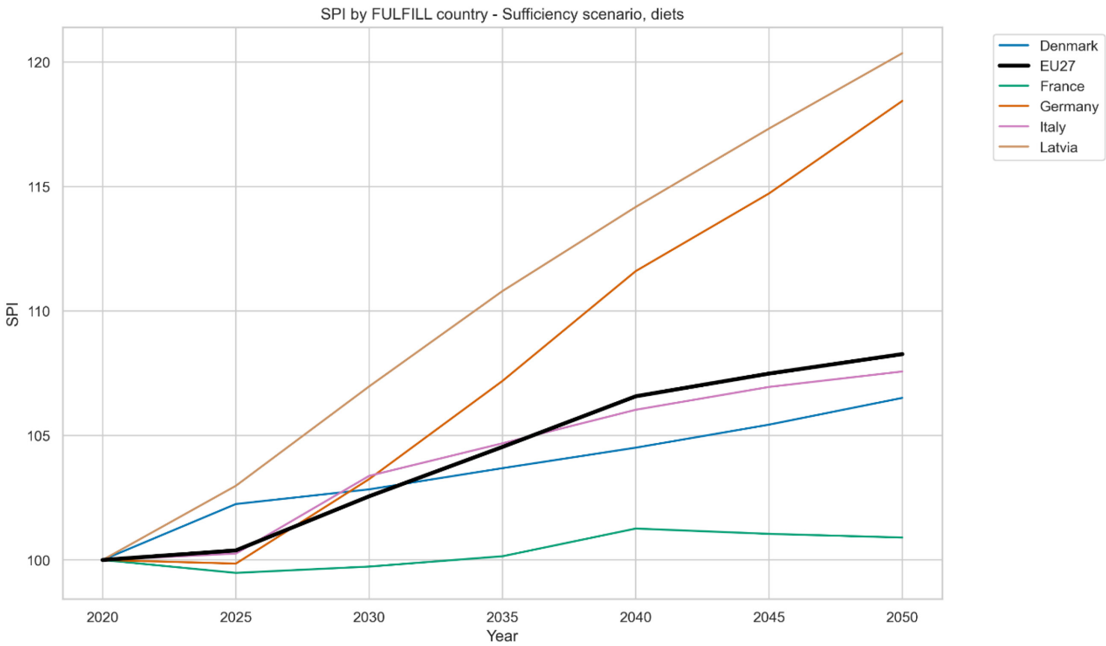

Figure 16. Projected SPI, Sufficiency Scenario, diets. FULFILL countries and EU27

The SPI for the EU27 shows a steady increase up to 108.26 in 2050 (vs. 105.84 under the *Reference Scenario* and 108.94 under the *Sufficiency Scenario, all measures*). Denmark experiences a smooth increase in SPI to 102.24 in 2025, rising to 106.5 by 2050. Germany shows significant increases in SPI, particularly reaching 111.6 in 2040, maintaining high levels through 2050. France sees a significant increase in SPI due to changing diets, peaking at 101.2 in 2040 and then softening around 101 by 2050. Italy experiences a notable increase in SPI, almost tying EU27 in 2035 and then stabilizing around 107.5 through 2050. Latvia experiences the highest SPI, rising to 110.8 in 2030, to then climb up to 120.35 by 2050 under the *Sufficiency Scenario, diets*.

Sufficiency scenario, flying less. **Figure 17** displays the outcomes of SPI for FULFILL countries resulting from the representation of the *Sufficiency Scenario, flying less*.

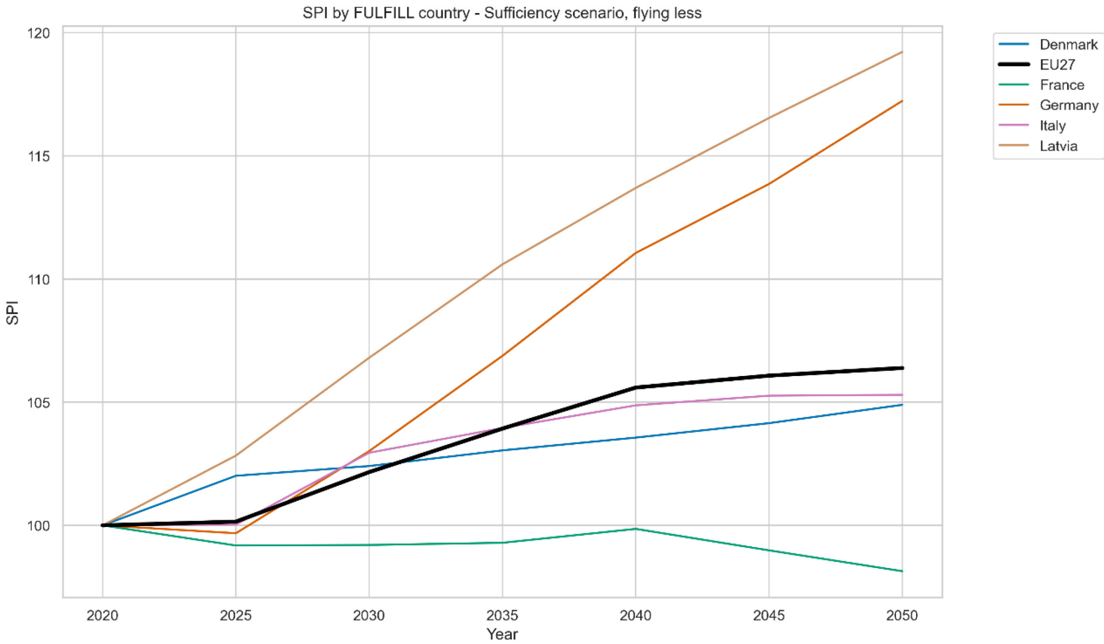

Figure 17. Projected SPI, Sufficiency Scenario, flying less. FULFILL countries and EU27

The SPI for EU27 under the *Sufficiency Scenario, flying less* shows a modest increase, reaching 105.9 in 2040, and then stabilizing around 106.3 towards 2050. Generally, it follows a similar trajectory but with slightly higher values compared to the *Reference Scenario*. In 2050, the index would reach a lower value compared to the case of the SM "*diets*". Also, for the case of Latvia, Denmark, Italy, and Germany, SPI values generally show similar trends but with slightly higher peaks and growth rates compared to the *Reference Scenario*. For the case of France, the SPI under this scenario (individually taken) would not convey relevant benefits compared to the *Reference Scenario*.

Hence, the *Sufficiency Scenario, diets* emphasizes the reduction of passenger air travel and shows promising results in enhancing sustainable prosperity across the EU27 and all FULFILL countries. Countries like Germany and Latvia benefit significantly from these measures, demonstrating substantial SPI increases in the mid-term. However, the magnitude of the impact remains weaker than the results obtained for the impact of changing diets, which would convey most of the improvement in SPI performances.

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