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How the energy procurement switching strategies (driven by the Russia-Ukraine conflict) impact the global sustainability? The global sustainability dashboard

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ABSTRACT

The conflict between Russia and Ukraine has underscored the criticality related to the dependence on energy supply from Russia and the lack of energy autonomy by European countries. To obtain a progressive detachment from the Russian energy supply dependency, European countries have been adopting some measures, aimed at switching the natural gas supply from Russia to other countries, reducing the consumption of natural gas, and replacing energy source typology, e.g., switching from methane to coal or renewable sources. This paper develops a tool based on the Input-Output methodology, named Global Sustainability Dashboard (GSD), designed for assessing the potential consequences of a national strategy aimed at replacing energy source suppliers. GSD adopts 14 indicators to consider the three main sustainability dimensions (i.e., economic, environmental, and social) at both the national and global scale. As an illustrative case, the Italian energy diversification strategy is analyzed, to demonstrate the practical implementation of GSD. Findings are discussed from the numerical perspective.

1. Introduction

Nowadays, the global economy is highly dependent on imports of energy and therefore the national energy security depends on a stable network of international trade in energy (Shepard and Pratson, 2020). Nevertheless, the conflict between Russia and Ukraine has instigated significant alterations in the geopolitical balances that existed before February 24, 2022 (Orenstein, 2023). This event is generating widespread apprehensions and a spectrum of repercussions, notably within sectors such as the economy, finance, environment, energy, and society (Chen et al., 2023; Garbellini and Lampa, 2023; Jiang and Chen, 2024; Khurshid et al., 2024; Khurshid et al., 2023; Lei et al., 2023). In particular, in Europe, in a very short period, the criticality related to the dependence of energy supply on Russia and the lack of energy autonomy of European countries have become evident (Colgan et al., 2023; Cui et al., 2023; McWilliams et al., 2023). Additionally, this geopolitical turmoil has intensified the escalation in energy source prices, a trend triggered by the pandemic (Mišík and Nosko, 2023): the combined effect of both the pandemic and war crises led to the increase in natural gas prices up to the – previously unpredictable – level of +780% in August 2022 compared to May 2021 prices. In response to the above-mentioned events, the European Commission has adopted some emergency measures, intending to shield national economies and maintain an unchanged aggregate energy supply, all the while safeguarding households and enterprises (Matkovic and Anne, 2022). Nevertheless, over the medium and long term, aligning with the Union's energy strategy (European Commission, 2022), the European Commission's decision[1] involves a gradual and increasingly substantial reduction of reliance on Russian gas until complete autonomy is achieved, particularly via implementing three strategies: (1) replacement of supplies (e.g., from Russia to other countries); (2) replacement of energy sources (e.g., from methane to coal and renewable sources); and (3) reduction and saving of consumption (Ministry for Energy Transition, I, 2022). In this regard, the diversification strategy in investments in gas infrastructures, aimed at providing better security of supply improvement and preventing high costs and uncertainties in the European gas market, has become a hot

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[1] EUR-Lex: [https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32022R1369]

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topic nowadays (e.g., Hauser, 2021).

This paper deals with the first of the above-mentioned strategies, i.e., the replacement of supplies. Specifically, to the best of our knowledge, there are no studies that evaluate, in a comprehensive view, the impacts that measures of energy diversification, aimed at reducing the energy dependency from Russia, play on the three dimensions of sustainability (i.e., economic, environmental, and social), not limiting to consider the local level but addressing also a global perspective. In this regard, due to the strong interdependencies among global supply chains (Dubois et al., 2004; Tang et al., 2016) – recognized as relevant also for energy supply chains (Meckling and Hughes, 2018) – the act of consumption within a single country can precipitate environmental repercussions across numerous other nations through multifaceted pathways (Duan and Jiang, 2018; Fraccascia and Giannoccaro, 2019; Skelton et al., 2011; Zhu et al., 2022). Accordingly, traditional indicators based on domestic consumption (e.g., domestic resource extraction and emissions) are insufficient for comprehensively evaluating the environmental impacts attributed to (changes in) final consumption.

Although an increasing number of studies has been produced in a very short period, the literature has mainly focused on studying the economic consequences of the conflict.

Several studies have been devoted to assessing the consequences the conflict played on the energy market (Chen et al., 2023; Umar et al., 2022), which garnered significant attention due to the direct influence on global trade equilibrium (e.g., Bricout et al., 2022), as well as on the global production and marketing chains of food raw materials[2] (e.g., Abay et al., 2023). Other studies have addressed the environmental impact of war operations[3] (e.g., Rawtani et al., 2022). Nevertheless, assessing the overall sustainability impacts of energy diversification strategy is of high importance, given the strong interconnection among the economy, environment, and society (e.g., Dong et al., 2024; Luo et al., 2024; Zhao et al., 2024).

Aimed at filling this gap, this study develops the Global Sustainability Dashboard (GSD), designed for assessing the potential consequences that a national strategy aimed at replacing energy source suppliers would play on the three sustainability dimensions at both the national and global scale. In particular, our approach relies on the Input-Output methodology (Dietzenbacher and Lahr, 2004; Leontief, 1986) and uses the global Multi-Regional Input-Output (MRIO) tables, which are able to describe the interdependences among the national economies of some countries where each national economy is modelled in terms of a certain number of industry sectors. These tables encompass data that delineate the intricate network of global economic interdependencies and their corresponding environmental ramifications. The Input-Output approach has been proved very useful in mapping regional and international trade (Chen et al., 2018; Du et al., 2017; Zhu et al., 2022) and its impact in terms of sustainability (Ivanova and Wieland, 2023; Mubako et al., 2013; Wiedman and Lenzen, 2018). Indeed, as stated before, the act of consumption within a single country might precipitate environmental repercussions across numerous other nations through multifaceted pathways: the Input-Output approach is able to take into account these mechanisms and reveal the underlying paths. Moreover, the input-output methodology has been employed to facilitate various sustainability assessments. For example, Lang and Kennedy (2016) utilized global multiregional input-output models to evaluate the worldwide operational footprint of higher education institutions across five impact categories: energy consumption, water usage, material usage, land use, and CO_2 emissions. Peters et al. (2021) utilized a multiregional environmentally extended input-output model to evaluate the environmental and socio-economic impacts of the clothing and footwear value chain. Their study primarily addresses key environmental indicators such as energy consumption, climate impact, and water resource usage, along with socio-economic factors including wages and employment. Readers interested in deepening the literature about the measurement methods of sustainability and input-output models are referred, for instance, to the review by Wiedman and Lenzen (2018). Furthermore, such an approach has been used to investigate the impact of rapid changes in output production due to exogenous shocks (Contreras and Fagiolo, 2014; Galbusera and Giannopoulos, 2018; Zhang et al., 2023), as well as scenarios and policies related to the energy security (Kartal et al., 2023; Prabhu and Mukhopadhyay, 2023; Supasa et al., 2017).

Our approach leverages the concept of Global Emission Chains introduced by Fraccascia and Giannoccaro (2019) to derive an optimal and non-redundant set of 14 sustainability indicators, which holistically encompass all the three sustainability areas, at the level of the single industry of the single country, thus introducing the concept of GSD. To design the GSD, we relied on data sourced from EXIOBASE 3 (Stadler et al., 2018), a comprehensive global detailed Multi-Regional Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT) and one of the most extensive Environmentally-Extended-MRIO systems worldwide available. The MR-IOT serves as a tool for evaluating the environmental repercussions linked to the ultimate consumption of product categories. EXIOBASE 3 employs rectangular tables in a 163 industries by 200 products classification as its fundamental structure. Notably, this system encompasses 44 countries, five Rest of World regions, three employment skill levels per gender, 417 emission categories, 662 material and resources categories. As an illustrative case, we analyze the Italian energy diversification strategy to demonstrate the practical implementation of our methodology.

The paper is structured as follows. Section 2 presents a brief review of the scientific literature regarding the most important research areas that have been investigated regarding the Russia-Ukraine conflict. Section 3 presents the adopted methodology to design the GSD. The case study is presented in Section 4. Finally, the paper ends with discussion, implications, and conclusions in Section 5.

2. Literature review: Sustainability implications of the Russia-Ukraine conflict

A wide range of literature has investigated the (actual and potential) consequences of geopolitical shocks from several perspectives. For instance, from an economic perspective, geopolitical risks are able to affect natural resource prices (e.g., Li et al., 2023; Liu et al., 2024; Mignon and Saadaoui, 2024; Zheng et al., 2023), which in turn can impact the global and local economic stability (e.g., Sokhanvar et al., 2023; Zhao et al., 2023). Nevertheless, geopolitical shocks might promote technological progress and drive the transition towards the adoption of renewable energy sources (e.g., Ben Cheikh and Ben Zaied, 2024; Pengfei et al., 2023).

Concerning the Russia-Ukraine conflict, due to the relevance of the events that occurred so rapidly, to date, a substantial volume of research has already emerged in this short span, aiming to dissect this phenomenon from several perspectives (e.g., Cui et al., 2023; Prohorovs, 2022; Steffen and Patt, 2022; Umar et al., 2022). In this regard, several studies explored the relationship between geopolitical risk and economic policy uncertainty that is leading to no longer negligible environmental consequences (e.g., Anser et al., 2021; Khan et al., 2023; Pata et al., 2023; Sweidan, 2023). This literature review is not intended to be exhaustive on the topic, but rather to provide the readers with an overview of the main investigated research areas concerning the sustainability implications of the Russia-Ukraine conflict.

Several studies addressed the economic repercussions of the conflict.

[2] Notably, Ukraine holds a pivotal position as a primary exporter of such materials, particularly to impoverished and emerging nations; disruption of these exports could potentially result in substantial losses of these resources, thereby instigating a global food crisis.

[3] The explosions of munitions of different types and the destructions determine an environmental impact on air, land, and water, which not only is attributable to the GHG production, but also to the enormous releases in the environment of toxic substances of various origins.

European nations swiftly implemented commercial and financial sanctions with the aim of economically isolating Russia. For this reason, there has been some interest in analyzing the *short-term economic effects of isolating Russia from international trade*, thus generating interruptions in the economy in different isolation scenarios. In this regard, Estrada and Koutronas (2022) introduced the concepts of "trade suffocation" and "investment desgrowth", new economic phenomena to explain the uncharted territory of economic sanctions and their consequences on the affected economies. Mardones (2022) highlighted that Russia would face a drop in production of 10.1% in the scenario with sanctions from the European Union and 14.8% when the sanctions are also applied by Australia, Canada, Japan, the United States, and the United Kingdom. Fang and Shao (2022) underscored that the Russia-Ukraine conflict markedly elevates the volatility risk within commodity markets, particularly those pertaining to agricultural products, metals, and energy. Additionally, they noted the existence of significant risk spillovers between the metal and energy markets.

Ukraine holds a prominent position as a major global producer of food raw materials. Given that Ukraine's agri-food exports to the EU-27 reached 5.4 billion euros in 2020, accounting for a substantial 28% share,[4] the economic dimensions of the crisis are intricately interlinked with developments in the agri-food sector. For this reason, from the economic and social sustainability perspectives, the *consequences on the food supply chains security* have been subjected to thorough examination in various studies. For instance, Abay et al. (2023) employed a global vulnerability analysis to pinpoint the most vulnerable regions and countries, while Ben Hassen and El Bilali (2022) underscored the immediate and far-reaching cascading repercussions of the conflict on worldwide food security. The study by Jagtap et al. (2022) delved into the consequences of the conflict on the efficiency and adaptability of global food supply chains, particularly following the impacts of the COVID-19 outbreak. They highlighted the dual sources of instability, which resulted in food price hikes leading to shifts in demand among countries reliant on imports from Ukraine. The investigation identifies six key segments of the most vulnerable impacted food supply chains and proposes strategies and solutions to mitigate the resultant supply chain disruptions.

The conflict is exerting an impact on the global geopolitical framework, particularly within the realm of the *energy sector and energy exchanges*. Zakeri et al. (2022) analyzed the effects on the global energy sector of both the COVID-19 pandemic (which caused drastic fluctuations in energy demand and the loss of more than 99,000 jobs in the first months of the pandemic only in the USA) and the war, that posed substantial challenges to energy security. Particularly, the war underscored the imperative for enhanced energy diversification and heightened reliance on local, renewable energy resources. Nonetheless, the findings indicate that global policymakers are predominantly prioritizing short-term objectives, seeking new fossil fuel supply channels to bolster energy security. Consequently, the opportunity for phasing out fossil fuels could be missed. The joint effects of the pandemic and the Russia-Ukraine conflict exert an influence also on the creation of fair and just financing mechanisms necessary for accelerating the transition required by the decarbonization agenda. The increase in raw material and labor prices caused by the two crises has consequent impacts on global supply chains and technology. This creates an unfair landscape, as entities seeking access to green technologies – which are typically more cost-intensive to implement – find themselves impeded from doing so. Paradoxically, these stakeholders often find themselves at the forefront of bearing the consequences of climate change impacts (Allam et al., 2022). Moreover, geopolitical changes, related to different crisis scenarios, are leading to energy price shocks that affect the global economic stability (Zhao et al., 2023).

[4] https://www.ismea.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/11684

This issue transcends the purview of developing economies. Analogous reflections regarding energy investments, notably in the context of potential impediments to the proliferation of clean primary energy technologies, are also under scrutiny within well-structured and adeptly managed energy systems. The study conducted in Norway by Malka et al. (2023) underscores that achieving the decarbonization objectives and ensuring security of supply necessitate the adoption of a mitigation strategy centered on diversifying the national energy landscape and instituting large-scale integration of renewable energy sources. Furthermore, achieving zero emissions by the end of 2050 is impossible without applying the carbon tax and post-carbon capture storage (CCS), especially in the oil and gas sector.

Moreover, the energy transition is modifying the corporate positioning of the European international oil companies (IOCs). Notably, several studies have underscored that the augmented fragmentation within the political and market landscape of the energy sector will result in a diminished overall geopolitical influence wielded by IOCs (e.g., Bricout et al., 2022). Lambert et al. (2022) critically evaluated the novel gas supply policies of the European Union (EU) alongside the pragmatic potential for diversifying gas provisions in the short and medium terms. Their analysis emphasized that attaining adequate supplementary gas supplies to replace approximately two-thirds of Russian supplies — per the REPower EU policy — within a condensed timeframe is a challenging endeavor for the EU. Consequently, within the medium term spanning 2023 to 2030, both the United States and Qatar may emerge as pivotal contributors of additional Liquefied Natural Gas (LNG) supplies for the EU, consequently curbing Russia's market shares, revenues, and political influence.

The situation in Germany holds particular significance, given its substantial reliance on imports from Russia. The study of Halser and Paraschiv (2022) delves into the economic consequences of the embargo, evaluating both the impact on demand and the supply-related factors capable of alleviating the resultant supply deficit. The study computes a potential for short-term import substitution of 13 billion cubic meters (bcm), while accounting for demand reductions across various sectors estimates a cumulative maximum of 24.1 bcm. Nonetheless, even under the most optimistic outlook, there appears to persist an import shortfall of roughly 9 bcm per annum. Consequently, this underscores the necessity for a deferred transition away from coal and nuclear power, an accelerated integration of renewable energy, and judicious consideration in implementing consumer restrictions.

The literature has also addressed the *environmental* concerns of the war. Pereira et al. (2022) and Rawtani et al. (2022) discussed the detrimental effects that military activities exert on diverse environmental facets, encompassing air quality and the emission of greenhouse gases, biodiversity, soil composition, and the morphological alteration of landscapes, alongside the availability and quality of water resources, as well as the potential for radiation leakage from nuclear facilities. Accordingly, due to the intense fighting, there is evidence of severe air pollution and greenhouse gas emissions. The heightened deforestation and the consequential destruction of habitats are profoundly impacting biodiversity, thereby potentially affecting wildlife populations, and diminishing the ecosystems' capacity to effectively regulate both air quality and climate dynamics. The ongoing conflict is projected to precipitate soil degradation, subsequently impinging upon agricultural productivity, a matter of particular significance, given Ukraine's global prominence in the domain of food production. The impacts on human health are already tremendous and are expected to be even higher due to exposure to high levels of contamination and sanitary conditions degradation.

Ultimately, the conflict between Russia and Ukraine has extended to the *cyberspace* with an unprecedented intensity and scale of opinion fighting. The social cognitive war fighting with cyber-physical-social systems (CPSS) would significantly impact every aspect of our life and an analysis of the evolutionary dynamics of public opinion fighting seems to play a significant role (Chen et al., 2022).

All in all, to the best of our knowledge, there are no studies that evaluate the impacts on the three dimensions of sustainability at the local and the global level of measures such as the energy suppliers' switching strategy.

3. Methodology

The(GSD is a tool developed based on the Global Emission Chains (GECs) proposed by Fraccascia and Giannoccaro (2019). The GEC of the j-th industry of the k-th country highlights the amount of CO_2 emitted by each of the industries of each country per economic unit of final demand of industry j of country k, due to the international trade. While GECs are limited to consider only CO_2 emissions, the GSD is computed on a set of 14 indicators, which are described in the reminder of this section.

3.1. Data source

In this paper, the MRIO tables provided by EXIOBASE 3 database (Stadler et al., 2018) are used. These tables cover 49 countries (28 EU members, 16 major economies, and five rest of the world regions) for the years from 1995 to 2011 – additionally, estimations that go up to 2022 are available. For each of these countries, 163 industries are considered. For each year, there is a harmonized global level input-output table recording the input-output relationships between any pair of industries in any pair of countries. Data are in current basic prices expressed in million euros.

MRIO tables – and specifically those provided by EXIOBASE – are composed by three parts: (1) the transaction matrix (Z) is a (163 × 49) × (163 × 49) matrix whose generic element $Z_{(m-1)\times 163+i,(k-1)\times 163+j}$ denotes the output produced by the i-th industry of the m-th country that is transferred to the j-th industry of the k-th country; (2) the vector of the aggregated final demand ($\overrightarrow{f}$), which is given by the sum of household consumption and government expenditures of each country, is a (163 × 49) × 1 vector, whose generic element $f_{(m-1)\times 163+i}$ denotes the final demand observed by the i-th industry of the m-th country; (3) the vector of the total output produced ($\overrightarrow{x}$) is a (163 × 49) × 1 vector, which is the sum of the output destined as intermediate product to other industries and the output destined to fulfill the final demand, whose generic element $x_{(m-1)\times 163+i}$ denotes the total output by the i-th industry of the m-th country.

3.2. The global sustainability dashbord

To build the Global Sustainability Dashbord (GSD) within EXIOBASE we have selected a set of indicators belonging to the three areas of sustainability (i.e., social, environmental, and economic) that are relevant to our study, in order to provide a more comprehensive view of the phenomenon. The methodological approach employed to derive an optimal and non-redundant selection of indicators was based on the findings of Steinmann et al. (2018). This study emphasized that, although MRIO databases supply extensive data on various environmental pressures and impacts, large sets of impact indicators are not ideal for targeted communication with decision-makers. Therefore, drawing upon the indicators available in EXIOBASE (base year 2011; version 3.2.4), they proposed an optimal set of environmental impact indicators from a numerical standpoint, which are displayed in Table 1.

In the current study, EXIOBASE (base year 2021; version 3.4) serves as the chosen database. Since there is no complete correspondence with the database used by Steinmann et al. (2018), from EXIOBASE (base year 2021; version 3.4) we have selected the indicators in line with those proposed by Steinmann et al. (2018). Specifically, for the indicators from "2" to "6" displayed in Table 1, the most likely heuristic selection of indicators both aligning with the study by Steinmann et al. (2018) and present in EXIOBASE (base year 2021; version 3.4) appears to be encompassed by the set displayed in Table 2.

The existing differences compared to Steinmann's choice concern the following indicators: (1) "Particulate matter formation (Hierarchist)" (PM10 intake, [kg]) of the ReCiPe 2008 method (indicator "1" in Table 1) and (2) "Land occupation damage to ecosystem quality" [PDF × m^2 × y/m^2 × y] of the Impact2002+ method (indicator "7" in Table 1) – this indicator being derived directly from the Eco-indicator 99 method (Goedkoop and Spriensma, 2000). Specifically, both these indicators are not present in EXIOBASE (base year 2021; version 3.4), which is the data source used for this study. Therefore, through the most likely heuristic selection of indicators present in EXIOBASE (base year 2021; version 3.4), the indicator "Particulate matter formation (Hierarchist)" (PM10 intake, [kg]) of the ReCiPe 2008 method has been replaced by the following two indicators: (1) PM10 [kg] and (2) Particulate matter/ Respiratory inorganics midpoint | ILCD recommended CF | emission-weighted average PM2.5 equivalent [kg PM2.5-eq] – both present in EXIOBASE (base year 2021; version 3.4). Note that the inclusion of the indicator estimating PM2.5 is conservative, as it allows for the evaluation of a pollutant that, in terms of human health, has the potential to be more harmful than the impact caused by PM10. This inclusion thus enhances the level of detail in the analysis. Furthermore, through the most likely heuristic selection of indicators present in EXIOBASE (base year 2021; version 3.4), the "Land occupation damage to ecosystem quality" [PDF × m^2 × y/m^2 × y] indicator of the Impact2002+ method, has been replaced by the following four indicators: (1) Damages to human health caused by climate change (H.A) | ECOINDICATOR 99 (H.A) | [DALY]; (2) Damage to Ecosystem Quality caused by ecotoxic emissions (H.A) | ECOINDICATOR 99 (H.A) [PDF × m^2 × yr]; (3) Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication (H.A) | ECOINDICATOR 99 (H.A) | [PDF × m^2 × yr]; and (4) Land use Crop, Forest, Pasture [km^2]. In addition to incorporating land use, these indicators also account for human health damages induced by climate change, as well as the impacts on ecosystem quality resulting from ecotoxic emissions and the combined effects of acidification and eutrophication. Similar to the previous replacement, this inclusion further enhances the level of detail in the analysis.

The previous list is finally integrated with the following indicators, in

Table 1
Indicators used by Steinmann et al. (2018).

#	Numerically best indicator set	Method
1	Particulate matter formation (Hierarchist)	ReCiPe 2008
2	Freshwater aquatic ecotoxicity (infinite time horizon)	CML 2001
3	Marine ecotoxicity (infinite time horizon)	ReCiPe 2008
4	Global warming (100 year time horizon)	EDIP 2003
5	Terrestrial ecotoxicity (100 year time horizon, Individualist)	ReCiPe 2008
6	Photochemical oxidation (Maximum Increment Reactivity)	CML 2001
7	Land occupation damage to ecosystem quality	Impact 2002+

Table 2
Selected indicators available in EXIOBASE 2021, version 3.4, aligned with Steinmann et al. (2018) findings.

#	Indicator / impact	Unit
2	Freshwater aquatic ecotoxicity (FAETP inf) | Problem oriented approach: baseline (CML, 1999) | FAETP inf. (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq.
3	Marine aquatic ecotoxicity (MAETP inf) | Problem oriented approach: baseline (CML, 1999) | MAETP inf. (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq.
4	Climate change midpoint | ILCD recommended CF | Global warming potential 100 years	kg CO2-Equivalents
5	Terrestrial ecotoxicity (TETP100) | Problem oriented approach: non baseline (CML, 1999) | TETP 100 (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq.
6	Photochemical oxidation (MIR; very high NOx) | Problem oriented approach: non baseline (CML, 1999) | MIR 1997; very high NOx (Carter, 1994, 1997, 1998; Carter, Pierce, Luo & Malkina, 1995)	kg formed ozone

order to cover also the economic and social dimensions: (1) Value added [€]; (2) Employment [1000 p.]; and (3) Employment hour [hr].

The above-mentioned indicators represent a heuristic selection of indicators present in EXIOBASE (base year 2021; version 3.4) aligning with those identified by Steinmann et al. (2018) that are not available in the database we selected for this study. Other selections of indicators could potentially cover the three environmental, economic, and social areas. The heuristic choices we made, closely aligning with the results of Steinmann et al. (2018), allowed a limited number of indicators to be obtained, with which to construct the dashboard.

All in all, the resulting GSD proposed in this study adopts the indicators displayed in Table 3 that adopts an appropriate re-numbering. The Sustainable Development Goals mainly related to each indicator are reported.[5]

All in all, the development of the GSD involved obtaining an optimal and non-redundant set of indicators by adapting the indicators proposed by Steinmann et al. (2018) from EXIOBASE version 3.2.4/2011 to the indicators available in the database utilized in the present study (EXIOBASE version 3.4/2021). Discrepancies identified between the indicators in the two databases were addressed using a conservative approach: additional indicators were identified, which, from an impact perspective, could potentially pose greater harm compared to the impact associated with the original indicators that could not be utilized. Moreover, we augmented the resulting indicators with one indicator of economic sustainability and two indicators of social sustainability.

The GSD is therefore made up of fourteen indicators relating to the three areas of sustainability: eleven indicators out of fourteen describe the environmental impacts to underline how important this aspect is both in the original choice of Steinmann et al. (2018) and in the choices made in this work. The ecological aspects considered by the indicators represent a set of impact categories that cover every aspect of possible damage.

In particular, the GSD of the j-th industry of the k-th country highlights the numerical value of each of the above-mentioned 14 indicators computed at the global level, per unit of output produced by that industry. Differently from GECs, which consider the final demand, we decided to take into account the overall output production, which is considered to be more representative. For instance, considering the indicator "PM10", the GSD of the j-th industry of the k-th country will report the kg of PM10 produced at the world level per unit of output produced by that industry of that country.

In order to build the GSD, we relied on EXIOBASE, which includes data on the above-mentioned sustainability indicators computed for each industry of each country for each year between 1995 and 2011, plus estimated data for each year between 2012 and 2021. For the sake of simplicity, only the procedure used to compute the indicator "Employment hours" (EH) of the GSD is presented; notice that all the other 13 indicators can be computed via the same mathematical approach.

Let e^{EH} be the $(163 \times 49) \times 1$ vector whose generic element $e^{EH}{}_{(k-1)\times 163+j}$ denotes the amount of employment hours required by industry j of country k.[6] Then, the $(163 \times 49) \times 1$ vector ei^{EH} is computed by the following equation:

$$\overrightarrow{ei^{EH}} = \widehat{x}^{-1} \bullet \overrightarrow{e^{EH}} \tag{1}$$

where the generic element $ei^{EH}_{(k-1)\times 163+j}$ denotes the amount of employment hours required by industry j of country k for each unit of output produced. Finally, the $(163 \times 49) \times (163 \times 49)$ S^{EH} matrix is computed as follows:

$$S^{EH} = \widehat{ei}^{EH} \bullet \left(Z \bullet \widehat{x}^{-1}\right) \tag{2}$$

where the "hat" is used to denote a square matrix so that $\widehat{ei}^{EH}_{uu} = ei^{EH}_{u} \forall u = 1 \ldots (163 \times 49) \times (163 \times 49)$ and $\widehat{ei}^{EH}_{uv} = 0 \forall u \neq v$. Here, the generic element $S^{EH}_{(m-1)\times 163+i,(k-1)\times 163+j}$ indicates the amount of employment hours required by the i-th industry of the m-th country per economic unit of output produced by the j-th industry of the k-th country. Hence, the amount of employment hours required at the global level for economic unit of production of the j-th industry of the k-th country (denoted as $EH_{j,k}$) can be computed as the sum of the above-mentioned column, i.e.:

$$EH_{j,k} = \sum\nolimits_{m=1}^{c} \sum\nolimits_{i=1}^{n} S^{EH}_{(m-1)\times 163+i,(k-1)\times 163+j} \tag{3}$$

Similarly, we can compute the amount of employment hours required by all the industries of the m-th country per economic unit of output produced by the j-th industry of the k-th country (denoted as $EH^{m}_{j,k}$) as follows:

$$EH^{m}_{j,k} = \sum\nolimits_{i=1}^{n} S^{EH}_{(m-1)\times 163+i,(k-1)\times 163+j} \tag{4}$$

As an example, Table 8 in Appendix A1 displays a piece of the S matrix computed for the indicator "employment hours" considering the "natural gas extraction, excluding surveying" industry of two countries, i.e., Russia and Italy. According to Eq. (3), 4791.83 employment hours are required at the world level to produce one million euros of output by the Russian "natural gas extraction, excluding surveying" industry, while 7498.73 employment hours are required to produce one million euros of output by the correspondent industry in Italy. Furthermore, to produce one million euros of output produced by the Italian "natural gas extraction, excluding surveying" industry, 0.0066 employment hours are required by the Russian "Processing of Food products" industry and 0.5616 employment hours are required by the Italian "Processing of Food products" industry.

Table 9 in Appendix A2 displays the employment hours required by all the industries of each country (over the rows) per economic unit of output produced by the Russian (first column) and Italian (second column) "natural gas extraction, excluding surveying" industry, computed according to Eq. (4). For instance, it can be noted that producing one million euros of output of the Russian "natural gas extraction, excluding surveying" industry requires 4338.63 domestic employment hours, 16.07 h by Indian industries, and 15 h by Chinese industries. Producing one million euros of output of the Russian "natural gas extraction, excluding surveying" industry requires 3904.24 domestic employment hours, 160.01 h by Indian industries, and 68.83 h by Chinese industries. This table can thus be used to highlight who are the countries mostly involved, in terms of employment hours required, in the production chain of the "natural gas extraction, excluding surveying" industry.

GSD works under the assumption that all the outputs generated by one industry have the same workforce intensity. Such an assumption is due to the lack of input-output tables for specific products and is also adopted by other studies (Caro et al., 2017; de Vries and Ferrarini, 2017; Fraccascia and Giannoccaro, 2019).

4. Case study: The Italian switching strategy for natural gas

In this section, the GSD is applied to assess the sustainability impacts of the energy switching strategy adopted by the Italian government. We selected this case due to the significant role that Russian gas has played in fulfilling the domestic natural gas demand – around 40% of the overall demand in 2021, with 30.4 billion cubic meters out of 76 billion

[5] Please notice that the association between the SDGs and the impact categories is a subject of ongoing exploration within the scientific community, and the associations proposed in the table represent only a general indication deduced from some studies that have begun to address this topic (Hannouf et al., 2023; Sanyé-Mengual and Sala, 2022).

[6] This vector has been built according with the data available on EXIOBASE 3 in another format.

Table 3
Indicators used for the Global Sustainability Dashboard.

#	Indicator	Unit	Sustainability Area	Environmental impact category	Deals mainly with SDG
1	Value Added	€	Economic		1 No poverty
2	Employment	1000 p.	Social		1 No poverty; 8 Decent work and economic growth
3	Employment hours	hr	Social		1 No poverty; 8 Decent work and economic growth
4	Damages to human health caused by climate change (H.A) | ECOINDICATOR 99 (H.A)	DALY	Environmental	Human health	3 Good health and well-being
5	Damage to Ecosystem Quality caused by ecotoxic emissions (H.A) | ECOINDICATOR 99 (H.A)	PDF×m2×yr	Environmental	Ecotoxicity	3 Good health and well-being; 14 Life below water; 15 Life on land
6	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication (H.A) | ECOINDICATOR 99 (H.A)	PDF×m2×yr	Environmental	Acidification and eutrophication	6 Clean water and sanitation; 14 Life below water
7	Freshwater aquatic ecotoxicity (FAETP inf) | Problem oriented approach: baseline (CML, 1999) | FAETP inf. (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq	Environmental	Ecotoxicity	3 Good health and well-being; 14 Life below water; 15 Life on land
8	Marine aquatic ecotoxicity (MAETP inf) | Problem oriented approach: baseline (CML, 1999) | MAETP inf. (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq	Environmental	Ecotoxicity	3 Good health and well-being; 14 Life below water; 15 Life on land
9	Climate change midpoint | ILCD recommended CF | Global warming potential 100 years	kg CO2eq	Environmental	Climate change	13 Climate action
10	Terrestrial ecotoxicity (TETP100) | Problem oriented approach: non baseline (CML, 1999) | TETP 100 (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq	Environmental	Ecotoxicity	3 Good health and well-being; 14 Life below water; 15 Life on land
11	Photochemical oxidation (MIR; very high NOx) | Problem oriented approach: non baseline (CML, 1999) | MIR 1997; very high NOx (Carter, 1994, 1997, 1998;Carter, Pierce, Luo & Malkina, 1995)	kg formed ozone	Environmental	Photochemical oxidation	13 Climate action
12	PM10	kg	Environmental	Particulate matter	3 Good health and well-being
13	Particulate matter/Respiratory inorganics midpoint | ILCD recommended CF | emission-weighed average PM2.5 equivalent	kg PM2.5-eq	Environmental	Particulate matter	3 Good health and well-being
14	Land use Crop, Forest, Pasture	km^2	Environmental	Land use	2 Zero hunger; 6 Clean water and sanitation; 13 Climate action; 15 Life on land

cubic meters of gas consumed.[7] Immediately close to the outbreak of the conflict between Russia and Ukraine, the Italian government recognized the urgent necessity to implement strategic measures, aimed at ensuring the security of domestic supplies and mitigating the adverse repercussions on industries and households stemming from the conflict. Accordingly, the Ministry of Ecological Transition[8] launched the

[7] https://culturaeconsapevolezza.mase.gov.it/sites/default/files/2023-01/Piano_nazionale_contenimento_consumi_gas_naturale_MASE.pdf

[8] Currently, the name of that ministry is "Ministry of Environment and Energy Security".

"*National plan for the containment of natural gas consumption*", encompassing several initiatives designed chiefly to: (1) rapidly diversifying the origin of the supplies of gas imported from Russia to other states, replacing 25 Gscm (giga standard cubic meter) of Russian gas with gas from other countries by 2025; (2) maximizing the use of available gas pipeline infrastructures to achieve a capacity of around 12 Gscm (doubling from Algeria, doubling from Trans Adriatic Pipeline (TAP), increasing the national production from the current 3 up to 6 Gscm); and (3) augmenting the national Liquefied Natural Gas (LNG) re-gasification capacity to approximately 13 Gscm (comprising up to 3.5 billion cubic meters from Egypt, 1.4 billion cubic meters from Qatar, a gradual increase of 4.6 billion cubic meters from Congo, and approximately 3.0–3.5 billion cubic meters from ongoing negotiations with other countries like Angola, Nigeria, Mozambique, Indonesia, and Libya).

The remainder of this section is divided into two subsections. Section 4.1 concerns the application of the GSD to the case study. Section 4.2 presents the numerical results.

4.1. Application of GSD to the case study: Scenarios analyzed and computations of the effects

The scenario analyzed in the numerical case study results from the following actions, in line with the "*National plan for the containment of natural gas consumption*" (Ministry for Energy Transition, I, 2022): (1) reduction by 25 GScm in the import of natural gas from Russia; (2) increase by 3 GScm in the domestic production of natural gas; and (3) increase by 22 GScm in the import of natural gas from the rest-of-the-world. In particular, referring to the last action, the following increase in natural gas imports have been considered: 6 GScm from Algeria, 3.5 GScm from Egitto, 4.6 GScm from Congo, 3 Gscm from Angola, Libya, Mozambique, and Nigeria (here, we have assumed that such an increase is equally shared among these countries, i.e., that each of them contributes with 0,75 GScm[9]), 1.4 GScm from Qatar, 3 GScm from Azerbaijan, and 0.5 GScm from Indonesia.

The input-output tables display data in monetary terms. In order to convert Scm into euros, we have adopted the following approach. First, from the input-output tables referring to 2021 we have extracted the monetary value of the output of the Russian "Extraction of natural gas and services related to natural gas extraction, excluding surveying" industry purchased by Italy, which is equal to 7532 million euros. Then, we have divided such an amount by 30.4, which is the amount of GScm that Italy purchases from Russia.[10] As a result, we have computed the economic value of natural gas as 247.77 (=7532/30.4) million euros per GScm.[11] This data has been used to model the monetary value of the above-mentioned actions. In particular: (1) the reduction by 25 GScm in the import of natural gas from Russia has been modelled as a decrease by 6194.26 (=25 × 247.77) million euros in the output of the Russian "Extraction of natural gas and services related to natural gas extraction, excluding surveying" industry; (2) the increase by 3 GScm in the domestic production of natural gas has been modelled as an increase by 743.31 (=3 × 247.77) million euros in the output of the Italian "Extraction of natural gas and services related to natural gas extraction, excluding surveying" industry; (3) the increase by 22 GScm in the import of natural gas from the rest-of-the-world (Algeria, Angola, Azerbaijan, Egypt, Indonesia, Nigeria, Libya, Mozambique, Qatar) has been modelled as an increase in the outputs of the "Extraction of natural gas and services related to natural gas extraction, excluding surveying" industry of the following countries: (a) 4236.88 (=17 × 247.77) million euros by rest-of-the-world African countries (denoted by WF region in EXIOBASE); (b) 346.88 (=1.4 × 247.77) million euros by Middle-East countries (denoted by WM in EXIOBASE); and (c) 867,2 (=3.5 × 247.77) million euros by Asian countries (denoted by WA in EXIOBASE).

4.2. Results

Table 4 and Table 5 display the value of all the 14 indicators for the "natural gas extraction, excluding surveying" industry, computed according to Eq. (3) and Eq. (4), respectively for Italy, Russia, African countries (WF), Asian countries (WA), and Middle-East countries (WM). It can be noticed, for instance, that producing one million euros of output in Italy would release 32.28 Kg of PM10 (indicator 12) globally (Table 4), of which 17.88 Kg (55.4%) within the national borders (Table 5). Producing the same amount of output by the Russian "natural gas extraction, excluding surveying" industry would produce 57.5 Kg of PM10, of which 54.92 Kg (95.5%) within the national borders. Hence, it can be noted that, with reference to the PM10 indicator, the Italian production would be more environmentally friendly than the Russian one, ceteris paribus. This means that, ceteris paribus, replacing one million euros of natural gas extracted in Russia with one million euros of natural gas extracted in Italy would decrease the PM10 by 2.58 (=57.5–54.92) Kg. Alternatively, the Russian production is more environmentally friendly at the global level in terms of terrestrial ecotoxicity (indicator 10): 4.61 kg 1.4-dichlorobenzene eq. vs. 34.76 kg 1.4-dichlorobenzene eq. generated by the Italian production (Table 4). Nevertheless, if we consider the local perspective, i.e., where this impact is generated, it can be noted that 3.92 kg 1.4-dichlorobenzene eq. (corresponding to the 85% of the overall impact) are released in Russia per million euro of output produced by the Russian industry vs. 2.86 kg 1.4-dichlorobenzene eq. (corresponding to the 8.3% of the overall impact) released in Italy by the Italian industry (Table 5).

Table 6 displays the effects of the Italian diversification strategies on the 14 indicators introduced in Table 3 computed at the Italian level (see Eq. (4)). The table highlights the total effect and also decomposes it according to its three main drivers: (1) the reduction of imports of natural gas from Russia; (2) the increase in national (Italian) production; and (3) the increase in exports from the rest of the world. For instance, considering the employment hours indicator, the table shows that 2.94E+06 new employment hours will be created in Italy, as the result of: (1) 2.90E+06 new employment hours thanks to the increase in the national production of natural gas; (2) 4.07E+04 new employment hours thanks to the increase in the imports of natural gas from the rest-of-the-world – these further hours are driven by the increase in the intermediate outputs provided by Italy to the rest-of-the-world countries, which will be required because of their higher production of natural gas; and (3) the reduction of 7.07E+03 h due to the lower imports of natural gas from Russia – such a reduction is driven by the lower demand of Italian intermediate products by Russia.

It can be noted that all the indicators are higher than zero. In particular, from the economic and social perspectives, increasing the national extraction of natural gas would create new value added and new employment at the national level. However, the Italian diversification strategy would decrease the environmental performance at the national level, mainly driven by the increase in the Italian production of natural gas. For instance, let us consider the PM10 indicator: at the national level, the PM10 emissions would rise by 9610 Kg, as the result of 9480 additional Kg due to the increase in the national production of natural gas, 534 additional Kg due to the increase in the natural gas import from the rest-of-the-world, and a reduction of 400 Kg thanks to the reduction in the natural gas imports from Russia.

Table 7 displays the effects of the Italian diversification strategies on the same indicators, in this case computed at the global level (see Eq. (6)). From the economic and social perspectives, the Italian diversification strategy would allow to create new value added (+562 M€) and new employment (+1.64 • 10^8 employment hours). Indeed, the negative

[9] Such an assumption is driven by the lack of data about which specific quantities will be supplied by each of these four countries.

[10] https://culturaeconsapevolezza.mase.gov.it/sites/default/files/2023-01/Piano_nazionale_contenimento_consumi_gas_naturale_MASE.pdf

[11] As a double check, this value is consistent with the price of natural gas between April and May 2021 (https://www.eex.com/)

Table 4
Numerical values of all the 14 indicators computed for the "natural gas extraction, excluding surveying" industry of several countries, according to Eq. (3). Data are per million euros of output.

#	Indicator	Unit	Italy	Russia	WF	WA	WM
1	Value Added	€	2.43E-01	7.53E-02	1.64E-01	1.29E-01	1.21E-01
2	Employment	1000 p.	3.78E-03	2.37E-03	1.80E-02	1.07E-02	1.53E-03
3	Employment hours	hr	7.50E+03	4.79E+03	3.95E+04	2.25E+04	4.01E+03
4	Damages to human health caused by climate change (H.A) | ECOINDICATOR 99 (H.A)	DALY	1.26E-01	1.10E-02	5.37E-02	3.79E-02	5.02E-02
5	Damage to Ecosystem Quality caused by ecotoxic emissions (H.A) | ECOINDICATOR 99 (H.A)	PDF × m^2 × yr	2.04E+03	5.35E+03	3.71E+04	3.49E+04	1.18E+04
6	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication (H.A) | ECOINDICATOR 99 (H.A)	PDF × m^2 × yr	6.29E+03	1.62E+03	6.32E+03	4.58E+03	3.36E+03
7	Freshwater aquatic ecotoxicity (FAETP inf) | Problem oriented approach: baseline (CML, 1999) | FAETP inf. (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq	1.71E+02	4.02E+02	8.60E+02	8.38E+02	3.38E+02
8	Marine aquatic ecotoxicity (MAETP inf) | Problem oriented approach: baseline (CML, 1999) | MAETP inf. (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq	7.06E+05	1.51E+06	2.54E+06	3.17E+06	1.33E+06
9	Climate change midpoint | ILCD recommended CF | Global warming potential 100 years	kg CO2eq	5.70E+01	8.66E+01	1.57E+02	1.61E+02	6.44E+01
10	Terrestrial ecotoxicity (TETP100) | Problem oriented approach: non baseline (CML, 1999) | TETP 100 (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq	3.48E+01	4.61E+00	4.12E+01	1.69E+01	1.38E+01
11	Photochemical oxidation (MIR; very high NOx) | Problem oriented approach: non baseline (CML, 1999) | MIR 1997; very high NOx (Carter, 1994, 1997, 1998;Carter, Pierce, Luo & Malkina, 1995)	kg formed ozone	6.28E+05	5.41E+04	2.82E+05	1.83E+05	2.47E+05
12	PM10	kg	3.23E+01	5.75E+01	1.89E+02	1.88E+02	8.56E+01
13	Particulate matter/Respiratory inorganics midpoint | ILCD recommended CF | emission-weighed average PM2.5 equivalent	kg PM2.5-eq	2.01E+01	4.45E+01	1.11E+02	1.25E+02	4.67E+01
14	Land use Crop, Forest, Pasture	km^2	1.75E-02	1.55E-02	4.46E-01	4.13E-02	1.63E-02

Table 5
Numerical values of all the 14 indicators computed for the "natural gas extraction, excluding surveying" industry of several countries, according to Eq. (4). Data are per million euros of output.

#	Indicator	Unit	Italy	Russia	WF	WA	WM
1	Value Added	€	1.46E-01	7.17E-02	1.50E-01	1.09E-01	1.13E-01
2	Employment	1000 p.	2.06E-03	2.15E-03	1.74E-02	1.02E-02	1.16E-03
3	Employment hours	hr	3.90E+03	4.34E+03	3.83E+04	2.12E+04	3.20E+03
4	Damages to human health caused by climate change (H.A) | ECOINDICATOR 99 (H.A)	DALY	1.01E-02	1.01E-02	5.09E-02	3.50E-02	4.93E-02
5	Damage to Ecosystem Quality caused by ecotoxic emissions (H.A) | ECOINDICATOR 99 (H.A)	PDF × m^2 × yr	1.26E+03	4.95E+03	2.93E+04	2.24E+04	1.16E+04
6	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication (H.A) | ECOINDICATOR 99 (H.A)	PDF × m^2 × yr	9.91E+02	1.46E+03	5.70E+03	4.25E+03	3.20E+03
7	Freshwater aquatic ecotoxicity (FAETP inf) | Problem oriented approach: baseline (CML, 1999) | FAETP inf. (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq	1.32E+02	3.88E+02	6.65E+02	5.31E+02	3.30E+02
8	Marine aquatic ecotoxicity (MAETP inf) | Problem oriented approach: baseline (CML, 1999) | MAETP inf. (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq	5.78E+05	1.46E+06	1.98E+06	2.23E+06	1.31E+06
9	Climate change midpoint | ILCD recommended CF | Global warming potential 100 years	kg CO2eq	4.99E+01	8.27E+01	1.22E+02	1.01E+02	6.33E+01
10	Terrestrial ecotoxicity (TETP100) | Problem oriented approach: non baseline (CML, 1999) | TETP 100 (Huijbregts, 1999 & 2000)	kg 1.4-dichlorobenzene eq	2.86E+00	3.91E+00	3.72E+01	9.65E+00	1.34E+01
11	Photochemical oxidation (MIR; very high NOx) | Problem oriented approach: non baseline (CML, 1999) | MIR 1997; very high NOx (Carter, 1994, 1997, 1998;Carter, Pierce, Luo & Malkina, 1995)	kg formed ozone	4.82E+04	4.94E+04	2.68E+05	1.69E+05	2.42E+05
12	PM10	kg	1.79E+01	5.49E+01	1.52E+02	1.38E+02	8.09E+01
13	Particulate matter/Respiratory inorganics midpoint | ILCD recommended CF | emission-weighed average PM2.5 equivalent	kg PM2.5-eq	1.27E+01	4.28E+01	8.61E+01	9.31E+01	4.39E+01
14	Land use Crop, Forest, Pasture	km^2	7.55E-05	1.48E-02	4.17E-01	4.02E-02	9.98E-03

consequences of reducing the imports from Russia are more than compensated by the positive consequences of increasing the national production of natural gas and increasing the imports from the rest-of-the-world countries. Unfortunately, such a strategy would result in a decrease in all the environmental performance indicators at the world level. Indeed, according to Table 4, producing one million euros of output of "natural gas extraction, excluding surveying" industry in Russia would generate 32.3 kg of PM10; producing the same amount in Italy would generate 57.5 kg (+78% compared to Russia), in African countries 189 kg (+485%), in Middle-East countries 85.6 kg (+165%), and in Asian countries 188 kg (+482%). Such a result can be due to the fact that different countries might adopt different production technologies (e.g., Cheng et al., 2023; Tokito, 2018; Wang et al., 2023). Perhaps, the technologies used by Russia are more advanced, in terms of environmental efficiency, than those used by the considered African and Asian countries (Economides and Wood, 2009; Gallego-álvarez et al., 2014; Orazalin and Mahmood, 2018; Shvarts et al., 2018; Usman et al., 2021).

Fig. 1 depicts the delineated impacts segmented by geographical location, with corresponding numerical data provided in Appendix A2. From the economic and social perspectives, it can be noted that Russia is the more negatively affected country; nevertheless, four other countries would face light negative consequences: Estonia, Latvia, Poland, and Slovakia. Greece and Cyprus, on the other hand, would experience slight adverse repercussions solely concerning the value added at the domestic level. In contrast, the most favorable impact is anticipated for Italy, in

Table 6
Effects on Italy of the Italian diversification strategy, decomposed for: (1) effect of cutting the imports of natural gas from Russia; (2) effect of increasing the national production of natural gas; and (3) effect of increasing the imports of natural gas from the rest of the world.

#	Indicator	Effect of: *Reducing imports from Russia*	Effect of: *Increasing the Italian production*	Effect of: *Increasing imports from RoW*	TOTAL EFFECT
1	Value added [M€]	-4.67E-01	1.09E+02	1.67E+00	**1.10E+02**
2	Employment [1000p]	-3.64E-03	1.53E+00	2.09E-02	**1.54E+00**
3	Employment hours [hr]	-7.04E+03	2.90E+06	4.07E+04	**2.94E+06**
4	Damages to human health caused by climate change [DALY]	-1.02E-01	7.48E+00	1.33E-01	**7.51E+00**
5	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m2×yr]	-4.92E+04	9.39E+05	6.85E+04	**9.58E+05**
6	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m2×yr]	-3.43E+04	7.37E+05	1.37E+04	**7.16E+05**
7	Freshwater aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	-5.32E+03	9.83E+04	2.97E+03	**9.59E+04**
8	Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	-2.38E+07	4.30E+08	7.78E+06	**4.14E+08**
9	Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]	-2.26E+03	3.71E+04	5.25E+02	**3.54E+04**
10	photochemical oxidation [kg formed ozone]	-3.03E+01	2.12E+03	1.80E+02	**2.27E+03**
11	Climate change midpoint [kg CO2-Equivalents]	-4.89E+05	3.58E+07	6.34E+05	**3.60E+07**
12	PM10 [Kg]	-4.00E+02	9.48E+03	5.34E+02	**9.61E+03**
13	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	-6.14E+02	1.33E+04	8.36E+02	**1.35E+04**
14	Land use Crop, Forest, Pasture [Km]	-9.85E-04	5.62E-02	1.06E-01	**1.61E-01**

Table 7
Global effects of the Italian diversification strategy, decomposed for: (1) effect of cutting the imports of natural gas from Russia; (2) effect of increasing the national production of natural gas; and (3) effect of increasing the imports of natural gas from the rest of the world.

#	Indicator	Effect of: *Reducing imports from Russia*	Effect of: *Increasing the Italian production*	Effect of: *Increasing imports from RoW*	TOTAL EFFECT
1	Value added [M€]	-4.67E+02	1.81E+02	8.48E+02	**5.62E+02**
2	Employment [1000p]	-1.47E+01	2.81E+00	8.60E+01	**7.41E+01**
3	Employment hours [hr]	-2.97E+07	5.57E+06	1.88E+08	**1.64E+08**
4	Damages to human health caused by climate change [DALY]	-6.82E+01	9.35E+01	2.78E+02	**3.03E+02**
5	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m2×yr]	-3.31E+07	1.52E+06	1.92E+08	**1.60E+08**
6	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m2×yr]	-1.00E+07	4.67E+06	3.19E+07	**2.65E+07**
7	Freshwater aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	-2.49E+06	1.27E+05	4.49E+06	**2.13E+06**
8	Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	-9.34E+09	5.25E+08	1.40E+10	**5.16E+09**
9	Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]	-5.36E+05	4.23E+04	8.25E+05	**3.31E+05**
10	photochemical oxidation [kg formed ozone]	-2.85E+04	2.58E+04	1.94E+05	**1.91E+05**
11	Climate change midpoint [kg CO2-Equivalents]	-3.35E+08	4.67E+08	1.44E+09	**1.57E+09**
12	PM10 [Kg]	-2.76E+05	1.50E+04	5.94E+05	**3.34E+05**
13	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	-3.56E+05	2.40E+04	9.93E+05	**6.61E+05**
14	Land use Crop, Forest, Pasture [Km]	-9.61E+01	1.30E+01	1.93E+03	**1.85E+03**

tandem with its newly engaged suppliers, notably Algeria, Egypt, and Congo. It can be noted that while for African countries the increase in employment is almost proportional to the increase in the value added, for Italy and Qatar the increase in employment is less than proportional to the increase in the value added. This phenomenon could be attributed to the relatively less labor-intensive nature of the natural gas extraction supply chains in Italy and Qatar as compared to their counterparts in African countries (e.g., Černý et al., 2024; Cooper et al., 2016).

Changes in environmental performance appear, on average, conversely proportional to changes in economic and social performances. In other words, countries whose economic and social performances increase tend to exhibit a decline in environmental performance. Nevertheless, some interesting – and sometimes counterintuitive – results can be highlighted:

- Despite a decrease in the value added, Russia would face a decrease also for two environmental performances, namely "Damages to human health caused by climate change" (+18.99 DALY) and "Climate change midpoint" (+1.01E+08 kg CO2-Equivalents). This result is fully counterintuitive; rather, one would have expected an

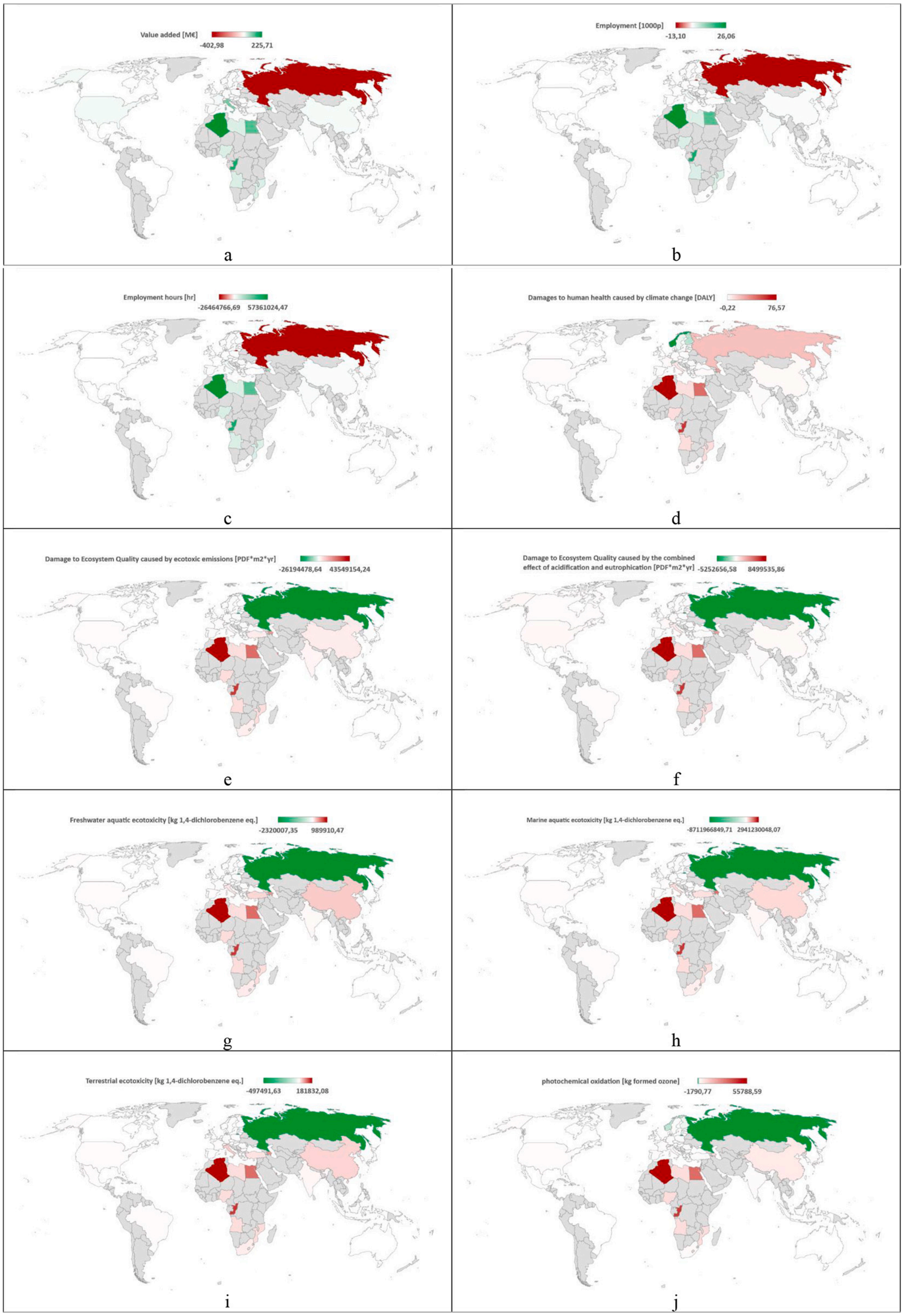

Fig. 1. Graphical representation of the effects of the Italian diversification strategy, computed at the country level, according to the GSD. Indicators considered: (a) Value added [€]; (b) Employment; (c) Employment hours; (d) Damages to human health caused by climate change [DALY]; (e) Damage to Ecosystem Quality caused by ecotoxic emissions [PDF × m^2 × yr]; (f) Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF × m^2 × yr]; (g) Freshwater aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]; (h) Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]; (i) Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]; (j) Photochemical oxidation [kg formed ozone]; (k) Climate change midpoint [kg CO2-Equivalents]; (l) Particulate matter/Respiratory inorganics midpoint [kg PM2.5-eq]; (m) PM10 [Kg]; (n) Land use Crop, Forest, Pasture [Km^2].

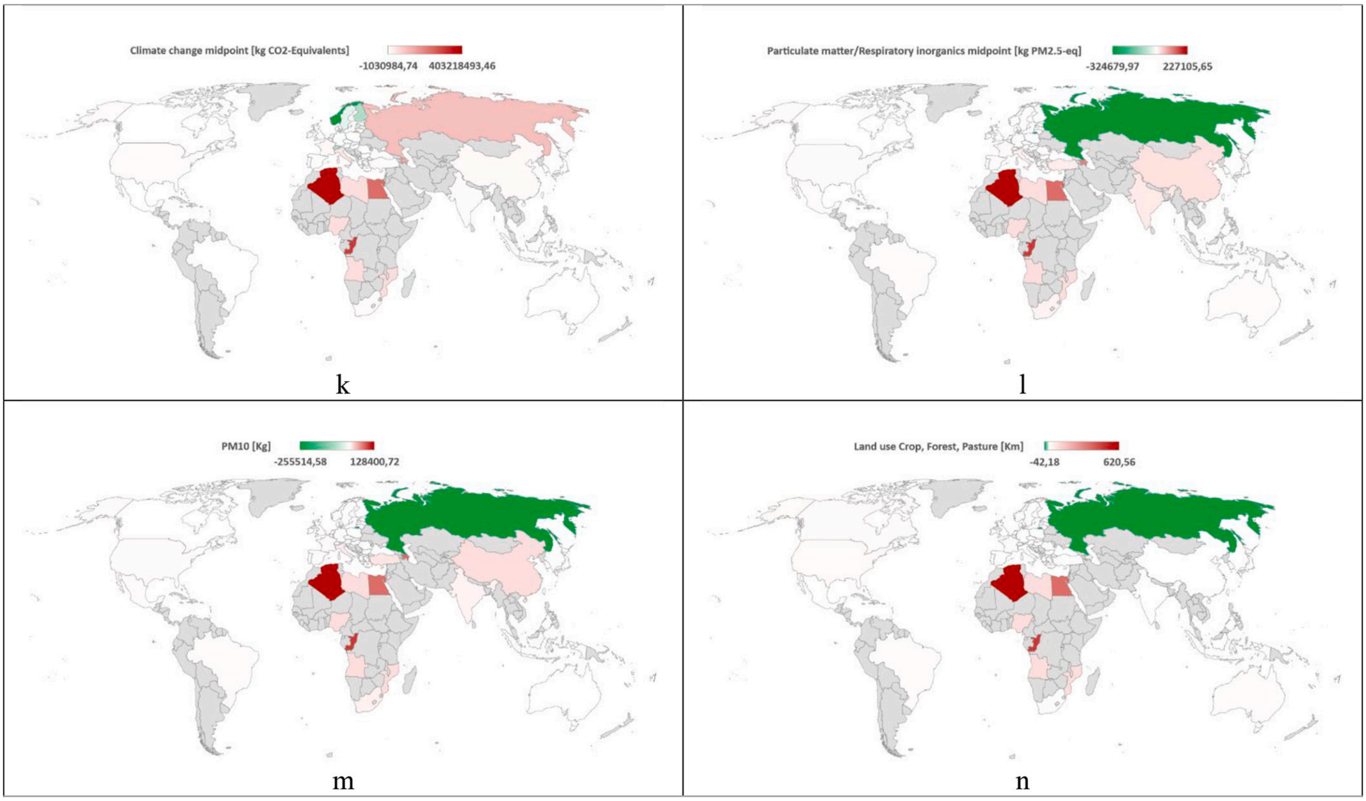

Fig. 1. (*continued*).

increase in all the indicators concerning the environmental performance in Russia, driven by the lower production of natural gas. However, it can be noted that the value of the "Damages to human health caused by climate change" indicator decreases by 62.36 DALY as the effect of the Italian reduction of natural gas imports from Russia (Table 11), while increases by 80.13 DALY as the effect of the increase in natural gas production in Italy (Table 12), and further increases by 1.21 DALY as the effect of the Italian increase in natural gas imports from other countries (Table 12). This outcome discloses the hidden role of Russia within the natural gas extraction supply chain in Italy, presumably involving the provision of intermediate products to Italian companies – underscored by the noteworthy rise of 38 million euros in Russia's value added attributed to Italy's amplified natural gas production (as indicated in Table 12). An analogous trend can be highlighted for the "Climate change midpoint" indicator.

- An opposite result can be found for Switzerland (−0.057 DALY, −273,109 kg CO2-Equivalents), Finland (−0.052 DALY, −286,439 kg CO2-Equivalents), and Norway (−0.2196 DALY, −1,030,987 kg CO2-Equivalents): in these countries, the increase of such two indicators couples with an increase in the value added. Norway also shows an important decrease in "Photochemical oxidation" (−395.29 kg formed ozone). Hence, these countries would benefit from the Italian switching strategy from both the economic and environmental perspectives, ceteris paribus.
- China shows an increase in the value of the three ecotoxicity indicators (i.e., "Freshwater aquatic ecotoxicity", "Marine aquatic ecotoxicity", "Terrestrial ecotoxicity"), as well as in the value of the two particular matter indicators (i.e., "Particulate matter/Respiratory inorganics midpoint" and "PM10"). From the numerical perspective, such an increase is similar to what happens in Angola, a country that is directly involved in the Italian diversification strategy. Such an increase might be due to the role that China plays in the African and Asian supply chains of natural gas extraction, perhaps because of providing these countries with intermediate products (e.g., Cahen-Fourot et al., 2020; Deng et al., 2021; Xu et al., 2023) – indeed, notice the increase of 7 M€ in the Chinese value added driven by the Italian increase in natural gas imports from other countries (Table 12).

5. Discussion, implications, and conclusions

This paper proposes the GSD to assess the sustainability implications, at the global and local levels, of an energy switching strategy undertaken by a given country. From the methodological perspective, the GSD is useful to map the economic, environmental, and social sustainability of the global production chain of single industries. The proposed tool relies on the input-output approach and exploits the MRIO tables provided by the EXIOBASE database (Stadler et al., 2018). The GSD of a given industry is computed on an optimal set of 14 non-redundant indicators (see Table 3), which take into account the three dimensions of sustainability.

From the theoretical perspective, the GSD has several strengths: (1) thanks to its high granularity, it can be used to assess multiple impacts at the level of a single country; (2) it allows to underscore hidden and even counterintuitive impacts, which would have been difficult to find using traditional methods of analysis; and (3) thanks to its high flexibility, it can be adopted to model many other strategies, different from those considered in this paper. Furthermore, although GSD considers 14 indicators, the mathematical approach used to compute them can possibly be adopted for many other indicators.

As a case study, GSD is used to assess the consequences of the Italian energy diversification strategy, driven by the conflict between Russia and Ukraine, on the three key dimensions of sustainability. Thanks to the GSD, it is possible to underscore the extent to which the energy replacement strategy designed by the Italian government will create new value added and employment at both the national and global levels, but is detrimental in terms of environmental performance worldwide.

Specifically, the findings offer novel insights into the environmental repercussions stemming from the Russia-Ukraine conflict. To date, scholarly investigations have predominantly concentrated on evaluating the direct environmental consequences (Racioppi et al., 2022; Rawtani et al., 2022); however, our study sheds light on the potential indirect environmental ramifications resulting from the redirection of energy sourcing away from Russia towards other nations. Indeed, the extensive integration of natural gas within global supply chains (see, e.g., Kan et al., 2020, Kan et al., 2019) underscores the necessity of considering indirect impacts to avoid underestimating their effects.

Moreover, these findings emphasize the imperative of transitioning towards low-carbon energy sources, a stance corroborated by a substantial body of literature (e.g., Anekwe et al., 2024; Bogdanov et al., 2021; Healy and Barry, 2017; Papadis and Tsatsaronis, 2020; Zhang et al., 2024), consistently with the Sustainable Development Goal 7 (Ensure access to affordable, reliable, sustainable and modern energy for all).[12] Indeed, from an environmental perspective, switching from Russia to another supply of natural gas can be an effective solution only in the short period, aimed at ensuring energy security to citizens and companies. In this regard, multiple solutions exist for reducing natural gas consumption in Italy in the short term, as outlined by Pastore et al. (2022). Nonetheless, over the long term, nations ought to advocate for the substitution of fossil fuels with renewable energy sources. In this respect, numerous studies in the literature have underscored the potential environmental benefits stemming from such a transition (Udemba and Tosun, 2022; Vögele et al., 2023; Zakari et al., 2022). Furthermore, a transition towards renewable energy sources holds the potential to enhance the resilience and stability of the energy landscape by shielding nations from the inherent volatility of conventional energy markets and geopolitical tensions (Carfora and Scandurra, 2024).

Beyond its relevance to the particular case study under scrutiny, policymakers can leverage the GSD for conducting preliminary analyses and hypothetical scenarios, aimed at delineating strategies oriented towards both short-term and long-term objectives. Regarding the short-term outlook, where policymakers must ensure energy security for companies and households, the GSD can aid policymakers in a specific country in discerning the most suitable alternative suppliers of natural gas to Russia, considering their (indirect) environmental impact at the national level. In this context, the efficacy of these strategies in advancing all Sustainable Development Goals – not solely those pertaining to energy – can be readily evaluated. Regarding the long-term outlook, the GSD can assist policymakers in the transition towards renewable and cleaner energy sources, aligning with the Sustainable Development Goals. For example, it can support them in formulating innovative energy strategies aimed at shifting from natural gas to renewable energy sources. In both scenarios, the anticipated impacts of these strategies at both the national and global levels, encompassing considerations beyond the economic sphere, can be forecasted.

This paper has several limitations that should be acknowledged. First, our study relies on the input-output methodology, which could be subject to several uncertainties, related to data quality, as well as assumptions and simplifications. In our specific case, EXIOBASE provides MRIO tables with data updated up to 2011, while data concerning the upcoming years are just forecasts. Nevertheless, EXIOBASE is recognized as a reliable database for input-output analysis – with reference to both real and forecasted data – and has driven many contributions in the literature (Tukker et al., 2018), even regarding the impacts of the Russia-Ukraine conflict (Chai et al., 2024; Martínez-García et al., 2023; Zhang et al., 2023). Furthermore, Exiobase is quite well aligned with the most popular multi-regional input–output (MRIO) databases (Giljum et al., 2019; Moran and Wood, 2014; Steubing et al., 2022). Even though our study is based on forecasted data, the methodology still remains valid and can be applied to the new data, once they will become available. Future studies could be devoted to conduct uncertainty analyses (Lenzen et al., 2010; Yamakawa and Peters, 2009) to further refine our results. Furthermore, EXIOBASE is used as data source to build the GSDs, whose indicators are constrained by information available in the database. Other indicators could be used to assess the global sustainability, if other databases are used as a data source.

Our study relies on a static input-output model. Although these models have been proven effective to study the impact that exogenous shocks would play on the economic structure and environmental performances at the country level (Petrella and Santoro, 2011; Rocco et al., 2020), more recently several authors have proposed to study these dynamics via dynamic input-output models (Galbusera and Giannopoulos, 2018; Pichler and Farmer, 2022). In this context, static input-output models might exhibit limitations in capturing dynamic processes, such as price fluctuations, and they presuppose an immediate transition to a new scenario, thereby disregarding transitional dynamics that could be more effectively explored through alternative model frameworks. In this regard, future studies could be conducted by adopting dynamic input-output models.

Finally, future studies could adopt the GSD to assess the sustainability impacts of other kinds of energy strategies, such as the replacement of fossil fuels with green energy, as well as to assess which is the best scenario in terms of different energy mix.

CRediT authorship contribution statement

Michele De Nicolò: Writing – review & editing, Writing – original draft, Software, Investigation, Data curation, Conceptualization. **Luca Fraccascia:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Pierpaolo Pontrandolfo:** Writing – review & editing, Supervision.

Declaration of competing interest

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

Data availability

Data are available in appendix

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[12] https://sdgs.un.org/goals/goal7

Appendix A1: Pieces of the S matrix and the EH matrix presented in Section 3.2

Table 8
Part of the S matrix – Eq. (2) – computed with respect to "employment hours" indicator for the "natural gas extraction, excluding surveying" industry in Russia and Italy (data in employment hours per million €). The last row is computed according to Eq. (3).

		Russia	…	Italy
Russia	Processing of Food products nec	1.1933	…	0.0066
	Manufacture of beverages	0.3622	…	0.0017
	Manufacture of fish products	0.8710	…	0.0055
	Manufacture of tobacco products	0.0615	…	0.0003
	Manufacture of textiles	1.8654	…	0.0130
	Manufacture of wearing apparel; dressing and dyeing of fur	0.6231	…	0.0023
	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	0.2609	…	0.0029
	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	1.4126	…	0.0112
…	…	…	…	…
Italy	Processing of Food products nec	0.0002	…	0.5616
	Manufacture of beverages	0.0001	…	0.1019
	Manufacture of fish products	0.0001	…	0.5426
	Manufacture of tobacco products	0.0000	…	0.0121
	Manufacture of textiles	0.0056	…	4.2889
	Manufacture of wearing apparel; dressing and dyeing of fur	0.0004	…	1.4780
	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	0.0017	…	0.8390
	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0.0016	…	1.7268
	Sum	**4791.83**		**7498.73**

Table 9
Employment hours required by all the industries of each country (over the rows) per economic unit of output produced by the Russian (first column) and Italian (second column) "natural gas extraction, excluding surveying" industry. Data is computed according to Eq. (4).

	Russia	Italy
AT	0.44	5.72
BE	0.46	12.22
BG	2.60	9.43
CY	0.27	2.31
CZ	1.35	6.03
DE	2.79	39.20
DK	0.15	2.13
EE	0.75	0.66
ES	3.18	187.11
FI	0.87	2.51
FR	1.35	26.57
GR	1.63	6.10
HR	0.31	19.23
HU	1.12	12.09
IE	0.61	17.21
IT	1.14	3904.24
LT	2.36	2.25
LU	0.06	1.93
LV	0.92	1.07
MT	0.18	0.81
NL	1.06	13.50
PL	7.54	23.63
PT	0.36	5.46
RO	1.32	25.56
SE	0.53	3.50
SI	0.55	8.71
SK	2.13	6.29
GB	1.78	33.04
US	2.08	74.15
JP	0.59	3.48
CN	15.00	68.83
CA	0.60	3.93
KR	1.20	4.84
BR	1.96	25.49
IN	16.07	160.01
MX	1.39	30.74
RU	4338.63	299.42
AU	0.24	1.16
CH	1.09	20.99
TR	4.97	18.53
TW	0.92	5.33
NO	0.14	4.52
ID	2.21	29.84
ZA	1.03	23.41
WA	85.74	338.04
WL	6.62	174.64
WE	246.10	161.62
WF	20.61	1445.37
WM	6.84	225.88
Sum	**4791.83**	**7498.73**

Appendix A2: Detailed numerical results

Table 10
Detailed results, decomposed by country, of the Italian diversification strategy. The first row displays the values at the global level.

	Value added [M€]	Employment [1000p]	Employment hours [hr]	Damages to human health caused by climate change [DALY]	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m^2 × yr]	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m^2 × yr]	Freshwater aquatic ecotoxicity [kg 1.4-dichloro-benzene eq.]	Marine aquatic ecotoxicity [kg 1.4-dichloroben-zene eq.]	Terrestrial ecotoxicity [kg 1.4-dichloroben-zene eq.]	photochemical oxidation [kg formed ozone]	Climate change midpoint [kg CO2-Equivalents]	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	PM10 [Kg]	Land use Crop, Forest, Pasture [Km^2]
	561.8874	**74.12489**	**1.64E+08**	**303.3143**	**1.6E+08**	**26,528,775**	**2,125,470**	**5.16E+09**	**331,059.6**	**191,137.5**	**1.57E+09**	**660,925.9**	**333,560.1**	**1846.651**
AO	28.21343	3.257837	7,170,150	9.571553	5,443,661	1,062,445	123,739.2	368,000,000	22,729.08	6973.595	50,402,465	28,388.29	16,050.14	77.56999
AT	0.341257	0.004118	6250.441	0.011963	5085.133	428.5299	491.8481	687,793.2	41.30473	11.35932	57,939.24	47.22344	38.52682	0.000854
AU	0.773601	0.007151	12,587.58	0.021103	25,615	6189.489	788.8981	1,398,529	237.375	93.7875	96,496.51	449.6158	234.7711	1.265184
AZ	84.06423	7.970116	16,589,317	27.03315	17,177,204	3,277,920	404,375.4	1,680,000,000	75,458.73	7594.772	131,000,000	111,046	76,064.01	33.17786
BE	1.415247	0.014931	26,392.25	0.0778	31,460.35	1234.708	1211.083	4,040,869	329.6226	84.41767	380,704.1	135.7362	48.75133	0.044235
BG	0.013278	0.007351	14,966.33	0.074221	69,403.59	18,846.79	4471.898	11,467,133	498.2969	10.68768	346,718.8	580.0292	149.292	0.865405
BR	0.303535	0.031719	70,117.29	0.117728	227,027.4	61,292.9	4818.912	13,790,737	856.4698	108.2584	578,626.4	970.4419	543.7669	3.352141
CA	0.142798	0.006792	12,627.57	0.072724	−7392.23	31,570.41	−1186.44	−6,331,342	−638.753	28.48452	333,414.2	187.7613	30.5512	7.77082
CG	173.0424	19.9814	43,976,920	58.70553	33,387,787	6,516,331	758,933.7	2,250,000,000	139,405	42,771.38	309,000,000	174,114.9	98,440.86	475.7626
CH	1.581999	0.008294	15,896.35	−0.057	22,300.02	−4563.01	850.8582	2,166,662	402.932	141.0225	−273,109	547.9704	269.1996	0.029953
CN	7.092034	0.361571	872,891.2	1.527197	3,213,035	179,717.3	199,601.5	414,000,000	29,945.17	4323.771	7,271,360	26,161.62	15,876.43	0.320748
CY	−0.01112	0.000408	1061.132	−0.00013	592.1835	1005.351	59.45881	245,054.4	24.56896	−0.62753	−2079.05	11.95188	5.70628	0.016966
CZ	0.087552	0.000777	1159.355	0.008906	2980.906	833.1697	178.1797	568,343.6	40.56302	12.86843	40,850.22	71.95762	36.56025	0.01187
DE	3.198022	0.042908	56,004.77	0.155739	63,716.31	27,252.11	3936.494	18,344,685	1492.142	59.8434	690,384.5	700.9681	427.122	0.26266
DK	0.297193	0.002709	4888.706	−0.00057	11,894.15	1777.88	580.6047	1,767,542	263.7994	70.74652	−6500.75	261.7544	127.5539	0.075523
DZ	225.7074	26.06269	57,361,199	76.57243	43,549,288	8,499,562	989,913.5	2,940,000,000	181,832.6	55,788.76	403,000,000	227,106.3	128,401.1	620.5599
EE	−0.09043	−0.00134	−2728.91	−0.00419	111.1427	−793.355	21.29149	77,300.77	9.657669	−3.68075	−21,830.8	−15.8846	−11.4084	−0.00012
EG	131.6627	15.20324	33,460,700	44.66725	25,403,751	4,958,078	577,449.5	1,720,000,000	106,069	32,543.44	235,000,000	132,478.7	74,900.65	361.9933
ES	3.543371	0.122989	167,264	0.114157	139,319.5	−15,695.5	3793.016	240,243.4	−688.954	193.6283	538,647.1	565.3111	387.8911	1.10387
FI	0.012037	0.000369	777.2415	−0.05213	−738.682	−5476.31	−192.464	−1,006,551	−81.2289	−102.44	−286,439	1.902261	−1.92731	0.01064
FR	8.232438	0.086727	134,961.1	1.444877	127,448.5	210,025.9	4636.745	14,404,576	1074.205	587.7549	7,117,223	2296.702	1220.889	6.806255
GB	3.637507	0.041435	76,826.58	0.019758	79,909.05	16,301.01	2845.291	9,192,666	737.1273	78.45017	31,868.09	940.0811	489.8475	0.383179
GR	−0.0809	0.002623	5223.563	0.06398	90,696.24	20,137.43	5387.961	17,778,634	1892.292	489.2172	300,089.3	2079.889	1192.174	0.395771
HR	0.109529	0.007126	14,427.45	0.044988	2227.879	−953.24	153.857	597,784.1	17.22665	7.749148	219,571.9	0.48404	−11.2145	0.007661
HU	0.211072	0.005105	10,022.63	0.003552	3965.264	−340.171	173.1929	326,606.8	31.47202	13.27591	14,815.11	42.06521	18.83933	0.010681
ID	0.485828	0.0782	205,294.3	0.317613	171,608.9	9568.571	5067.696	22,040,630	1621.786	716.1637	1,675,290	2737.391	1707.693	0.096952
ID	14.01071	1.328353	2,764,886	4.505524	2,862,867	546,319.9	67,395.89	281,000,000	12,576.45	1265.795	21,773,730	18,507.67	12,677.33	5.529644
IE	1.04303	0.008609	16,960.72	0.031883	109,573.5	4179.721	3570.317	8,427,793	1252.867	523.0168	163,278.6	1578.114	837.0194	0.005165
IN	2.78757	0.479704	1,164,303	0.929052	1,779,474	99,894.59	20,649.45	90,857,873	5742.555	651.423	4,422,187	19,135.22	5698.123	1.144342
IT	109.9098	1.544893	2,935,730	7.507949	958,454.8	716,245.3	95,931.64	414,000,000	35,391.51	2273.614	35,958,525	13,514.99	9609.583	0.161162
JP	1.734119	0.02534	51,678.71	0.04041	154,300.1	−15,952.4	−425.524	−3,532,918	−80.1612	996.2066	190,858.4	1746.311	968.8539	0.0006
KR	1.134652	0.018243	44,510.85	0.094808	51,452.62	9112.411	2457.332	9,748,591	598.241	131.9902	451,221.3	420.5156	249.454	0.00018
LT	−0.1957	−0.0027	−5659.77	0.01532	2871.014	6009.348	121.2177	436,345.9	45.82313	17.26275	68,107.57	67.40673	5.040383	0.357471
LU	0.288559	0.001171	2402.443	0.003804	7045.338	638.8149	447.4319	1,183,573	77.43247	0.638952	17,889.32	56.40801	49.33998	0.004025
LV	−0.0851	0.000357	338.628	−0.01844	2109.119	1850.135	59.62609	130,984.7	23.92868	−1.49071	−90,699.5	3.445459	−24.562	0.804072
LY	28.21343	3.257837	7,170,150	9.571553	5,443,661	1,062,445	123,739.2	368,000,000	22,729.08	6973.595	50,402,465	28,388.29	16,050.14	77.56999
MT	0.004766	0.000729	1457.265	−0.00119	7624.929	504.2452	210.1325	586,201.3	98.04198	38.83471	−5772.01	133.8292	72.5647	0.001423
MX	0.198749	0.024602	46,703.32	0.003949	324,541.1	4009.048	6380.904	19,744,666	1242.04	96.79157	15,441.64	806.2476	570.9002	0.893605
MZ	28.21343	3.257837	7,170,150	9.571553	5,443,661	1,062,445	123,739.2	368,000,000	22,729.08	6973.595	50,402,465	28,388.29	16,050.14	77.56999
NG	28.21343	3.257837	7,170,150	9.571553	5,443,661	1,062,445	123,739.2	368,000,000	22,729.08	6973.595	50,402,465	28,388.29	16,050.14	77.56999

(*continued on next page*)

Table 10 (*continued*)

	Value added [M€]	Employment [1000p]	Employment hours [hr]	Damages to human health caused by climate change [DALY]	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m^2 × yr]	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m^2 × yr]	Freshwater aquatic ecotoxicity [kg 1.4-dichloro-benzene eq.]	Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]	photochemical oxidation [kg formed ozone]	Climate change midpoint [kg CO2-Equivalents]	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	PM10 [Kg]	Land use Crop, Forest, Pasture [Km^2]
NL	3.224961	0.014566	25,592.4	0.389947	67,043.66	8954.527	3777.124	7,704,682	701.1043	154.4081	1,909,172	708.5935	440.7589	0.125875
NO	2.138963	0.002085	4235.962	−0.21963	8025.873	−70,665.7	771.7372	−494,950	188.3484	−395.285	−1,030,987	260.1221	80.1775	−0.00003
PL	−0.23889	−0.00317	−8320.08	0.010237	5369	6346.615	471.8205	954,661.1	58.94906	5.396411	34,344.12	32.32346	1.349771	0.279919
PT	0.735459	0.021168	41,512.04	0.064896	72,122.21	7308.318	2859.483	6,166,506	69.12436	33.27538	303,962.9	576.1881	511.9484	0.051692
QA	53.87985	0.60791	1,632,144	19.8408	19,706,407	1,527,873	419,131.4	1,420,000,000	82,964.33	9538.672	97,866,624	81,198.26	56,182.78	6.543875
RO	0.288741	0.044554	83,797.86	0.036578	13,595.97	31,525.01	677.7285	1,376,100	100.5926	28.44569	160,895.7	223.5023	68.69995	2.55845
RU	−402.98	−13.0959	−2.60E+07	18.98614	−26,000,000	−5,252,670	−2,320,011	−8,700,000,000	−497,492	−1790.8	101,000,000	−324,680	−255,515	−42.185
SE	0.599304	0.002947	5608.315	−0.01551	11,650.32	1193.863	272.9117	1,039,531	34.92134	−9.86744	−96,975.5	59.85989	45.2456	0.045496
SI	0.136353	0.002294	4581.265	0.015784	732.4483	416.9487	77.4847	179,267	15.15865	14.90912	87,374.57	9.855203	7.591472	0.014745
SK	−0.17153	−0.00264	−5858.68	−0.00283	2376.611	−915.194	87.90455	165,059.4	32.48705	−23.7556	−14,440.3	35.76766	14.9352	−0.00017
TR	1.644176	0.03891	90,619.87	1.145927	3,069,434	116,207	152,643.6	336,000,000	19,158.17	623.1003	5,454,228	14,826.09	12,598.29	0.400605
TW	0.733847	0.024381	52,732.54	0.08661	69,910.95	7120.967	2549.907	6,319,650	310.3975	220.5042	411,089.9	570.7414	416.8674	0.017517
US	8.55148	0.095349	181,800	0.406176	135,085.7	213,955.2	5472.005	12,817,702	585.6102	246.6922	1,866,516	2658.431	1457.831	10.78277
ZA	1.219867	0.051162	114,438.5	0.367618	2,813,132	66,655.73	72,047.29	187,000,000	12,022.71	913.4026	1,813,427	9744.669	7220.863	1.678723

Table 11
Detailed effects, decomposed by country, of the reduction of natural gas imports from Russia. The first row displays the values at the global level.

	Value added [M€]	Employment [1000p]	Employment hours [hr]	Damages to human health caused by climate change [DALY]	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m² × yr]	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m² × yr]	Freshwater aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]	photochemical oxidation [kg formed ozone]	Climate change midpoint [kg CO2-Equivalents]	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	PM10 [Kg]	Land use Crop. Forest. Pasture [Km²]
	−466.692	**−14.665**	**-3E+07**	**−68.161**	**−3.3E+07**	**-1E+07**	**−2,490,198**	**−9.3E+09**	**−536,397**	**−28,544.4**	**−3.4E+08**	**−356,165**	**−275,849**	**−96.0516**
AO	−0.01808	−0.00263	−5599.55	−0.00973	−130.712	−475.183	−7.27564	−23,842.6	−1.53957	−9.63869	−54,078.2	−7.38525	−4.77737	−0.02523
AT	−0.18264	−0.00162	−2743.76	−0.00962	−714.851	−1171.29	−29.6405	−88,224.9	−3.62556	−4.19477	−46,912	−10.1567	−8.72171	−0.0001
AU	−0.14577	−0.00087	−1474.93	−0.04061	−1785.24	−4615.89	−192.389	−862,608	−68.9613	−26.5317	−209,358	−53.6626	−44.0767	−0.03139
AZ	−2.32963	−0.21097	−455,241	−0.7974	−1,221,320	−270,822	−30,026.2	−99,000,000	−6765.69	−642.077	−3,925,470	−4569.29	−2823.77	−1.97461
BE	−0.29473	−0.00181	−2875.2	−0.04358	−1073.95	−12,395.8	−52.7545	−495,400	−23.8139	−24.805	−211,696	−174.684	−124.235	−0.00025
BG	−0.13855	−0.00755	−16,121.7	−0.01813	−1140.41	−2617.76	−84.7767	−191,157	−9.25583	−6.95198	−87,284.9	−30.0671	−21.98	−0.0439
BR	−0.27537	−0.0053	−12,147.3	−0.00715	−4769.57	−1643.43	−306.201	−1,239,675	−113.574	−3.69832	−34,399.9	−34.9431	−23.5149	−0.01056
CA	−0.60671	−0.00211	−3687.71	−0.04107	−17,971.7	−10,535.9	−1955.54	−8,669,929	−832.623	−10.7816	−196,507	−201.721	−148.166	−0.04887
CG	−0.11086	−0.01614	−34,343.9	−0.05965	−801.701	−2914.45	−44.6239	−146,235	−9.4427	−59.1173	−331,679	−45.2962	−29.3012	−0.15477
CH	−0.49091	−0.00331	−6734.63	−0.08167	−541.734	−9906.08	−43.2229	−152,312	−3.63514	−21.4224	−390,415	−37.2548	−24.7862	−0.00055
CN	−0.74922	−0.0361	−92,888.4	−0.22551	−33,657.7	−28,874.1	−2615.01	−8,322,288	−740.15	−62.9226	−1,074,354	−714.932	−394.763	−0.00171
CY	−0.02718	−0.00081	−1664.62	−0.00228	−75.8956	−152.793	−8.2095	−35,674.2	−3.26859	−1.31758	−11,919.4	−0.71034	−0.41424	−4.7E-10
CZ	−0.20094	−0.0046	−8332.3	−0.02127	−713.115	−2335.31	−57.9238	−151,596	−9.69343	−8.77541	−103,089	−39.1311	−26.7518	−0.0022
DE	−1.37471	−0.013	−17,290.5	−0.13275	−4975.57	−14,422.6	−331.031	−1,432,826	−111.941	−103.55	−681,837	−119.045	−84.3641	−0.00044
DK	−0.12403	−0.00047	−936.321	−0.01054	−676.597	−2941.23	−41.8868	−199,135	−19.8902	−8.18221	−53,358.7	−46.4284	−36.1841	−0.00025
DZ	−0.1446	−0.02106	−44,796.4	−0.07781	−1045.7	−3801.46	−58.2051	−190,741	−12.3166	−77.1095	−432,625	−59.082	−38.219	−0.20188
EE	−0.1301	−0.0023	−4657.69	−0.00694	−386.527	−1396.46	−25.2399	−172,424	−8.80485	−5.3296	−35,002.9	−28.5277	−20.7024	−0.0035
EG	−0.08435	−0.01228	−26,131.2	−0.04539	−609.99	−2217.52	−33.953	−111,266	−7.18466	−44.9806	−252,365	−34.4645	−22.2944	−0.11776
ES	−0.74727	−0.00987	−19,700.6	−0.14571	−45,200.2	−59,910.8	−4903.86	−22,000,000	−2114.05	−40.7742	−694,962	−812.308	−522.437	−0.00215
FI	−0.32721	−0.00284	−5385.21	−0.08107	−4810.53	−10,750.8	−445.486	−2,027,557	−177.469	−131.57	−428,089	−109.777	−76.3682	−0.00302
FR	−1.06483	−0.00556	−8333.34	−0.16071	−2797.61	−23,012.6	−195.774	−877,235	−17.1423	−179.06	−766,366	−142.395	−126.487	−0.00076
GB	−0.76605	−0.00573	−11,002.2	−0.17602	−1175.86	−19,086.7	−78.0951	−475,802	−17.4635	−87.8305	−901,680	−118.707	−86.1999	−0.00519
GR	−0.44911	−0.00438	−10,083.4	−0.03573	−23,264.6	−11,784.6	−2565.38	−12,000,000	−1090.07	−13.3822	−171,592	−273.087	−166.461	−0.00018
HR	−0.04035	−0.0009	−1944.31	−0.01586	−314.021	−5159.99	−19.5704	−233,582	−8.65684	−5.76735	−77,464.2	−66.2662	−50.7114	−0.00058
HU	−0.12151	−0.00329	−6912.74	−0.01403	−408.643	−2227.49	−26.3257	−102,366	−5.31167	−7.1533	−70,048.9	−29.0642	−21.0677	−0.00154
ID	−0.09745	−0.0055	−13,676.3	−0.04602	−1126.83	−13,327.8	−103.148	−549,477	−30.1508	−14.3298	−219,398	−176.169	−131.673	−0.000018
ID	−0.38827	−0.03516	−75,873.5	−0.1329	−203,553	−45,137	−5004.37	−17,000,000	−1127.62	−107.013	−654,245	−761.548	−470.628	−0.3291
IE	−0.96489	−0.00196	−3759.64	−0.06727	−1506.31	−15,913.5	−112.193	−521,103	−17.8602	−29.9816	−323,767	−101.205	−82.8599	−0.00019
IN	−0.56348	−0.04113	−99,547.6	−0.02317	−13,425.6	−5935.15	−944.843	−2,870,809	−259.183	−25.273	−110,686	−486.236	−307.436	−0.00227
IT	−0.46668	−0.00364	−7037.8	−0.10211	−49,216	−34,263.4	−5323.85	−24,000,000	−2259.9	−30.3208	−488,927	−614.492	−399.519	−0.00099
JP	−0.38072	−0.00176	−3662.77	−0.09497	−80,429.5	−47,464.4	−8771.3	−39,000,000	−3753.5	−29.3286	−453,560	−848.68	−683.356	−0.0000065
KR	−0.24949	−0.003	−7428.39	−0.01862	−1112.52	−2007.77	−65.1722	−237,862	−12.0293	−6.1419	−88,555	−18.4	−9.29188	−9.9E-09
LT	−0.33759	−0.00708	−14,619.2	−0.01221	−598.206	−3787.44	−41.6651	−161,880	−9.424	−6.73019	−58,625.2	−65.9844	−50.5192	−0.03097
LU	−0.05992	−0.00018	−372.751	−0.0043	−152.993	−624.895	−11.1826	−33,885.1	−2.53679	−1.35409	−20,686.8	−1.56298	−1.19932	−0.00000049
LV	−0.13683	−0.00274	−5720.77	−0.03229	−1134.78	−4834.73	−70.3383	−274,083	−4.83666	−7.61874	−153,866	−52.2553	−47.7145	−0.00249
LY	−0.01808	−0.00263	−5599.55	−0.00973	−130.712	−475.183	−7.27564	−23,842.6	−1.53957	−9.63869	−54,078.2	−7.38525	−4.77737	−0.02523
MT	−0.04656	−0.00055	−1115.42	−0.00214	−4.43201	−64.4128	−0.45751	−1436.08	−0.1095	−0.20967	−10,249.7	−0.27359	−0.09878	−0.000022
MX	−0.05675	−0.00346	−8589.79	−0.02567	−16,799.1	−13,625.9	−504.456	−2,147,640	−140.685	−15.1647	−124,775	−212.286	−163.048	−0.0004
MZ	−0.01808	−0.00263	−5599.55	−0.00973	−130.712	−475.183	−7.27564	−23,842.6	−1.53957	−9.63869	−54,078.2	−7.38525	−4.77737	−0.02523
NG	−0.01808	−0.00263	−5599.55	−0.00973	−130.712	−475.183	−7.27564	−23,842.6	−1.53957	−9.63869	−54,078.2	−7.38525	−4.77737	−0.02523
NL	−0.44649	−0.00381	−6583.09	−0.0958	−1098.56	−15,014.7	−86.3179	−483,013	−33.6695	−25.7923	−463,031	−80.3479	−60.5998	−0.00528
NO	−0.08842	−0.00047	−859.634	−0.40201	−2169.14	−85,063.1	−223.653	−1,675,099	−53.2722	−505.672	−1,914,609	−433.799	−350.393	−0.0001
PL	−0.75744	−0.02097	−46,693.3	−0.06533	−5229.46	−5985.46	−486.194	−922,078	−61.8391	−25.7374	−316,641	−226.144	−143.257	−0.00951
PT	−0.08777	−0.00101	−2243.44	−0.03193	−7615.89	−6921.6	−833.83	−3,694,114	−358.787	−11.8415	−158,286	−106.734	−74.3861	−0.00015
QA	−1.30249	−0.0154	−42,385.5	−0.46302	−35,181.4	−63,576.7	−2010.46	−7,265,608	−570.4	−132.008	−2,229,954	−576.427	−363.405	−0.16737
RO	−0.09105	−0.0038	−8203.58	−0.01721	−884.008	−3410.46	−73.0772	−193,680	−10.3612	−3.49219	−82,498.1	−55.363	−32.5785	−0.000017
RU	−443.877	−13.3056	−27,000,000	−62.3573	−31,000,000	−9,038,007	−2,405,833	−9,000,000,000	−512,237	−24,231.8	−310,000,000	−340,175	−265,195	−91.6211

(*continued on next page*)

Table 11 (*continued*)

	Value added [M€]	Employment [1000p]	Employment hours [hr]	Damages to human health caused by climate change [DALY]	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m^2 × yr]	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m^2 × yr]	Freshwater aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]	photochemical oxidation [kg formed ozone]	Climate change midpoint [kg CO2-Equivalents]	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	PM10 [Kg]	Land use Crop. Forest. Pasture [Km^2]
SE	−0.18653	−0.0017	−3275.23	−0.03119	−2587.04	−1874.39	−251.45	−1,026,390	−93.8484	−25.1259	−171,950	−32.1464	−22.6853	−0.00055
SI	−0.14008	−0.00166	−3392.37	−0.00629	−363.986	−633.867	−48.8125	−61,314.2	−5.16668	−3.89669	−30,047.4	−16.9907	−10.7226	−0.00326
SK	−0.28121	−0.00613	−13,209.3	−0.00869	−652.035	−1642.53	−33.8464	−93,441.7	−6.98106	−37.0272	−42,715.1	−22.9891	−17.7767	−0.00743
TR	−0.4832	−0.01094	−30,788.1	−0.16872	−14,012.6	−18,144.5	−1052.76	−3,408,476	−283.118	−36.3244	−803,580	−145.97	−97.6234	−0.06432
TW	−0.10254	−0.00259	−5693.89	−0.02102	−3333.37	−2710.95	−330.283	−1,351,898	−125.534	−6.29775	−100,014	−58.7962	−40.7472	−0.00141
US	−2.00556	−0.00857	−12,892.2	−0.29425	−4581.61	−21,712.7	−491.021	−1,891,300	−167.181	−299.819	−1,514,209	−99.8207	−68.3907	−0.00155
ZA	−0.05189	−0.00275	−6391.65	−0.00537	−4726.82	−593.078	−403.633	−530,299	−32.2091	−3.1759	−25,531	−49.8298	−33.9566	−0.0003

Table 12
Detailed effects, decomposed by country, of the increase in natural gas production in Italy. The first row displays the values at the global level.

	Value added [M€]	Employment [1000p]	Employment hours [hr]	Damages to human health caused by climate change [DALY]	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m^2 × yr]	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m^2 × yr]	Freshwater aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]	photochemical oxidation [kg formed ozone]	Climate change midpoint [kg CO2-Equivalents]	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	PM10 [Kg]	Land use Crop. Forest. Pasture [Km^2]
	180.5222	**2.811857**	**5,573,883**	**93.5297**	**1,517,360**	**4,673,281**	**126,921.5**	**5.25E+08**	**42,338.79**	**25,839.38**	**4.67E+08**	**23,997.16**	**14,959.82**	**13.02246**
AO	0.290612	0.021966	47,120.82	0.113156	2239.276	3800.43	114.118	179,261.4	10.57639	73.03729	608,264.9	74.84536	43.98869	0.152549
AT	0.277466	0.002677	4251.375	0.016411	2750.903	933.4743	403.73	466,259.8	27.49005	6.733814	80,186.31	38.4991	34.62602	9.67E-05
AU	0.056836	0.000535	862.2052	0.004801	358.4504	758.5484	31.93838	126,452	10.40986	2.522323	23,004.38	10.2549	7.764899	0.002846
AZ	0.729164	0.101302	215,373.2	0.126022	57,437.92	61,053.84	1945.363	6,848,696	504.1497	68.13145	613,977.6	556.6085	243.9256	1.436384
BE	0.510088	0.005254	9082.667	0.015751	1353.168	2728.783	86.73724	387,964.7	30.87848	6.480133	75,023.33	40.57227	28.52768	9.55E-05
BG	0.089137	0.003349	7011.551	0.061575	748.0418	9644.514	105.2957	2,320,782	29.96304	1.582713	293,020.6	421.8308	42.75796	0.019256
BR	0.084029	0.009122	18,945.5	0.004333	6227.045	817.635	163.8772	519,874.6	37.43844	5.757067	20,602.94	52.17856	43.56227	0.002912
CA	0.173441	0.001628	2919.144	0.020708	2910.322	2339.331	359.4238	1,201,040	111.5157	4.577295	98,643.64	47.35509	31.8445	0.045889
CG	1.782418	0.134726	289,007.7	0.694024	13,734.23	23,309.3	699.9237	1,099,470	64.86851	447.9621	3,730,691	459.0516	269.7973	0.935632
CH	1.486529	0.007892	15,603.89	0.016194	2288.97	1943.097	130.6291	390,422.6	48.51344	17.33741	77,156.86	78.48486	33.07661	0.001824
CN	0.430713	0.020322	51,164.67	0.072825	6495.003	8554.612	508.5911	1,447,231	128.8783	16.30493	346,623	250.6866	140.3134	8.42E-07
CY	0.00428	0.000736	1715.189	4.49E-05	34.52499	13.8372	3.749779	16,103.18	1.57671	0.016794	215.4982	0.297668	0.182463	2.61E-10
CZ	0.175114	0.00251	4480.833	0.021809	901.303	1899.817	71.0024	452,970.3	14.20524	7.078698	104,037	48.05957	30.4838	0.001117
DE	2.141414	0.02163	29,134.56	0.199618	8443.065	13,860.01	668.5801	4,966,024	196.7158	66.97727	954,699.4	269.1328	207.5208	0.000495
DK	0.119904	0.000878	1582.268	0.002294	499.7047	807.6119	35.36032	144,930.1	15.6545	2.544886	10,932.88	16.51504	11.4804	0.00019
DZ	2.324893	0.175729	376,966.6	0.905249	17,914.21	30,403.44	912.944	1,434,091	84.6111	584.2984	4,866,119	598.7629	351.9095	1.220389
EE	0.009945	0.000253	492.7233	0.000574	88.59042	143.2225	10.08432	77,600.48	4.091893	0.180151	2781.741	2.757843	2.058309	0.000516
EG	1.356188	0.102509	219,897.2	0.528062	10,449.96	17,735.34	532.5507	836,553.3	49.35648	340.8407	2,838,569	349.2784	205.2805	0.711894
ES	2.281557	0.108893	139,079.1	0.032623	7154.507	9166.634	772.0262	2,944,141	276.0169	19.52367	155,450.3	117.0254	75.71145	0.002531
FI	0.109189	0.000982	1865.195	0.008265	1271.104	2894.373	123.6383	553,069	45.02962	13.46078	39,131.1	24.71117	14.12358	0.000575
FR	3.051948	0.013405	19,751.7	1.257666	7938.638	55,176.02	514.2753	1,976,407	45.76587	373.9742	6,280,401	229.329	214.8386	0.000138
GB	1.043752	0.013111	24,556.8	0.048924	1663.872	6589.147	87.2597	337,544.6	24.57649	13.09707	233,717.5	37.76062	24.88389	0.01636
GR	0.105868	0.001988	4533.191	0.031442	13,579.37	6976.718	1611.359	9,005,384	624.7677	21.91317	149,749.7	236.646	129.3816	1.44E-05
HR	0.088431	0.007021	14,295.64	0.051673	908.1626	3292.685	54.30022	178,387.2	12.06087	11.19172	252,756.2	31.88641	21.0326	0.003141
HU	0.162261	0.004482	8984.943	0.007876	439.1575	1007.641	39.15814	63,944.79	4.2248	5.064614	37,955.56	15.87844	10.95669	0.002643
ID	0.032189	0.007703	22,181.82	0.011266	915.4178	1927.224	47.62086	131,509	11.80925	4.674551	53,719.5	41.94789	30.39291	7.28E-05
ID	0.121527	0.016884	35,895.53	0.021004	9572.986	10,175.64	324.2271	1,141,449	84.02495	11.35524	102,329.6	92.76809	40.65426	0.239397
IE	1.499059	0.006524	12,795.64	0.086645	2260.953	12,938.45	165.9038	352,713.1	26.02615	52.88181	427,477.9	64.27822	34.8034	0.000669
IN	0.316286	0.048282	118,937.4	0.017599	14,638.07	2571.693	508.3192	1,297,833	98.24904	53.75868	84,048.59	750.3342	551.8203	0.00063
IT	108.7083	1.527595	2,902,063	7.477007	939,190.3	736,776.3	98,284.32	4.3E+08	37,126.57	2124.073	35,813,938	13,293.02	9475.501	0.056157
JP	0.142198	0.001291	2584.464	0.015253	10,149.36	6138.781	1110.796	4,920,797	469.073	3.92097	72,548.55	108.5675	86.24131	6.79E-08
KR	0.059835	0.001512	3601.137	0.003092	551.3797	417.0862	44.10177	168,301.9	15.09438	1.456069	14,708.95	6.223463	3.075658	1.83E-09
LT	0.033176	0.000809	1675.962	0.001909	19.54143	287.4449	1.950505	11,608.7	0.481994	0.362909	9138.029	3.131454	2.466641	0.001215
LU	0.195134	0.000693	1433.229	0.002429	1363.555	399.3181	98.20927	288,274.5	21.68954	0.738083	11,563.2	6.921788	5.432911	8.66E-07
LV	0.00812	0.000404	796.3095	0.003666	103.3844	447.763	8.221769	34,660.19	0.954032	0.74844	17,461.19	3.674561	3.490009	0.000149
LY	0.290612	0.021966	47,120.82	0.113156	2239.276	3800.43	114.118	179,261.4	10.57639	73.03729	608,264.9	74.84536	43.98869	0.152549
MT	0.019244	0.000298	605.2066	0.000447	51.46163	25.39204	2.941622	12,807.04	0.921582	0.187259	2127.949	0.893666	0.428012	7.79E-06
MX	0.061684	0.012507	22,851.05	0.003871	1554.233	1823.563	60.28745	255,527.5	17.16289	2.394177	18,470.55	35.07525	25.69598	7.41E-05
MZ	0.290612	0.021966	47,120.82	0.113156	2239.276	3800.43	114.118	179,261.4	10.57639	73.03729	608,264.9	74.84536	43.98869	0.152549
NG	0.290612	0.021966	47,120.82	0.113156	2239.276	3800.43	114.118	179,261.4	10.57639	73.03729	608,264.9	74.84536	43.98869	0.152549
NL	1.430609	0.005663	10,034.93	0.326616	1358.496	8393.887	134.4246	393,802.5	31.80027	80.60788	1,616,992	40.40391	27.55704	0.006756
NO	1.992714	0.001587	3362.24	0.146812	635.2219	7262.021	116.1149	339,943.7	26.02276	40.21735	712,832.7	54.40479	35.97454	3.78E-06
PL	0.24175	0.008097	17,567.41	0.014378	1411.574	1230.744	85.61722	211,467.7	16.20226	4.950233	68,551.53	45.25825	28.21854	0.00232
PT	0.085176	0.00238	4056.766	0.007588	1131.576	1447.232	117.0637	507,940.2	48.24049	1.831522	36,157.71	16.09231	11.40732	0.000339
QA	3.514393	0.059043	167,895.3	0.39235	104,115.3	36,597.25	3096.737	8,749,115	522.7853	153.0655	1,945,439	877.1327	570.9272	0.255584
RO	0.131767	0.008835	19,000.63	0.005697	2158.334	738.796	123.5473	250,984.2	18.55036	4.120252	27,229.38	20.37131	11.64443	1.56E-06
RU	38.62752	0.111277	222,560.3	80.13382	113,961.1	3,532,515	8314.317	15,981,396	561.8206	20,815.34	4.01E+08	3261.059	994.4524	7.098756

(*continued on next page*)

Table 12 (*continued*)

	Value added [M€]	Employment [1000p]	Employment hours [hr]	Damages to human health caused by climate change [DALY]	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m^2 × yr]	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m^2 × yr]	Freshwater aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]	photochemical oxidation [kg formed ozone]	Climate change midpoint [kg CO2-Equivalents]	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	PM10 [Kg]	Land use Crop. Forest. Pasture [Km^2]
SE	0.18784	0.001348	2603.253	0.002479	1315.487	593.6062	81.93778	339,415.8	28.14271	1.529329	11,884.01	11.2829	7.886135	0.001095
SI	0.233886	0.003216	6473.203	0.019876	574.6262	735.7806	73.40931	124,429	9.710026	16.53917	106,943	15.9982	11.67365	0.015635
SK	0.062268	0.002232	4673.016	0.003215	917.887	404.4363	42.34458	83,274.56	11.84663	5.862188	15,579.78	19.74664	11.67929	0.003847
TR	0.151028	0.007186	13,771.51	0.041183	19,126.84	5083.862	1080.307	2,887,572	186.8184	11.22072	196,248.3	93.6846	68.22158	0.050878
TW	0.043821	0.001883	3960.152	0.007703	554.6527	867.1859	55.09307	207,152.1	17.9585	1.801992	36,644.3	15.03579	9.591982	3.11E-08
US	1.636394	0.030736	55,118.98	0.109597	1577.881	8273.363	188.512	374,167.7	29.63292	47.03901	534,764.1	71.80331	37.7188	0.000142
ZA	0.02316	0.008061	17,403.63	0.001138	2061.599	149.0458	86.18268	177,887.7	10.17981	3.567689	5423.604	38.75556	32.01384	0.000292

Table 13
Detailed effects, decomposed by country, of the increase in natural gas imports from other countries.

	Value added [M€]	Employment [1000p]	Employment hours [hr]	Damages to human health caused by climate change [DALY]	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m² × yr]	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m² × yr]	Freshwater aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]	photochemical oxidation [kg formed ozone]	Climate change midpoint [kg CO2-Equivalents]	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	PM10 [Kg]	Land use Crop. Forest. Pasture [Km²]
	848.0572	**85.97804**	**1.88E+08**	**277.9455**	**1.92E+08**	**31,901,835**	**4,488,746**	**1.4E+10**	**825,117.4**	**193,842.6**	**1.44E+09**	**993,093.6**	**594,449.6**	**1929.681**
AO	27.94089	3.238502	7,128,629	9.468123	5,441,552	1,059,120	123,632.3	367,000,000	22,720.04	6910.196	49,848,278	28,320.83	16,010.93	77.44267
AT	0.246431	0.003064	4742.829	0.005172	3049.082	666.3489	117.7586	309,758.3	17.44024	8.820278	24,664.9	18.88105	12.62251	0.000859
AU	0.86254	0.00749	13,200.31	0.056912	27,041.79	10,046.83	949.3488	2,134,685	295.9264	117.7968	282,849.8	493.0235	271.083	1.293724
AZ	85.6647	8.079787	16,829,185	27.70453	18,341,086	3,487,688	432,456.2	1,780,000,000	81,720.27	8168.718	134,000,000	115,058.7	78,643.85	33.71609
BE	1.199891	0.01149	20,184.78	0.105626	31,181.14	10,901.7	1177.101	4,148,304	322.558	102.7425	517,376.3	269.8482	144.4582	0.044392
BG	0.062692	0.011548	24,076.51	0.03077	69,795.96	11,820.03	4451.379	9,337,508	477.5897	16.05695	140,983.2	188.2655	128.5141	0.89005
BR	0.494873	0.027897	63,319.13	0.120543	225,570	62,118.69	4961.236	14,510,538	932.6049	106.1996	592,423.4	953.2064	523.7195	3.359789
CA	0.576065	0.007277	13,396.14	0.093088	7669.146	39,766.99	409.6749	1,137,547	82.35434	34.68879	431,277.6	342.1268	146.8729	7.773797
CG	171.3708	19.86282	43,722,256	58.07116	33,374,855	6,495,936	758,278.4	2,250,000,000	139,349.6	42,382.54	306,000,000	173,701.1	98,200.36	474.9817
CH	0.586385	0.003707	7027.088	0.008473	20,552.78	3399.98	763.4519	1,928,551	358.0537	145.1075	40,148.88	506.7403	260.9092	0.028679
CN	7.410543	0.377354	914,614.9	1.679877	3,240,198	200,036.8	201,708	421,000,000	30,556.44	4370.388	7,999,090	26,625.86	16,130.87	0.32246
CY	0.011777	0.000482	1010.56	0.002108	633.5541	1144.307	63.91853	264,625.4	26.26084	0.673254	9624.891	12.36456	5.938061	0.016966
CZ	0.113376	0.002871	5010.824	0.008368	2792.718	1268.667	165.1012	266,968.9	36.05122	14.56514	39,902.21	63.02915	32.82826	0.01295
DE	2.431313	0.03428	44,160.72	0.088871	60,248.81	27,814.74	3598.944	14,811,487	1407.367	96.41639	417,521.8	550.8806	303.9652	0.262608
DK	0.301319	0.002305	4242.759	0.00768	12,071.04	3911.501	587.1312	1,821,747	268.0351	76.38385	35,925.08	291.6677	152.2576	0.075581
DZ	223.5271	25.90802	57,029,029	75.74499	43,532,419	8,472,960	989,058.8	2,940,000,000	181,760.3	55,281.57	399,000,000	226,566.7	128,087.4	619.5414
EE	0.029722	0.000708	1436.06	0.002172	409.0788	459.8871	36.44707	172,124.6	14.37063	1.468699	10,390.38	9.885265	7.235704	0.002863
EG	130.3908	15.11301	33,266,934	44.18457	25,393,911	4,942,560	576,950.9	1,710,000,000	106,026.9	32,247.58	233,000,000	132,163.9	74,717.66	361.3991
ES	2.009086	0.023968	47,885.47	0.227246	177,365.2	35,048.58	7924.848	19,667,516	1149.084	214.8788	1,078,159	1260.594	834.6167	1.103488
FI	0.230063	0.002231	4297.254	0.020674	2800.74	2380.165	129.3841	467,936.7	51.21033	15.66982	102,518.3	86.96846	60.31729	0.013087
FR	6.245317	0.078883	123,542.7	0.347922	122,307.4	177,862.5	4318.243	13,305,404	1045.581	392.8409	1,603,188	2209.768	1132.538	6.806881
GB	3.359804	0.034053	63,272	0.146855	79,421.04	28,798.59	2836.127	9,330,924	730.0143	153.1836	699,830.4	1021.028	551.1635	0.37201
GR	0.262342	0.005014	10,773.73	0.068268	100,381.5	24,945.37	6341.978	21,141,097	2357.592	480.6862	321,931.6	2116.33	1229.253	0.395939
HR	0.061447	0.001002	2076.121	0.009174	1633.737	914.0632	119.1272	652,978.4	13.82262	2.32478	44,279.95	34.86387	18.46435	0.005099
HU	0.170326	0.003912	7950.428	0.009706	3934.75	879.6827	160.3604	365,028.1	32.55888	15.3646	46,908.48	55.25099	28.95033	0.009577
ID	0.55109	0.075998	196,788.8	0.352372	171,820.3	20,969.18	5123.223	22,458,597	1640.127	725.819	1,840,969	2871.612	1808.973	0.096896
ID	14.27745	1.346631	2,804,864	4.617421	3,056,848	581,281.3	72,076.03	296,000,000	13,620.05	1361.453	22,325,645	19,176.45	13,107.31	5.619348
IE	0.508857	0.004046	7924.72	0.012511	108,818.8	7154.749	3516.606	8,596,182	1244.702	500.1166	59,567.37	1615.041	885.076	0.00469
IN	3.034766	0.472554	1,144,913	0.934618	1,778,262	103,258.1	21,085.97	92,430,850	5903.489	622.9372	4,448,824	18,871.12	5453.738	1.14598
IT	1.668225	0.020943	40,704.57	0.133057	68,480.5	13,732.46	2971.169	7,780,971	524.8414	179.8619	633,513.5	836.4688	533.6002	0.10599
JP	1.972642	0.025805	52,757.01	0.120131	224,580.2	25,373.27	7234.982	30,521,161	3204.261	1021.614	571,870.1	2486.423	1565.968	0.000606
KR	1.324304	0.019734	48,338.1	0.110336	52,013.76	10,703.09	2478.402	9,818,151	595.176	136.676	525,067.3	432.6922	255.6702	0.00018
LT	0.108715	0.003578	7283.513	0.025617	3449.678	9509.338	160.9322	586,616.8	54.76514	23.63003	117,594.7	130.2596	53.09294	0.38723
LU	0.153343	0.000656	1341.965	0.005676	5834.777	864.3915	360.4052	929,183.7	58.27972	1.25496	27,012.94	51.04921	45.10639	0.004025
LV	0.043612	0.002693	5263.09	0.010189	3140.511	6237.1	121.7426	370,407.6	27.8113	5.379589	45,704.79	52.02618	19.66247	0.806417
LY	27.94089	3.238502	7,128,629	9.468123	5,441,552	1,059,120	123,632.3	367,000,000	22,720.04	6910.196	49,848,278	28,320.83	16,010.93	77.44267
MT	0.032087	0.00098	1967.475	0.000498	7577.9	543.266	207.6484	574,830.4	97.22989	38.85712	2349.7	133.2091	72.23546	0.001437
MX	0.193813	0.015559	32,442.07	0.025748	339,786	15,811.4	6825.073	21,636,778	1365.562	109.5621	121,746.4	983.4582	708.2518	0.893929
MZ	27.94089	3.238502	7,128,629	9.468123	5,441,552	1,059,120	123,632.3	367,000,000	22,720.04	6910.196	49,848,278	28,320.83	16,010.93	77.44267
NG	27.94089	3.238502	7,128,629	9.468123	5,441,552	1,059,120	123,632.3	367,000,000	22,720.04	6910.196	49,848,278	28,320.83	16,010.93	77.44267
NL	2.240837	0.012716	22,140.56	0.159131	66,783.73	15,575.39	3729.017	7,793,893	702.9736	99.59252	755,211	748.5374	473.8017	0.124399
NO	0.234668	0.000965	1733.357	0.035568	9559.794	7135.421	879.2755	840,205.1	215.5978	70.16964	170,788.8	639.5167	394.5956	0.0000666
PL	0.276793	0.009701	20,805.78	0.061185	9186.885	11,101.33	872.3971	1,665,271	104.5859	26.18355	282,434	213.2094	116.3878	0.287106
PT	0.738053	0.019803	39,698.71	0.089241	78,606.53	12,782.69	3576.249	9,352,680	379.671	43.28532	426,091.7	666.8298	574.9272	0.0515
QA	51.66795	0.564272	1,506,634	19.91147	19,637,474	1,554,853	418,045.1	1,420,000,000	83,011.94	9517.614	98,151,139	80,897.55	55,975.26	6.455659
RO	0.248028	0.039514	73,000.81	0.04809	12,321.64	34,196.67	627.2584	1,318,796	92.40344	27.81763	216,164.4	258.4941	89.63402	2.558465
RU	2.270002	0.098384	187,217	1.209618	4,371,390	252,821.7	77,507.89	293,000,000	14,183.02	1625.677	5,781,429	12,233.68	8685.16	42.33737

(*continued on next page*)

Table 13 (*continued*)

	Value added [M€]	Employment [1000p]	Employment hours [hr]	Damages to human health caused by climate change [DALY]	Damage to Ecosystem Quality caused by ecotoxic emissions [PDF×m^2 × yr]	Damage to Ecosystem Quality caused by the combined effect of acidification and eutrophication [PDF×m^2 × yr]	Freshwater aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Marine aquatic ecotoxicity [kg 1.4-dichlorobenzene eq.]	Terrestrial ecotoxicity [kg 1.4-dichlorobenzene eq.]	photochemical oxidation [kg formed ozone]	Climate change midpoint [kg CO2-Equivalents]	Particulate matter/ Respiratory inorganics midpoint [kg PM2.5-eq]	PM10 [Kg]	Land use Crop. Forest. Pasture [Km^2]
SE	0.59799	0.003295	6280.296	0.013206	12,921.87	2474.648	442.4242	1,726,505	100.627	13.72915	63,090.23	80.72339	60.04481	0.044954
SI	0.042551	0.000738	1500.435	0.002199	521.8078	315.0356	52.88788	116,152.2	10.6153	2.266637	10,478.98	10.84768	6.640375	0.002369
SK	0.047415	0.001254	2677.653	0.002649	2110.76	322.8969	79.40638	175,226.4	27.62148	7.409441	12,694.99	39.01008	21.03257	0.003418
TR	1.976349	0.042666	107,636.4	1.273459	3,064,320	129,267.6	152,616	337,000,000	19,254.47	648.204	6,061,559	14,878.37	12,627.69	0.414049
TW	0.792563	0.025093	54,466.28	0.099925	72,689.67	8964.733	2825.097	7,464,397	417.9726	224.9999	474,459.2	614.5019	448.0226	0.018925
US	8.920644	0.073177	139,573.2	0.590828	138,089.5	227,394.6	5774.515	14,334,835	723.1584	499.4724	2,845,961	2686.448	1488.503	10.78418
ZA	1.248594	0.045853	103,426.5	0.371846	2,815,797	67,099.76	72,364.74	187,000,000	12,044.74	913.0108	1,833,534	9755.743	7222.806	1.678729

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