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Evaluating industrial sustainability in OECD countries: A cross-country comparison

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ABSTRACT

The negative impacts associated to industrial activities have lead policymakers and scholars to elaborate broad interventions for sustainable and circular growth. These strategies entail the participation of a multitude of actors, each of whom is responsible for the achievement of different industrial sustainability and circular economy targets. A successful implementation of these strategies must be based on robust measurement systems, evaluating both policy implementation process and its outcomes. With this purpose, the aim of this paper is to present a novel approach for industrial sector performance, with respect to sustainability and circular economy. In doing so, by exploiting an OECD procedure, we built an *Industrial Sustainability Index* and four sub-indices evaluating different aspects of industrial sustainability and circular economy interventions: inputs, firm activities, outputs and resource efficiency outcomes. Furthermore, a scenario based on a Disparity Index has been used to evaluate the distance of each statistical observation from an efficient solution. This methodology has been tested on 36 OECD countries. The proposed approach allows policymakers to easily identify both weaknesses and best practices of the whole system and, thus, balance policy interventions according to the punctual needing of sectors, aspects or actors.

1. Introduction

Environmental degradation is at the heart of international debate due to the implications of pollution (De Haas and Popov, 2018). Among the main, industrial activities result the less sustainable ones for the global sphere (Zuo et al., 2017; Tseng et al., 2018). Apart from their environmental impacts, severe social and economic implications of industrial activities have been acknowledged (Arbolino and De Simone, 2019). From a social point of view, concerns on current production systems stem from the high resource consumption rates to poor working conditions, vulnerability, inter- and intragenerational equity (Ruiz-Mercado et al., 2011). On the economic side, extraction and, thus, supply of raw materials have become increasingly expensive and risky, leading developed countries to be strongly dependent for raw materials supply (Omri and Nguyen, 2014). Therefore, uncontrolled industrial development risks violating all the guiding principles for a sustainable industrial development, thus not allowing to achieve 2030 sustainable development goals (Lamichhane et al., 2021).

Over time, the idea that industrial sector might be the driver of low-carbon initiatives has pushed several interventions on both economic and managerial sides (Ghisellini et al., 2016). Achieving this target requires the involvement of organisations, enterprises and stakeholders and the reinterpretation of the actions to be undertaken (Durmaz et al., 2010; Velenturf and Purnell, 2021). According to Geissdoerfer et al. (2017), among the most concrete modes to foster sustainability–together with increasing inputs, certification activities, sustainable output and eco-innovation (Aldieri et al., 2019a) – the shift from linear production towards circular economy allows a reduction of resource supply, usage and waste. In this way, CE becomes a fundamental pre-condition for achieving sustainable and durable development. All these actions require cooperation between private and public sector (Baum et al., 2009; Kocmanova et al., 2017): for their part, enterprises become the active players in the realization of internal actions and strategies; on the other side, governments act as driver of eco-innovation by encouraging the transfer of resources and best practices, thus creating the backdrop for developing sustainable and circular industrial sectors.

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In this vein, a strategic management approach inside and outside business has to be implemented to drive new development models (Metaxiotis et al., 2010). In this vein, worldwide governments and international organisations have undertaken to increase industrial sustainability (IS) and reduce resource use (Martinho, 2021). Among international organization, OECD has produced a large set of guidelines and methodologies to evaluate sustainable development (OECD, 2010; OECD, 2020; OECD, 2021). These methodologies mostly exploit performance indicators and composite indexes for sustainability assessment (OECD, 2014). In addition, an increasing number of researchers has developed methodologies to assess sustainable achievements of the industrial sector (Arbolino et al., 2018).

Despite the extent of the literature (De Pascale et al., 2021), some fundamental relationships are still neglected in the assessment of industrial sustainability, thus failing in fully evaluating the effectiveness of actions implemented (Cagno et al., 2019). Firstly, no robust methodology to assess the role of actions aimed at promoting circular economy (CE) in increasing the sustainability of the industrial sector has been developed. Indeed, even though their nexus is recognised by theoretical literature, the two phenomena are usually analysed separately. Secondly, a framework assessing the relation among the actions undertaken during the whole process of CE/IS policy implementation (from inputs supply, until the production of relevant outputs) is still missing.

To cope with these weaknesses, this paper aims at evaluating industrial sustainability in OECD countries by offering an innovative methodology. For this propose, a composite index named *Industrial Sustainability Index* (*ISI*) has been built. This allows to capture the effect of industrial sustainability policies, in terms of actions realised by both private and public actors. This allows to evaluate the whole production cycle, considering either industrial sustainability inputs, activities, outputs, or the outcomes in terms of resource efficiency. Therefore, it also incorporates CE actions to understand their role in increasing industrial sustainability, by evaluating their impacts on resource inflows and waste outflows. Moreover, the disaggregation of the production process into different phases and the subsequent identification of comparable thresholds allows a clear comparison of the selected statistical units (36 OECD countries), as well as the identification of weakness and strengths. For the purposes of this research, a scenario identifying the distance of each statistical observation from an efficient threshold is identified by exploiting a quartile system, as the average between the second and the fourth quartile. However, other thresholds might be identified based on policymaker willingness (e.g., an ideal scenario). This allows for the provision of targeted policy suggestion to support policymakers in their decision making.

This research contributes to the debate on the ongoing policy assessment methodologies. The innovative contribution relies in the assessment of the role of circular economy in fostering industrial sustainability and defining sustainability-promoting policies. Furthermore, it proposes relevant methodological novelties trying to make assessment as robust as possible (i.e., calculation of thresholds, construction of policy scenarios, identification of weakness and strengths during the policy implementation and production process).

The paper is structured as follows. Section 2 reviews the literature on measures of industrial sustainability; Section 3 outlines the proposed methodology. Section 4 presents the main results while Section 5 concludes the paper and provides policy implications.

2. Measures of industrial sustainability

The evolution of current industrial models towards sustainable activities has stressed the importance of robust methodology to assess effective policy implementation (Geng et al., 2012; Szopik-Depczyńska et al., 2018; Arbolino et al., 2019). Several methodologies have been proposed, most of which encompasses the use of indicators and composite indexes, alternatively.

Indicators represent simple measures that quantitatively assess economic, social and/or environmental development in a specific area (Ness et al., 2007). However, they fail to provide an overall picture of progresses towards industrial sustainability (Narula and Reddy, 2015). By contrast, composite indexes (CIs) summarize the multidimensional features of the selected phenomenon succeeding in capturing the changes (either positive or negative) that occur in one or more dimensions considered, allowing an overall assessment (Almássy and Pintér, 2018).

However, in the most recent literature, no assessment tool considers the prominent role of CE in enhancing sustainability within the industrial sector. Indeed, these two phenomena are separately analysed, thus resulting into two strands of literature dealing with the two topics (IS and CE) separately.

With reference to industrial sustainability, composite indexes are largely used to evaluate both processes and policies (Singh et al., 2012; Cagno et al., 2019; El Gibari et al., 2019; Feil et al., 2019; Lemke and Bastini, 2020). These indexes might be distinguished according to the analysed level (Fig. 1):

- *Micro-level CIs* address the evaluation of industrial sustainability at firm level. These indexes deal with the corporate environmental performances – that is the efforts to implement internal sustainable policies, also with reference to specific industrial sector such as the automotive supply chain companies (Azevedo et al., 2012), steel industries (Singh et al., 2007), bio-refineries (Joglekar et al., 2020) and manufacturing companies (Dočekalová and Kocmanová, 2016; Cai and Lai, 2021; Mengistu and Panizzolo, 2021). Among this group are the "G score method" (Jung et al., 2001), the ITT Flygt Sustainability Index (Pohl, 2006) and the Index Corporate Sustainability (Kocmanova et al., 2017).
- *Meso-level CIs* evaluate industrial sustainability at sector level. Similarly, to the first group, also these indexes can present a focus on specific sectors (Dolge et al., 2020), i.e., automotive (Amrina and Yusof, 2012; Li and Mathiyazhagan, 2018), iron and steel industries (Long et al., 2016), mining (Aroudo Mota et al., 2017), logistics (Martí et al., 2017). Within this group, indexes for the assessment of industrial sustainability within industrial areas and parks have been developed (Tolstykh et al., 2020). Furthermore, other indexes have been proposed in order to evaluate the sustainability of industrial processes in terms of performances (Krajnc and Glavič, 2005; Zhou et al., 2012; Harik et al., 2015; Wang et al., 2018) and to guide the choices of the involved investors (López et al., 2007).
- *Macro-level CIs* encompass several dimensions of sustainability. These indexes assess performance at aggregate levels, such as national or regional. Isla (1997) have been proposed Two "Synthetic environmental indices" by evaluating the environmental performances of Barcelona municipalities. The World Economic Forum proposed the Environmental Sustainability Index (ESI) which provides a measure of the overall progresses towards sustainability for 142 countries (World Economic Forum, 2002). Bui et al. (2017) propose an indicator-based sustainability assessment framework (iSAF) in order to evaluate sustainability of selected sector at national and global scale by applying the proposed index to the mining sector of APEC economies. By exploiting Multi-Criteria Decision Analysis (MCDA) based on Analytic Hierarchy Process (AHP), Cucchiella et al. (2017) build a composite index comparing environmental and energetic sustainability of European countries. Lemke and Bastini (2020) developed a national comprising all the three domains of sustainable development and tested it on Germany.

As regard the CE indexes, they evaluate the achievement level of the main related goals: recycling, reuse, repair, remanufacturing, sharing of product, change in the consumption patterns and new business models and systems (Govindan and Hasanagic, 2018). As in the previous review, also CE indexes can be classified according to their level of analysis:

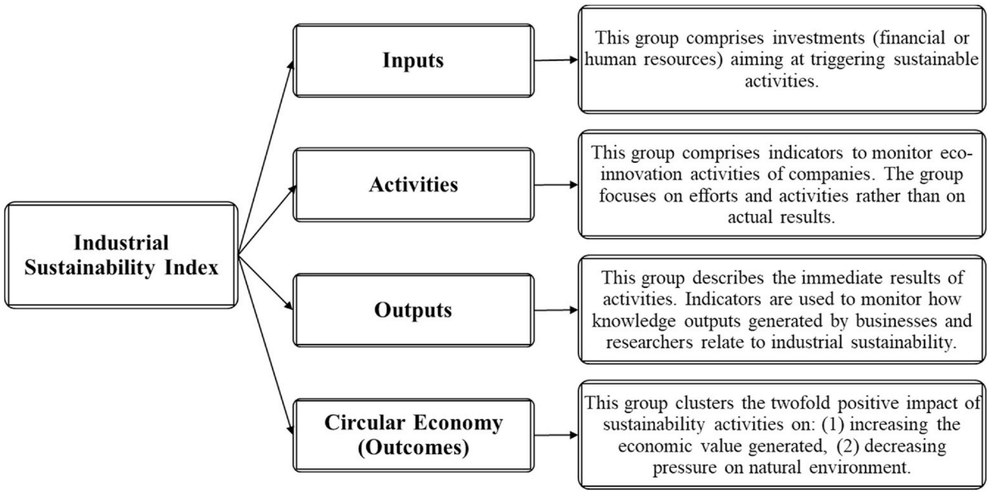

Fig. 1. ISI framework (own elaboration).

- *Micro-level indexes* assess CE at company, product or consumer level (Ghisellini et al., 2016). An extensive literature review on the topic is provided by Sassanelli et al. (2019), providing a description of the main methodologies aimed at assessing circularity of companies. These indexes represent a tool for improving products towards circularity (Evans and Bocken, 2013; Di Maio and Rem, 2015; Cayzer et al., 2017) and, consequently, to inform both consumer about their purchasing decisions (Van Schaik and Reuter, 2016) and administrators with respect to the sustainability level of companies (Azevedo et al., 2017; Bovea and Pérez-Belis, 2018)
- *Meso-level indexes* evaluate performance of both industrial sectors, eco-industrial parks systems (EIPs) and industrial symbiosis (IS) district. EIPs represent a group of firms located in a unique area, where reciprocal collaboration allows obtaining economic, environmental and social efficiency (Indigo Development, 2006). The latter is an EIP presenting peculiar features allowing companies to act as a close ecosystem and reduce dependence on external resources (Chertow et al., 2008). Among the indicators belonging to this level, Karlsson and Wolf (2008) propose a Method for the Analysis on Industrial energy systems (MIND) to analyse the interaction between firms and districts. Li and Su (2012) propose the Evaluation Index System to study the level of CE development in chemical sector companies. The Resource Productivity Indicator (RP) has been proposed by Wen and Meng (2015) with the aim of describing resource efficiency in the industrial sector. Pagotto and Halog (2016) construct the Eco-Efficiency Performance which provides a measure of both economic and environmental efficiency performance of a system in the Australian agri-food systems. Kayal et al. (2019) construct the Wastewater Circonomics Index with the aim of revealing production and recycling efficiency of the selected sector.
- *Macro-level indicators* are essential for the measurement of policies and programs efficiency at city, province, region and country level (Ghisellini et al., 2016). Even though most of them have been developed for China (Guo-gang, 2011; Chun-rong and Jun, 2011; Geng et al., 2012; Wu et al., 2014), recently, the European Commission has set a plan for assessing CE in EU (EC, 2018), which represent a monitoring framework. Furthermore, several indicators have been proposed by Organisations worldwide, which can be used to assess the development in CE, such as the Resource Efficiency Scoreboard (EU, 2013) and the Green Growth Indicators, by OECD (2014).

As it can be noticed, despite the large number of indexes, current measures of industrial sustainability do not consider the plurality of goals involved and the whole production process. In addition, the role of public and private investments, actions and behaviours is often neglected, together with the recognised role played by the EC principles. This results in a disregard of the phenomenon as a policy issue, not providing a measure of potential and needed improvements.

3. Methodology

Based on a standardized methodology and considering a consolidated framework for the selection of indicators, our approach relies on two different steps. First, by means of Principal Component Analysis (PCA), we built a composite index called "Industrial Sustainability Index" (ISI). The construction of four further sub-indices allows to analyse different dimensions of the concerned phenomenon (Inputs, Activities, Outputs, Circular Economy), to capture their relations and their role in the overall industrial sustainability level. Secondly, based on a Sustainability Disparity Index (SDI), a policy scenario compares the effectiveness of actions implemented in OECD countries in allowing the achievement of "*efficient*" targets. These targets are identified by using a system of quartile values. This scenario represents a goal to be pursued, but it might also be modified according to the needs of policymakers.

3.1. Data selection

The framework for selecting and classifying indicators has been constructed following the European Eco-innovation Index (EEI), that, in our opinion, provides a comprehensive and complete indicator framework for assessing the concerned phenomena. Within this scheme, basic indicators are classified into four areas: (i) inputs; (ii) activities; (iii) outputs; (iv) socio-economic outcomes; (v) resource efficiency outcomes. In selecting the data to use, this scheme has been modified by excluding socio-economic outcomes since, despite the relevance of economic implications within industrial sustainability framework, their assessment is not the focus of the present analysis. ISI is based on 29 indicators referring to industry and extracted from the OECD, the International Organization for Standardization (ISO) and the World Bank datasets (Table 1). As said, they are gathered into four categories:

1. Inputs comprise financial and human resources investments, likely to trigger sustainable activities; thus, this group gathers indicators describing the levels of R&D expenditure, as well as the financial support of governments for environmental activities (Ravšelj and Aristovnik, 2018; Songling et al., 2018).
2. Activities gathers indicators monitoring firm eco-innovation activities; they focus on the efforts in terms of green innovation and

Table 1
Variables selection.

N.	Label	Indicator	Measure	Source
Inputs				
1	BERD	R&D Expenditure of business Sector	% GDP	OECD
2	GOVERD	R&D Expenditure of Public Sector	% GDP	OECD
3	Env_budg_gov	Environment-related budget allocations for R&D	% Government budget allocations for R&D	OECD
4	R&Dsupport_direct	Government-financed BERD	% Total Business R&D	OECD
5	R&Dsupport_indirect	Indirect government support through R&D tax incentives	% Total Business R&D	OECD
6	Env_taxes	Environment-related taxes	% GDP	OECD
7	Env_ODA	Environment-related ODA	% ODA	OECD
Activities				
8	ISO50001	ISO14001 Certificates (environmental management system)	Number/million inhabitants	IOS
9	ISO14001	ISO50001 Certificates (energy management system)	Number/million inhabitants	IOS
10	Prod_Innov	Product innovating firms	% Total firms	OECD
Outputs				
11	Inno_air_poll	Air pollution abatement innovation	% Total Patents	OECD
12	Inno_water_man	Water pollution abatement innovation	% Total Patents	OECD
13	Inno_waste_man	Waste management innovation	% Total Patents	OECD
14	Inno_Enc_monitor	Environmental monitoring innovation	% Total Patents	OECD
15	Inno_water_adapt	Water-related adaptation technologies innovation	% Total Patents	OECD
16	Innov_wastewater	Wastewater treatment innovation	% Total Patents	OECD
17	Innov_ghg_disposal	Capture, storage, sequestration or disposal of greenhouse gases	% Total Patents	OECD
18	Innov_energy	Energy generation, transmission or distribution innovation	% Total Patents	OECD
19	Inno_poll_building	Climate change mitigation technologies to buildings	% Total Patents	OECD
20	Innov_env_prod	Climate change mitigation technologies: goods production or processing	% Total Patents	OECD
21	Env_tech	Development of environment-related technologies	% Total technologies	OECD
Circular Economy (outcomes)				
22	WASTE	Industrial waste	Waste generated/ Value added (Manufacturing activities)	OECD; WB
23	En_Cons_Ind	Energy consumption in industry	% Total energy consumption	OECD
24	Output_en	Energy intensity of GDP	GDP/Energy consumption	WB
25	En_cons_GDP	Total energy consumed per units of GDP produced	Energy consumption/GDP	WB
26	WATER_GDP	Water abstraction	Total water abstraction/GDP	OECD; WB
27	Water_Ind_VA	Water abstraction per added industrial value	Freshwater abstractions (thousands m3)/ value added (US$)	OECD; WB
28	GHG_en	CO2 emissions by energy production	Tonnes of CO2 equivalent (per inhabitant)	WB
29	GHG_ind	GHG emissions by industry	Tonnes of CO2 equivalent (per inhabitant)	WB

*Elaboration of the authors.

management (Scarpellini et al., 2016; Fernando and Wah, 2017; Aldieri et al., 2019b).

3. Outputs comprises variables assessing the achievement of industrial sustainable activities in terms of pollution abatement, monitoring and mitigation technologies (Abdul-Rashid et al., 2017; Costantini et al., 2017).
4. Circular Economy (outcomes) comprises eight variables dealing with Circular Economy, by measuring the impact of sustainability activities in terms of increased economic value and decreased pressure on the environment (Geissdoerfer et al., 2017; Govindan and Hasanagic, 2018).

3.2. Construction of the ISI

The methodology for building the ISI is based on the OECD (2008) standard methodology. It involves three steps, as follows:

1. Normalization, to transform variables having different units of measurement, allowing cross-unit comparisons without affecting the original data content.
2. Multivariate analysis (PCA), allowing to detect the correlation among the selected indicators to obtain a shorter set of variables.
3. Weighting and aggregation procedure, allowing to decrease the reduce intentionality in the assessment of the impact and to rank each statistical unit according to their individual scores.

3.2.1. Normalization

Among the several existing techniques (Böhringer and Jochem, 2007; OECD, 2008), *standard scores with z-values* have been adopted, as it is the most used for composite indexes elaboration (Antony and Rao, 2007; Singh et al., 2012). It is implemented based on the following:

$$z_i = \frac{x_i - \overline{x}}{S} \quad [1]$$

In doing so, it allows to convert each original variable x_i in a new variable with null mean ($\overline{x}$ is the average value among the observations) and variance (S is the standard deviation) equal to 1. Thus, the z-score represents the distance of the raw data from the mean, measured in standard deviations.

3.2.2. Multivariate analysis

With the purpose of explaining the relationships among indicators, PCA is applied for the examination of the whole structure of the chosen variables. This step allows to calculate and assign weights to each indicator, thus eliminating the subjectivity characterizing the weighting of the variables in constructing the composite indicators (Mann and Shideler, 2015). This multivariate statistical method entails two phases.

In the first step, the number of latent factors (principal component) representing the data has been defined by applying the Kaiser's criterion – also known as the *eigenvalue rule* – as method of factors extraction. According to this criterion, two conditions must be respected: i) each factor loading must be greater than one; ii) the sum of eigenvalues must account for more than 60% of the overall variance.

The second phase has involved the rotation of the factors (*Varimax* rotation; Linting et al., 2007) to both simplify data interpretation and minimize the number of variables which have high loadings on each factor (OECD, 2008).

3.2.3. Weighting and aggregation procedure

According to Antony and Rao (2007), weighting techniques grounded on factor score coefficients – also named *component scores* – estimated by means of regression methods have been applied. Following this approach, the weights to be associated to each variable have been obtained as the variance explained by the associated factors; thus, the factor score is the score of each statistical unit in the sample on each factor. Among several aggregation techniques, the simple additive weighting (SAW) method has been preferred since, together with its transparency and accuracy (Zhou et al., 2006; Devi and Sihotang, 2019), it implies a linear and proportional transposition of data, allowing to preserve the relative order of magnitude of the standardized scores (Afshari et al., 2010). Furthermore, given the presence of values equal to zero, other techniques (e.g., geometrical mean) could not be used (Arbolino et al., 2018). The SAW method is applied as follows:

$$I_j = \sum_{K=1}^{f} \left(\frac{\lambda k}{\Lambda}\right) * \alpha_k^{xj} \quad [2]$$

Where:

- I_j represents the composite indicator for each jth statistical unit;
- $\alpha_k^{xj} = \{\alpha_1^{xj}, \ldots, \alpha_f^{xj}\}$ is the factor scores of each case – xj – on each fth factors;
- $\lambda_k = \{\lambda_{k1}, \ldots, \lambda_{kf}\}$ is the variance (%) of each fth factor explains;
- Λ is the cumulative explained variance;
- xj represents the cases.

Subsequently, a standardization procedure has been implemented to normalize the resulting values, which can be either positive or negative. The *Min-Max normalization* procedure is as follows:

$$SI_j = \frac{(I_j - MinI)}{(MaxI - MinI)} * 100 \quad [3]$$

Where:

- SI_j represents the standardizes composite indicator for each jth case;
- The minimum and maximum values of I_j indicator are represented by Min I and Max I, respectively

By doing so, the value of the composite indicator can range from 1 to 100, facilitating the interpretation (Singh et al., 2012).

3.2.4. Sub-indices

This methodology has been applied for each group of variables, thus obtaining four sub-indices reflecting the composite index pillars. This allows to provide a comprehensive view of the industrial sustainability at country level by conveying information on countries' performances in fields such as environment, economy, society and technological development.

3.3. Construction of SDI

The final step of the analysis involved the construction of a scenario based on the calculation of an "*Efficiency*" threshold. Following the procedure by the OECD (2008), both ISI and pillars scores have been divided into quartile values. This allowed to build the "Efficient value" as the mean value between the second and the fourth quartile. A further Scenario might be constructed (i.e., the Ideal Scenario), by considering the maximum value of the fourth quartile as *ideal* threshold.

For calculating the Sustainability Disparity Index, the axiomatic formulation of the Sen (1976) Poverty Index – that is based on a revised version of both headcount and income gap ratios – has been followed. This allowed to obtain different distribution for the evaluation of territorial unbalances:

$$S = H[I + (1 - I)G_z] \quad [4]$$

Where:

- H represents the Disparity Diffusion Indicator, calculated as $H = q/N$, in which q are those countries below the threshold, while N is the total number of countries.
- I represents the Disparity Intensity Indicator, which measures the distance of less efficient countries from the threshold – expressed as value of the composite indices – following the calculation of the Income Gap Ratio, $I = 1/q\sum_{i=i}^{q} z - y_i/z$, in which z represents the threshold value, while y_i represents the value of the CI for each country.
- G represents the Gini Index, measuring the level of inequalities among the regions with values below the calculated threshold:

$$G = 1 \Big/ 2q^2 m \sum_{i=1}^{q} \sum_{j=1}^{q} |y_i - y_j| \quad [5]$$

4. Empirical results

The first step of ISI methodology relies on a Principal component Analysis. Following this step, eleven latent factors, explaining the 82.9% of the total variance, have been extracted. The represented correlation coefficients – i.e., the loadings of each variable on each factor – resulting from the *Varimax* rotation, range from −1 to +1. Table 2 shows factor loading as follows:

1. Factors 4 and 6 – explaining 7.7% and 7.2% of the total variance, respectively – provide a valuable description of the Industrial sustainability inputs. They may be interpreted as a measure of the effectiveness of tools aimed at encouraging the industrial sector to implement sustainable activities, i.e., such as investments in R&D and government incentives.
2. Factor 10 – despite only explaining the 5.2% of the total – represents the main description of Industrial Sustainability activities, to understand the efforts made by companies in spurring eco-innovation.
3. Factors 2, 3, 5, 7 and 11 – accounting for the 11.6%, 10%, 7.4%, 5.9% and 4.5% of the total variance, respectively – allow to have valuable information on the Industrial Sustainability outputs. It can be interpreted as a measure of the most immediate results of company environmental management.
4. Factors 1, 8 and 9 – accounting for the 12.6%, 5.7% and 5.4% of the total variance, respectively – are those factors explaining Resource Efficiency outcomes, that is the impact of industrial activities in terms of CE principles.

Table 2
Varimax rotation factor matrix.

Factors	1	2	3	4	5	6	7	8	9	10	11
% of variance	12.6	11.6	10	7.7	7.4	7.2	5.9	5.7	5.4	5.2	4.5
I-Sustanability index categories	4	3	3	1	3	2	3	4	4	2	1
BERD	0.015	−0.495	−0.246	0.299	−0.266	0.394	−0.242	−0.249	−0.046	−0.166	0.168
GOVERD	−0.072	0.105	−0.067	0.659	−0.185	0.083	−0.088	−0.410	−0.118	0.045	−0.038
Env_budg_gov	0.057	0.801	−0.162	−0.048	−0.024	−0.025	0.026	−0.146	−0.278	0.034	0.063
R&Dsupport_direct	0.005	0.077	−0.091	−0.074	−0.103	−0.844	−0.110	0.191	−0.117	0.003	−0.228
R&Dsupport_indirect	0.053	−0.126	−0.125	−0.059	0.847	0.071	−0.070	0.066	0.190	−0.010	−0.093
Env_taxes	0.116	0.124	0.124	0.051	−0.042	0.192	0.053	0.192	0.026	−0.011	0.853
Env_ODA	−0.171	−0.326	0.072	0.306	0.036	0.169	0.071	0.180	−0.494	0.309	−0.282
ISO50001	0.160	0.200	−0.041	0.245	−0.153	0.092	0.000	−0.109	0.203	0.807	0.005
ISO14001	−0.059	−0.109	0.501	−0.177	−0.187	0.528	−0.063	0.252	−0.052	0.255	0.028
Prod_Innov	−0.200	−0.229	−0.127	−0.039	0.476	0.489	−0.191	−0.046	−0.226	0.339	0.074
Inno_air_poll	0.202	−0.283	0.068	0.790	0.020	0.055	0.154	0.071	−0.073	0.303	0.009
Inno_water_man	0.147	0.734	0.419	−0.134	−0.173	−0.138	0.026	−0.201	0.006	−0.074	0.049
Inno_waste_man	0.050	0.873	−0.156	−0.008	−0.053	0.040	0.129	0.110	0.140	0.202	−0.010
Inno_Enc_monitor	−0.024	−0.159	0.037	0.759	0.410	0.018	−0.129	0.040	−0.001	−0.057	0.056
Inno_water_adapt	−0.447	−0.377	−0.042	−0.161	0.183	−0.353	−0.103	−0.232	−0.369	0.222	−0.037
Innov_wastewater	0.036	0.717	0.403	−0.135	−0.086	−0.091	0.038	0.051	0.155	−0.134	0.091
Innov_ghg_disposal	0.055	0.009	−0.067	0.211	0.777	0.014	−0.039	−0.189	−0.155	−0.124	0.058
Innov_energy	0.129	0.113	−0.135	−0.126	−0.077	0.083	0.890	0.018	−0.080	0.076	0.131
Inno_poll_building	−0.543	−0.207	−0.353	−0.128	0.247	−0.094	0.006	0.109	−0.119	0.263	0.408
Innov_env_prod	0.105	0.088	0.882	−0.014	−0.001	−0.039	0.223	−0.131	0.014	−0.074	0.089
Env_tech	0.131	0.106	0.413	0.119	−0.111	0.042	0.749	0.148	0.169	−0.115	−0.114
WASTE	0.077	−0.009	−0.923	−0.087	0.126	−0.031	0.116	0.059	−0.052	−0.007	−0.010
En_Cons_Ind	0.640	0.028	0.121	−0.049	0.084	−0.039	0.076	−0.420	0.318	0.139	0.275
Output_en	0.705	−0.193	−0.175	−0.252	0.160	0.050	0.096	0.250	0.130	0.367	0.063
En_cons_GDP	0.942	0.090	−0.091	0.073	0.093	0.034	0.126	0.104	0.062	0.080	0.022
WATER_GDP	0.473	0.017	−0.255	0.221	0.171	0.642	0.207	0.071	0.093	0.084	−0.202
Water_Ind_VA	0.158	−0.067	0.078	−0.082	0.030	0.114	0.030	−0.003	0.831	0.210	−0.037
GHG_en	0.103	−0.030	−0.152	−0.084	−0.123	−0.099	0.109	0.860	−0.029	−0.047	0.224
GHG_ind	0.922	0.128	0.122	0.048	−0.075	−0.032	0.026	−0.004	−0.005	−0.072	0.046

Table 3 shows the I-Sustanability index values – as well as the score of each sub-index – for the 36 OECD countries, as they result following the *Min-Max normalization* procedure. Belgium results as the best performer, reaching the top position of the I-Sustanability index score ranking. The four sub-indices allow to identify those areas where, despite the good performance achieved by Belgian industrial activities, improvements are required. Indeed, notwithstanding the high levels of inputs provided, industrial sustainability activities achieve lower scores, thus posing below the OECD average score. Differently, while being sensibly lower, score assessing outputs and Resource Efficiency outcomes pose above the average score. This result highlights the great efforts of Belgian governments for providing economic incentives, as well as legislative and bureaucratic support to firm transition towards industrial sustainability and CE (Henrotay et al., 2017; Keirsbilck, 2020). Simultaneously, the weakness of private activities for eco-innovation and sustainability is highlighted, thus requiring targeted policy interventions. Portugal and Latvia rank as second and the third best performers, respectively. Both countries, achieve very high scores in terms of Outputs and Circular Economy, while in terms of industrial sustainability activities, the two countries pose among the less sustainable at all. Following, Estonia achieves the highest values of both Industrial Sustainability activities and outputs in the whole sample, meaning that, differently from the previously analysed countries, companies have undertaken a great deal of work to implement valuable environmental management systems, thus also realizing the best results in term of outputs. By contrast, inputs, which are usually provided by public actors (national or local government), are much lower and below the OECD average value. Therefore, differently from the previously analysed countries, policymakers should focus on improving the provision of inputs to the industrial activities.

At the opposite, Iceland reports the worst results in terms of I-Sustanability index. This bad performance is clearly ascribable to the low scores achieved by the country with reference to all the pillars. In particular, Icelandic industrial sector shows low adherence to the main principles of Circular economy, as showed by the zero-score achieved. Similarly, New Zealand and USA classifies as 34th and 35th out of 36 countries involved in the analysis. The second sub-index score equal to 3.25 (USA) and 0.29 (New Zealand) is suggestive of the main weaknesses of these two countries production sectors. Indeed, the activities implemented by the private sectors to improve their environmental management have been very scarce, far below the OECD average score.

Overall, the Resource Efficiency outcomes (CE) pillar shows high values and low variation, pointing two different issues: (i) countries performance is very similar and (ii) the great efforts in adopting policies accomplishing with CE principles made. Only four countries out of 36 obtain scores below 50.00: (i) Iceland – with the lowest value equal to 0, (ii) New Zealand (39.60), (iii) Canada (47.07) and Australia (47.56).

4.1. SDI index results

Once calculated the level of Industrial Sustainability, the last step of the analysis relies on the construction of a policy scenario allowing to assess the relative distance of each country from an "efficient" level of industrial sustainability. The related threshold values are reported in Table 4, respectively.

The outcomes of the "*efficient*" scenario are presented in Table 5, where values for regions not achieving efficient performance are reported. These results show how far is each country from achieving, at least, efficiency in the implementation of industrial sustainability and circular economy actions. Overall, the largest part of the countries (28 out of 36) shows low levels of Industrial Sustainability. The worst performances are achieved by Iceland (−0.50), New Zealand (−0.31) and United States (−0.31), thus pointing them as the most inefficient countries in terms of overall Industrial Sustainability. Regarding the disaggregated analysis, results highlight that most of the inefficiencies in the transition towards sustainable industrial sectors are related to sustainable *Activities* and *Resource Efficiency outcomes*. Regarding the former, stronger actions on behalf of policymakers and governments

Table 3
ISI and four sub-indexes.

N.	Countries	I-Sustanability index	Inputs	Activities	Outputs	Circular economy
1	Belgium	100	100	23.38	73.3	70.6
2	Portugal	96.32	35.07	12.06	82.5	80.14
3	Latvia	92.87	44.75	14.22	66.98	86.1
4	Estonia	92.51	39.07	100	100	64.44
5	Luxembourg	89.97	46.03	14.81	58.3	69.73
6	Greece	88.31	46.53	16.49	78.85	70.44
7	Italy	87.78	69.95	20.96	55.58	80
8	Slovak Republic	84.84	32.21	19.37	78.94	70.59
9	Netherlands	82.77	63.13	18.88	60.57	69.55
10	Denmark	82.68	55.03	18.68	55.59	75.02
11	Hungary	82.09	51.97	8.28	56.68	81.99
12	United Kingdom	79.45	39.55	16.9	51.47	82.57
13	Poland	78.71	34.94	10.4	74.06	75.19
14	Lithuania	77.08	34.84	24.86	52.06	88.17
15	Germany	76.08	74.04	12.15	34.37	68.29
16	France	75.69	54.39	14.18	51.59	76.02
17	Finland	72.89	49.91	26.58	54.09	58.05
18	Chile	72.09	19.62	25.75	61.02	88.43
19	Ireland	71.94	0	9.9	38.11	100
20	Austria	70.01	70.4	6.71	34.64	70.25
21	Spain	69.95	29.4	14.05	52.84	79.8
22	Slovenia	68.69	57.25	8.51	37.44	71.43
23	Sweden	68.45	45.44	24.9	29.91	78.69
24	Norway	67.04	28.53	20.13	67.74	57.99
25	Czech Republic	64.25	39	18.49	42.13	62.4
26	Australia	62.27	19.26	16.84	70.95	47.56
27	Switzerland	60.48	10.84	14.79	21.54	90.04
28	Japan	60.24	48.68	15.96	27.52	74.69
29	Turkey	57.6	48.03	3.78	31.74	85.41
30	Canada	52.83	19.97	11.2	65.83	47.07
31	Korea	49.85	70.9	5.55	25	56.43
32	Mexico	40.04	32.9	7.74	34.44	85.55
33	Israel	39.33	38.81	0	0	85.26
34	United States	32.68	38.79	3.25	25.76	58.48
35	New Zealand	32.05	33.24	0.39	44.14	39.6
36	Iceland	0	27.73	11.48	24.36	0
-	**OECD**	**68.9**	**43.1**	**16.4**	**50.6**	**70.7**

Table 4
Input for the "efficient" scenario.

Scenario	ISI	Inputs	Activities	Outputs	Circular Economy
Minimum acceptable threshold (z1)	0.2439	0.1148	1.7677	0.2285	0.2439
q	29	31	35	30	35
N	36	36	36	36	36
Disparity Diffusion Indicator(H)	0.8056	0.8611	0.9722	0.8333	0.9722
Disparity Intensity Indicator (I)	1.2414	1.1613	1.0286	1.2000	1.0286
Sustainability Disparity Index (S)	0.8056	0.8611	0.9722	0.8333	0.9722
Gini index (G)	−0.0081	0.2924	−0.0495	−0.0495	0.0204
Disparity Diffusion Indicator(H)	1.0016	0.9594	1.0014	1.0083	0.9994

need to be implemented to improve the levels of activities, given the large differences reported in Table 5. As also reported in the previous analysis (Table 3), even the best performing countries report weaknesses when dealing with industrial sustainability activities, meant as the accomplishment of international standards or the introduction of innovations: i.e., Belgium and Estonia. With reference to the latter aspect, almost all countries (35 out of 36) need to improve the level of circular economy outcomes. Several countries are close to the efficiency threshold (e.g., Australia and Lithuania), while others need to implement strong interventions for supporting circular economy principles accomplishment.

5. Discussion

Currently, addressing the challenge of sustainable industrial development represents the best way to ensure a healthy economic growth (Căutișanu et al., 2018. The achievement of the related goals – increasing economic efficiency, adding value to enterprise, reducing environmental impact – is affected by exogenous factors, such as the implementation of proper planning by governments, the support of eco-innovation and the active partnership with entrepreneurial system (Costa et al., 2010; Aquilani et al., 2018).

Together with the progress in implementation of industrial sustainability and circular economy principles, the definition of robust assessment tools has drawn the attention of both scholars and policymakers, willing to improve the available information at all territorial levels. Recent literature has focused on these issues by proposing several indicators and methodologies encompassing the three dimensions of sustainability: environmental, economic and social (Cagno et al., 2019; Ioppolo et al., 2019). Assessment methodologies have been tested on different levels: national, regional and industry sectorial (Zhou et al., 2018). CIs proved to be the most useful methodology; they are widely accepted as a tool for performance monitoring and policy analysis in the field of industrial sustainability (Zhou et al., 2018; El Gibari et al., 2019). However, several criticisms might be identified in the current literature, such as the absence of (i) robust methodologies to assess the role of actions aimed at promoting CE in increasing the sustainability of the industrial sector or (ii) a framework assessing the relation among the actions undertaken during the whole process of CE/IS policy implementation (from inputs supply, until the production of relevant outputs). In order to overcome this problem, this paper aimed at analysing and assessing industrial sustainability as a complex and comprehensive

Table 5
Results of the “efficient” scenario.

N.	Country	I-Sustanability	Inputs	Activities	Outputs	Circular economy
1	Australia	−0.13	−0.04	−0.15		−0.01
2	Austria	−0.09	−0.01	−0.20	−0.30	−0.18
3	Belgium			−0.11		−0.17
4	Canada	−0.19	−0.04	−0.18	−0.05	−0.34
5	Chile	−0.07	−0.04	−0.10	−0.09	−0.05
6	Czech Republic	−0.12	−0.03	−0.14	−0.24	−0.23
7	Denmark	−0.01	−0.02	−0.14	−0.13	−0.14
8	Estonia		−0.03			−0.22
9	Finland	−0.07	−0.02	−0.09	−0.14	−0.26
10	France	−0.05	−0.02	−0.16	−0.16	−0.14
11	Germany	−0.05	−0.01	−0.17	−0.30	−0.19
12	Greece		−0.02	−0.15		−0.18
13	Hungary	−0.02	−0.02	−0.19	−0.12	−0.09
14	Iceland	−0.50	−0.04	−0.17	−0.38	−0.67
15	Ireland	−0.08	−0.05	−0.18	−0.27	
16	Israel	−0.27	−0.03	−0.24	−0.57	−0.07
17	Italy		−0.01	−0.12	−0.13	−0.11
18	Japan	−0.14	−0.02	−0.15	−0.35	−0.15
19	Korea	−0.21	−0.01	−0.21	−0.37	−0.27
20	Latvia		−0.03	−0.16	−0.04	−0.06
21	Lithuania	−0.05	−0.03	−0.10	−0.16	−0.05
22	Luxembourg		−0.02	−0.16	−0.11	−0.18
23	Mexico	−0.26	−0.03	−0.19	−0.30	−0.07
24	Netherlands	−0.01	−0.02	−0.13	−0.09	−0.18
25	New Zealand	−0.31	−0.03	−0.23	−022	−0.39
26	Norway	−0.10	−0.03	−0.13	−0.04	−0.26
27	Poland	−0.04	−0.03	−0.18		−0.14
28	Portugal		−0.03	−0.17		−0.11
29	Slovak Republic		−0.03	−0.13		−0.17
30	Slovenia	−0.09	−0.02	−0.19	−0.28	−0.17
31	Spain	−0.09	−0.03	−0.16	−0.15	−0.11
32	Sweden	−0.10	−0.02	−0.10	−0.33	−0.12
33	Switzerland	−0.14	−0.04	−0.16	−0.40	−0.04
34	Turkey	−0.16	−0.02	−0.22	−0.32	−0.07
35	United Kingdom	−0.03	−0.03	−0.14	−0.17	−0.09
36	United States	−0.31	−0.03	−0.22	−0.37	−0.26

phenomenon, involving inputs, activities, outputs and efficient use of resources.

The proposed methodology follows the OECD (2008) procedure and encompasses several existing techniques in an innovative way. A two steps methodology – the building of both ISI and Sustainability Disparity Index (SDI) – on a sample of 36 OECD countries has been applied. The first CI index has provided important evidence on industrial sustainability. Indeed, large differentials can be identified with relation to the sub-indices, mainly in terms of activities and CE implementation. With reference the achievement of satisfactory results in terms of CE, most of the countries are lagging behind. These results have been confirmed in the SDI index analysis, which has shown that these pillars represent a major issue in the analysed countries. While the existence of large unbalances in terms of IS and CE among and within countries had already been highlighted by literature (Marino and Pariso, 2020), our analysis allows to provide a unique framework to tarted necessary policy interventions, to improve performance. Looking at disaggregated results, strong interventions are required to drive industrial system transition, especially towards CE. On behalf of public actors, together with incentives and control practices, several barriers should be removed to ease the implementation of IS, such as administrative burdens, delays in human capital formation, among others (Garcés-Ayerbe et al., 2019). Indeed, following the results of our analysis, countries where these processes have been initiated proved high performance. This is the case of Belgium, where recent policy interventions have moved to remove the concerned barriers, for example providing incentives and both legal and bureaucratic support to firm aiming to enhance transition (Henrotay et al., 2017; Keirsbilck, 2020). In doing so, in line with the aims of the Special issue purposes, the proposed methodology presents as a robust quantitative approach for both selection of actions and strategies to be implemented for achieving sustainable development.

6. Conclusions

The outcomes of this study enable to legitimate the choice of the composite index as a tool to sustain the industrial policies assessment, considering exhaustive attributes of different contexts, such as social, economic and political. The methodology was constructed to be easily used, with appropriate adjustments, at different territorial levels or with reference to different production sectors. Therefore, in presence of robust data, further research could consider constructing this index at a smaller scale – i.e., regional, provincial, or municipal level – or as a focus on precise industries – i.e., chemical industry, agri-food chains, etc. In doing so, the set of indicators might be easily expanded to allow ISI fulfilling the strong sustainability paradigm. Similarly, from a methodological point of view, different scenarios could be constructed by considering different and higher thresholds (such as an “*ideal*” scenario), according to the necessities of policymakers. Finally, a recalibration of the index could be performed by exploiting multicriteria dimension analysis-based techniques and non-linear/non-compensatory approach.

Despite the useful results provided, the proposed approach presents some limitations. Indeed, despite the intention of expanding the research to smaller territorial levels or different production sectors, data required could not be easily available. Furthermore, while statistical units are easily comparable in a precise year, the variation of both factors and relative weights over a longer time span might affect the construction of the different sub-index, thus potentially affecting comparative assessment.

CRediT authorship contribution statement

R. Arbolino: Conceptualization, Methodology, Formal analysis, Software, Supervision. **R. Boffardi:** Data curation, Writing – original draft, Formal analysis, Writing – review & editing. **G. Ioppolo:** Conceptualization, Supervision, Visualization, Writing – review & editing. **T.L. Lantz:** Data curation, Writing – original draft, Formal analysis. **P. Rosa:** Supervision, Visualization, Writing – review & editing.

Declaration of competing interest

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

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