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Exploring the ecological efficiency as the path to resilience

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ABSTRACT
The permanent changes in society affect, among other, the environment. This is why environmental efficiency plays a very important role, being quantified in different forms. In our paper we have developed a composite index of ecological efficiency taking into account two dimensions, environmental pollution and resource consumption, each one being characterized by specific indicators. Thus, using this index, the aim was to evaluate and rank the level of greening of each country in Europe. Crises over time, including the health crisis caused by coronavirus, have focused to resilience, so we have highlighted whether it is significantly influenced by the ecological efficiency index. In addition, we analyzed whether ecological efficiency is related to investments in a country, financial, material and technological potential.

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1. Introduction

Any human activity involves intervention in nature through the consumption of resources and effects on environmental factors. Any ecological system is in permanent transformation, especially through production and consumption, the human activity being a constant of them (Anghelache et al., 2020; Bai et al., 2021; Bashir et al., 2021a; Zeraibi et al., 2021). The systems theory takes into account the balance of the system, and the environmental protection and sustainable development principles indicate the accessibility threshold of human intervention by maintaining environmental conditions or improving them (Brundtland Report, 1987). More recently, were registered concerns to accelerate 'adaptation action', towards a climate-resilient future in 2030 (Adaptation Action Agenda, GCA, 2021a), based on 'system-level resilience' (GCA, 2021b, Second Press release). Extreme phenomena, black swan

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events, past and present crises (such as the pandemic) have shown us that the effects are complex, difficult to quantify (by current statistical indicators) and lead to lifestyle changes and environmental intervention. As such, an approach to measuring efficiency from an ecological perspective, as a component of developing the systems resilience, is a necessary step, which involves complex research - analysis of the impact of actions and measurement of effects, link intensity, and results from the effort to finance 'pro-environmental' technological innovation.

In the literature, there are few works that present the association between ecological efficiency and resilience, and the present paper fills this gap, in a new approach, considering the eco-efficiency a determinative factor for robust resilience of the socio-economic systems. It is difficult to analyze the relationship between multidimensional ecological efficiency and resilience in human economic and societal systems, so it is necessary to develop a composite index of ecological side of efficiency (IESE), at the country level, in order to capture both the use of natural resources and the impact on environment (mainly measured as pollution indicators). So, in order to achieve this index, we used two dimensions, environmental pollution and resource consumption, for each one being reported specific indicators. In addition, we highlighted whether there is a link between the IESE and investments at country level, both material and financial, considering technological transfer a direct and ongoing way to improve both components of the index. After that, in order to respond to the research objective of identifying the relationship between ecological efficiency and resilience of economic and social development systems, we analyzed whether there is a direct determination, the nature and characteristics of this relationship, and the intensity of this influence.

The main purpose of the paper is to highlight the relationship between development sustainability, measured by the IESE composite index and resilience index and to see to what extent IESE correlated with investments sustains robust resilience achieving at countries level, and if there are registered significant difference according to development level (GDP/capita). The investment was measured by two dimensions – inputs (gross fixed capital formation - as financial source and innovation index as technological potential) and outputs (domestic material consumption, and the share of SMEs with product innovations). Thus, the novelty of our paper resides in creating a new composite index reflecting the country ecological efficiency and highlighting the relationship between this index and resilience.

Therefore, the paper is structured as follows. The section of literature review presents an overview of selective studies regarding ecological efficiency and resilience, while section 2 is dedicated exploring the relation ecological efficiency - resilience using a bibliometric analysis. Section 3 presents the methods used in the analysis and incorporates information related to the data used in the analysis. Section 4 presents the main empirical results, while the last part focuses on discussions and outcomes. Finally, main conclusions are summarised.

2. Literature review

The ecosystem networks growth and development involved the balance between efficiency and resilience (Bashir et al., 2021b; Ho & Ulanowicz, 2005; Ulanowicz et al., 2009; Zorach & Ulanowicz, 2003). Efficiency reflects ensuring long-term integrity (Li & Yang, 2011), while resilience represents the ability to respond to disruptions by achieving a stable state (Holling, 1973). Regarding the relationship between ecological efficiency and resilience in the literature, there are few papers to present this association (Derissen et al., 2011), the concept of eco-efficiency not being compared to resistance (Korhonen & Seager, 2008). There are several recent papers according to which the concepts of efficiency and resilience are radically different from each other (Goerner et al., 2009), but have not been studied in economic and societal systems, ecological efficiency missing from resilience research (Korhonen & Snäkin, 2015).

2.1. A new approach in designing efficiency of ecological systems

The literature focuses on the analysis of resource consumption and the impact on the environment (eco-efficiency) or on energy transfer (ecological efficiency) (Oxford Dictionary).

Ecological efficiency is defined as increasing production, but using few resources (Schmidheiny, 1992; Welford, 1998) or value generation reported per unit of environmental influence (Brattebo, 2005; Huppes & Ishikawa, 2005a). Ecological efficiency is the link between environmental issues and economic and business challenges (Huppes & Ishikawa, 2005b), being an extension of efficiency (Lazear, 2000). The concept of ecological efficiency is present in multiple areas, such as: public policy (Hukkinen, 2003, 2004), cleaner production (Stevenson & Evans, 2004), industrial ecology (Ehrenfeld, 2005) and environmental management and corporate sustainability (Figge & Hahn, 2004).

Sustainability has been increasingly characterized by objectives aiming ecological efficiency by minimizing waste or beneficial reuse, investing in technological improvements that increase material or energy yields and changing the demand for energy resources from oil to those based on of renewable energy (Caglar et al., 2021; Jiang et al., 2021; Korhonen & Seager, 2008; Nathaniel & Khan, 2020; Noja et al., 2021; Panait et al., 2019; Rehman et al., 2021; Van den Bergh, 2000).

Ecological efficiency is the main principle of ecological modernization, being the most successful concept regarding sustainable development (Jänicke, 2008), connecting environmental issues and economic and business challenges also in quantitative terms (Huppes & Ishikawa, 2005b). On the other hand, the sustainability strategy places ecological efficiency in the center, aiming at reducing both costs and environmental impact by minimizing or reusing waste, preventing pollution, or improving technology (Korhonen & Seager, 2008). Ecological efficiency represents a tool that analyzes sustainability, highlighting the empirical relationship in economic activities between the environment cost or value and the impact on the environment (Huppes & Ishikawa, 2005a). Thus, ecological efficiency represents the ratio between the economic added value and the impact on the environment. The high added value leads to the efficiency regarding the use of environmental services (Ehrenfeld, 2005), the results being beneficial both for the economy and for the environment (Porter & Van der Linde, 1995). It also sustains sustainability, representing the leading normative ideals in sustainable development work (Ehrenfeld, 2005, 2000, 1997; Jänicke, 2008), estimating that improvements in resource productivity can lead to a more prosperous and sustainable economy.

Ecological economics fosters a multidisciplinary environmental approach with sustainable development as its central concept (Van den Bergh, 2000). Statistical measurement of resources' consumption or effects, mainly through partial indicators, is useful in the analysis of environmental components and economic development, but does not allow a global overview on the ecological profile of all aspects regarding life and development at the national/regional/local level. Indicators, such as ecological footprint or different indicators of 'ecological efficiency' from the perspective of resources' use and quality of environmental components (which will be briefly highlighted in the paper) are presented (Ahmed et al., 2021; Kirikkaleli et al., 2021; Nathaniel et al., 2020; Rehman et al., 2021; Solomon et al., 2020; Zeraibi et al., 2021), some even with the same name although the content is different (eco-efficiency index). On the other hand, high complexity and uncertainty regarding life and business environment impact on quality of life, and finding optimal solutions (economic vs environment) to problems is sometimes not feasible. Moreover, efficiency does not necessarily promote resilience and specific material and energy flows are critical to industrial ecosystem transition and resilience. (Zhu & Ruth, 2013).

Crisis recovery efforts, represented by economic growth, have proved unsustainable and difficult to correlate with increasing ecological efficiency, and economic resilience is not always calibrated with eco-efficiency. Tradeoffs between resilience and efficiency is inadequate 'resilient firms can also respond to crises opportunistically in ways that also reshape their business landscape' (Reeves et al., 2020) and do not necessarily presuppose sustainable development.

Based on these considerations, in the paper we highlighted the need for a new approach in measuring efficiency from the perspective of sustainable development in terms of monitoring the ecological component and we developed a composite index (IESE), which includes the two sides treated so far separately or partially namely resources' consumption and, respectively, the quality of environmental factors (measured by indicators of pollution levels).

2.2. Resilience- a necessary approach toward sustainable future

Resilience, in a mechanical sense (loss recovery, return to the pre-crisis moment through the value of some indicators) does not imply maintaining a sustainable balance - ecological, maintaining sales markets or employment as a factor of competitiveness. Some experts consider resilience a short-term necessity, but economic resilience includes factors of adaptability (to a new business environment) and eco-efficiency and reconfiguration of workforce skills, which means an integrated approach to time horizons - short, medium, and long. It is important to adapt new and sudden change of environment and technology due to customers' demands and expectations (Akkaya & Tabak, 2020).

The concept of resilience has emerged in ecology, being connected with ecosystems sustainability, representing the property of dynamic models, but also a measurable amount (Carpenter et al., 2001). Resilience has become very popular lately (Meerow et al., 2016), generating information about socio-ecological systems and their sustainable management (Folke, 2006; Pickett et al., 2013), especially on climate change (Leichenko, 2011; Pierce et al., 2011; Solecki et al., 2011; Zimmerman & Faris, 2011) and on sustainability of dynamic capabilities (Akkaya & Üstgörül, 2020). It gains a very important place in the research of complex adaptive systems, including human economic systems and their sustainability (Crépin et al., 2012; Derissen et al., 2011; Folke, 2006; Strunz, 2012; Uehara, 2013). Thus, the term 'resilience' has shifted from the field of natural sciences to the lexicon of international development (Bahadur et al., 2013; Barrett & Constas, 2014).

The concept of resilience has captured the popular interest and is predominant applied to cities and urban areas. Holling (1973) defined resilience as the ability of a system to absorb changes that still persists, being distinguished by stability - the ability of a system to return to a state of equilibrium. *Resilience reflects the ability of a system (including socio-ecological and socio-technical networks) to maintain or return quickly to the desired functions in the face of disruption, to adapt, to change, and to rapidly transform systems that limit the capacity to current or future adaptation (*Meerow et al., 2016). The most popular definition of resilience is presented as the capability to survive natural or man-made hazards (Campanella, 2006; Ouyang et al., 2012).

Considering the previous comments and the 'black swan' events increasing (Taleb, 2007) we accept that 'resilience as the capacity for a system to survive, adapt, and flourish in the face of turbulent change and uncertainty' (Fiksel, 2007) is so much difficult to measure. So, resilience is a nonlinear, complex process that involves several stages, different depending on the degree of development, importance, risks and stressors involved. Although in the literature we meet several dimensions of resilience, the best known is the one offered by the OECD, according to which the areas that drive resilience are: economy, governance, environment and society.

2.3. An overview of the indices that characterize ecological efficiency. The IESE designing concept

Measuring and comparing or ranking according to ecological efficiency are very important for assessing the viability and performance of policies adopted in order to improve environmental sustainability and attractiveness (UN-ESCAP, 2009). A high degree of ecological efficiency involves reducing the consumption of resources (energy, materials, water) and increasing recycling, thus reducing the impact on the environment (Mickwitz et al., 2006). For the evaluation of ecological efficiency, several measurement guidelines, frameworks, set of indicators and indices have been proposed, both by public organizations, consultancy bodies and researchers (Storto, 2016). Sustainability and ecological efficiency indicators have been developed as ratios, including water consumption to inhabitants, and amount of CO2 produced per year (Storto, 2016). Pizzigallo et al. (2007) evaluated the environmental sustainability of the Province of Modena in Italy, using an energy based analysis. In order to evaluate the sustainability in China, Yin et al. (2014) used measurements of ecological

Table 1. Synthesis of the most well-known indices that characterize ecological efficiency.

Index	Description	Source
Ecological development efficiency index (EDEI)	resource exploitation, carbon emission, and energy infrastructures	Shen, Y., Sun, S., Yue, S., & Sun, X., 2020
Ecological efficiency of human development throught ecological impact index	the average overshoot of CO2 emissions and material footprint vis-à-vis their per capita planetary boundaries, indexed on a natural exponential scale	Hicket (2020)
Sustainable Development Index measuring the ecological efficiency in delivering human development	material footprint and CO2 emissions sufficiency, threshold on the income indicator	Institute of Interdisciplinary Research into the anthrepocene, 2019
Environmental Performance Index	32 indicators of environmental performance	Yale University, 2020
Eco-efficiency Index	environmental impacts, energy consumption, emissions, material consumption, toxicity potential, Abuse and risk potential	Saling, P., Kicherer, A., & Dittrich-Krämer, B., 2002
Eco-Efficiency Index	global warming potential, ozone depletion potential, acidification potential, photo-chemical smog, solid wastes, water emissions,energy consumption, raw material consumption, land use,toxicity potential and risk potential.	Kicherer, A., Schaltegger, S., Tschochohei, H., & Pozo, B., 2007
Eco-efficiency comparison index	Water Consumption, Energy Consumption, CO2 Emissions, Wastewater Generation, Waste Generation	Pereira, C.P., Prata, D.M., Santos L.S., & Monteiro, L.P.C., 2018
Eco-efficiency Indicator	global warming, resources, chemical substances	Aoe, T., 2005
Ecological efficiency of cities	Waste, photovoltaics, transportation, electricity, pollution, popultion	Lo Storto, G., 2016

Source: Authors selection based on literature review.

efficiency indicators. Wang et al. (2015) evaluated the progress of ecological construction in China by means of a pre-set of qualitative and quantitative indicators.

There are many indices in the literature that aim to assess ecological efficiency, relating to the level of development (Shen et al., 2020), human development (Hickel, 2020; Institute for Interdisciplinary Research into the Anthropocene, 2019) and environment (Aoe, 2005; Kicherer et al., 2007; Pereira et al., 2018; Saling et al., 2002; Storto, 2016). Each index is composed of several dimensions depending on its area. A synthesis of the most well-known indices reflecting ecological efficiency is presented in Table 1.

However, some indices present some disadvantages, both due to the model implemented for measuring indicators and the different modality in which indicators are aggregated.

In our paper, to characterize ecological efficiency we have created a composite index of ecological side of efficiency (IESE) consisting of two dimensions: a) environmental pollution and b) resource consumption. The indicators related to these dimensions are: a) waste water discharge, exhaust emission, solid waste discharge; b) energy consumption, power consumption, water consumption, land resource consumption, manpower consumption (Yao et al., 2021) (Figure 1).

Composite indices are very useful for monitoring performance and conducting comparative studies, providing an overview and efficiency of a particular phenomenon (Saltelli et al., 2006). In general, composite indices use equal weights, but using

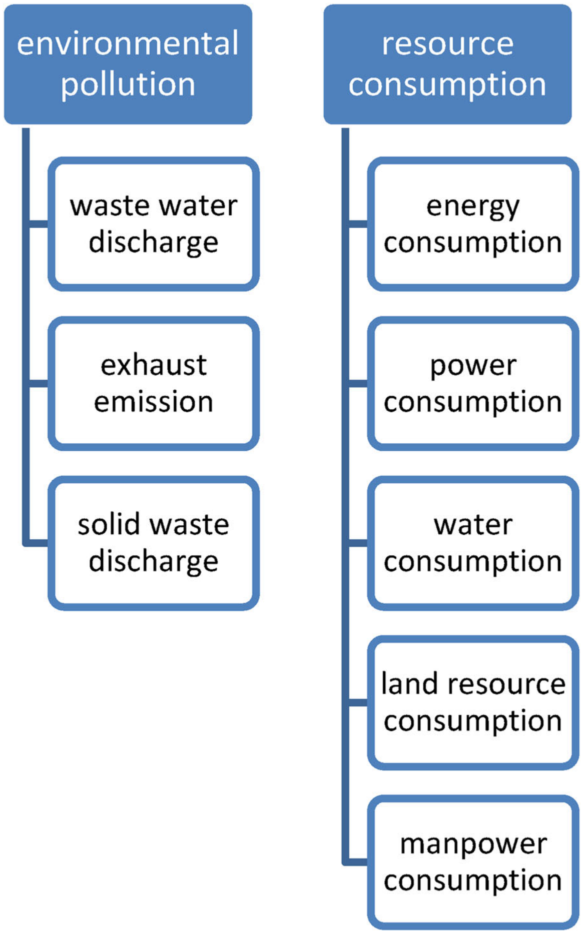

Figure 1. Indicators for estimating ecological efficiency.
Source authors

statistical methods and techniques (multivariate regression analysis, principal component analysis (PCA), and stochastic frontier analysis (SFA)) it can be obtained objective weights (Storto, 2016). In the case of the index created by us, we used multiple weights, justified by the principal component analysis.

2.4. Exploring the relationship between ecological efficiency and resilience in the context of economic crisis. A bibliometric analysis

In order to analyze the most relevant studies in the field we used bibliometric analysis, the principal source of scientific articles being the academic platform Web of Science. Thus, we have explored the content of 100 research articles related to efficiency, ecology and resilience. In order to highlight the structure of the scientific field, we used the content analysis, inspecting the most common words and the relationship between words.

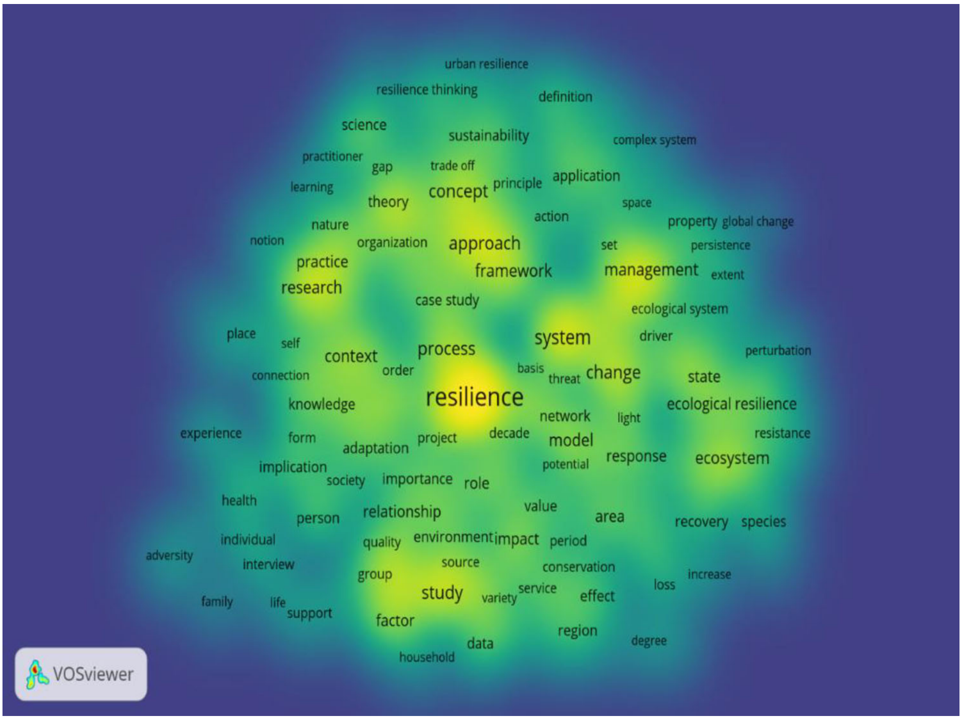

Figure 2. Most common words in scientific publications regarding ecological efficiency and resilience.
Source Authors

Analyzing the network of co-occurrences, a frequency of at least 20 times have been taken into account, with a correlation degree greater than 0.5. The analysis has been done using VOSviewer programme.

Based on the full content analysis we tried to identify the most common words on eco-efficiency and resilience. The empirical analysis proved that the most common words used are: 'resilience', 'process', 'system', 'management', ecosystem', 'ecological system', 'management', 'recovery', 'model', 'change', 'knowledge' (Figure 2).

And the most common combinations identified are: ecological system-perturbation-resistance-response-change-network; resilience-environment-impact-quality-context-importance-knowledge-implicationconcept-process-approach-framework-sustainability (Figure 3). In order to highlight this combinations of words being the most encountered it was explored the most correlated words within the selection of articles, using as threshold the value of 0.5.

Based on previous theoretical considerations, and on indept literature review, the following research hypotheses have been defined in order to reach significant answers to research aims:

Hypothesis 1: Ecological efficiency measured by IESE significantly influences resilience

Hypothesis 2: IESE is correlated with investments (direct investment as financial source and innovation index as technological potential, and, respectively domestic material consumption).

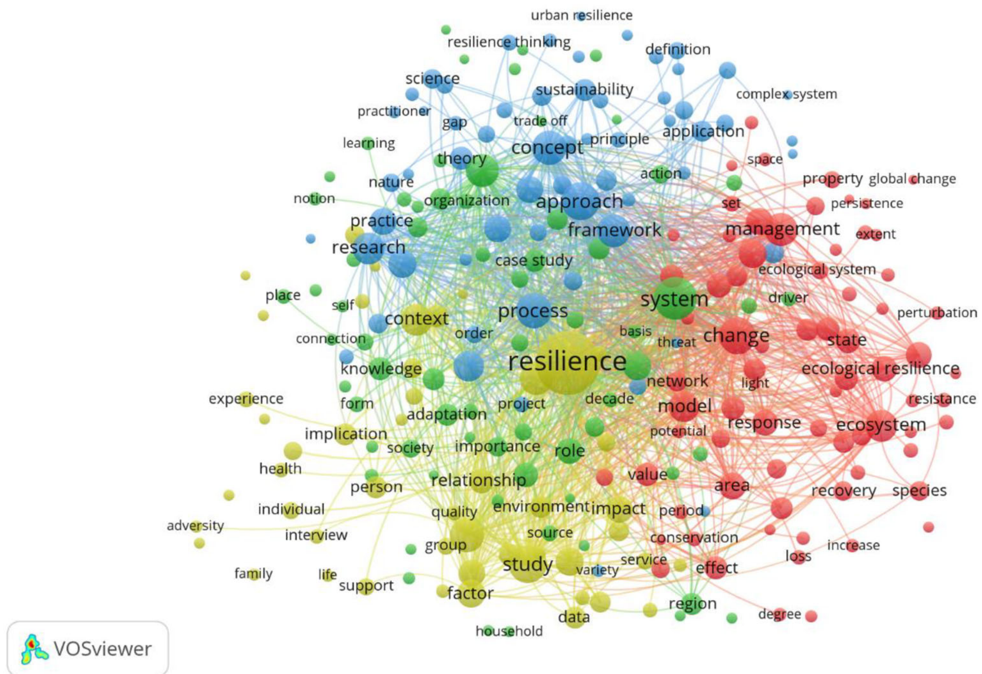

Figure 3. Word network in WOS publications' content.
Source Authors

3. Data and methodology

The first step in the research was to determine the value of IESE for European countries for the year 2020 based on the component indicators provided by Eurostat, (generation of wastewater - point sources - total, greenhouse gas emissions by source sector, municipal waste - tons, primary energy consumption - tones, fresh water abstraction by source - million m^3 and persons employed), FMGlobal (Global Resilience Index) and WIPO (Global Innovation Index) (H1).

To compose IESE we used the principal components analysis (PCA) (Nardo et al., 2005; OECD, 2008; Abdi & Williams, 2010). Principal component analysis (PCA) as a multivariate technique analyzes a data table in which observations are described by several inter - correlated quantitative dependent variables (Abdi & Williams, 2010). We select this method because PCA extracts the dominant patterns in the matrix in terms of a complementary set of score and loading plots (Wold et al., 1987). The purpose of this analysis is to condense the information of a large set of correlated variables into a few variables, while not throwing overboard the variability present in the data set (Jolliffe, 2002).

Several procedures have been proposed for determining how many principal components to retain: the Kaiser rule and the scree plot (Cattell), resampling methods, cross-validation methods, Bayesian procedures and statistical tests. Thus, the composite index will be determined using the weights recovered by each main component in the total variance of all components (Hăpău, 2018). The analysis of the principal components and the composition of the index was performed using SPSS

Table 2. KMO and Bartlett's test.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.767
Bartlett's Test of Sphericity	Approx. Chi-Square	410.418
	df	10
	Sig.	0.000

Source: authors.

The IESE impact on resilience was evaluated using regression analysis (Fox, 1997; Jaba, 2002; Paratchi et al., 2012), in which the independent variable is the resilience index. Regression analysis was performed using EViews.

Thus, the linear regression model has the following form:

$$y = \beta_0 + \beta_1 X_1 + \varepsilon \tag{1}$$

For H2, to highlight whether there is a connection between IESE and the investments in the economy, both financial and material, we performed the cluster analysis and the map using Tableau (Eisen et al., 1998; Milligan & Cooper, 1987; Sokal & Michener, 1958; Wilks, 2011). The homogenous groups were defined based on countries development level measured by GDP/capita).

4. Empirical results

4.1. Composition of IESE

The quality of the PCA analysis empirical results was assessed using the Bartlett sphericity test and the Kaiser – Meyer – Olkin (KMO) statistic which measures the adequacy of the sample of indicators in constructing a synthetic environmental efficiency indicator, highlighting a satisfactory analysis, as the test is statistically significant and the KMO statistic has a value higher than 0.5 (0.767) (Table 2). Thus, 76.7% of variance in our variables is common variance, which might be caused by underlying factors. The proportion is bigger than 50%, suggesting that the variables do 'factor well'.

According to the results of Table 3, the existence of two main components was highlighted, which recovers approximately 98.53% of the original variables.

Analyzing the correlation coefficients in the component matrix, the first main component has positive coefficients with green gas emissions (0.982), municipal waste (0.989), energy consumption (0.989) and water consumption (0.989). The second main component is mainly dominated by waste water (0.96) (Table 4).

Thus, the ecological efficiency index is built based on the weights of each main component in the total variance:

$$Ecological_{effiency} = \frac{79.53}{98.53} * \mathrm{PC1} + \frac{19.00}{98.53} * PC2$$

Table 3. Empirical results of the main component analysis.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.976	79.529	79.529	3.976	79.529	79.529
2	0.950	19.001	98.530	0.950	19.001	98.530
3	0.046	0.918	99.448			
4	0.027	0.550	99.998			
5	0.000	0.002	100.000			

Extraction Method: Principal Component Analysis.
Source: authors.

Table 4. Component matrix.

	Component	
	1	2
waste_water	0.279	**0.960**
greengas_emissions	**0.982**	−0.013
municipal_waste	**0.989**	−0.023
energy_consumption	**0.989**	−0.121
water_consumption	**0.989**	−0.115

Extraction Method: Principal Component Analysis.
a. 2 components extracted.
Source: authors.

Thus, according to the ecological efficiency index, Germany is on the first place, followed by Turkey, France, UK, Italy, Spain, Poland, Austria (Figure 4).

4.2. The influence of the IESE on the resilience index of European countries

To assess the influence of the ecological efficiency index on resilience in European countries, a regression model was estimated, where the IESE is the independent variable and resilience index is the dependent variable.

According to the results of Table 5, the model is valid for a probability of 90%, so the ecological efficiency index significantly influences the degree of resilience in the European countries. When the ecological efficiency index increases by one unit, the resilience index increases by 5.12 units (Table 6), confirming hypothesis 1. This result leads to the idea that for a resilient society it is necessary to invest in greening, which leads to resilience.

4.3. The link between the ecological efficiency index and investments in the economy at the level of European countries

In order to highlight whether there is a link between IESE and investments in the economy, we referred to direct investment, innovation index, and domestic material consumption.

As can be seen from Figure 5, the countries do not correspond in intensity with those related to IESE, so the link between IESE and domestic material consumption is weak and inverse, confirmed by the Pearson correlation coefficient (-0.31). If we

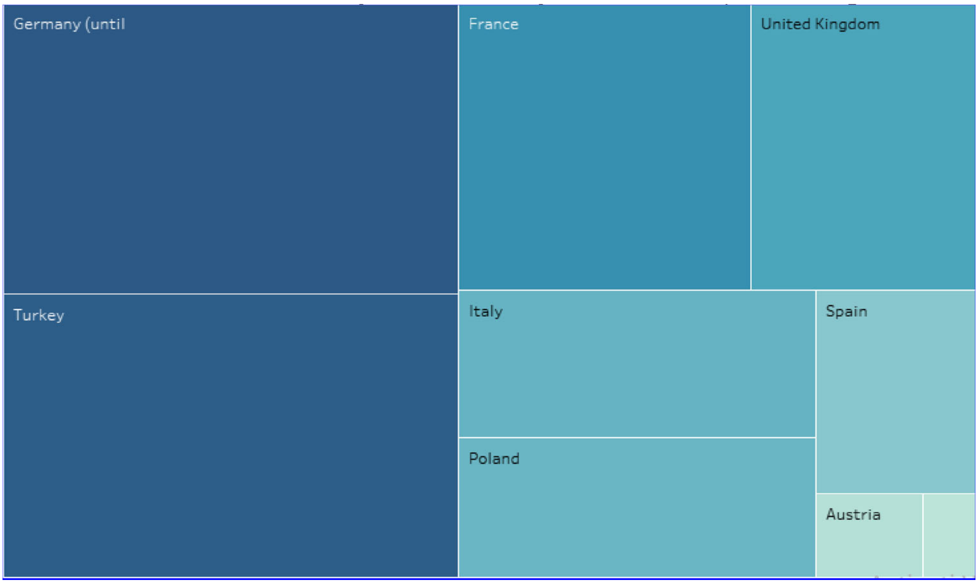

Figure 4. Ecological efficiency in Europe.
Source: authors

Table 5. ANOVA.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	417.909	1	417.909	2.797	0.103[b]
	Residual	4332.405	29	149.393		
	Total	4750.314	30			

a. Dependent Variable: resilience_index.
b. Predictors: (Constant), ecological_efficiency.
Source: authors.

Table 6. Empirical results of regression analysis.

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	82.355	2.207		37.318	0.000
	ecological_efficiency	5.118	3.060	0.297	1.673	0.103

Source: authors.

refer to direct investment in the reporting economy (flows) and Innovation Index, the connection with IESE is weak (Table 7), the Pearson correlation coefficient being 0.332 (in case of Innovation Index) and 0.069 (in case of direct invesments), confirming hypothesis 2.

Thus, the total amount of materials directly used by an economy leads to a low level regarding IESE, therefore a low resilience. On the other hand, when we refer to financial investments, there is no connection with ecological efficiency, the explanation being that a large part of these investments is mainly without affecting the environment, the principle of sustainability being very important nowadays. Another explanation could be the small share of material investments in total direct investments.

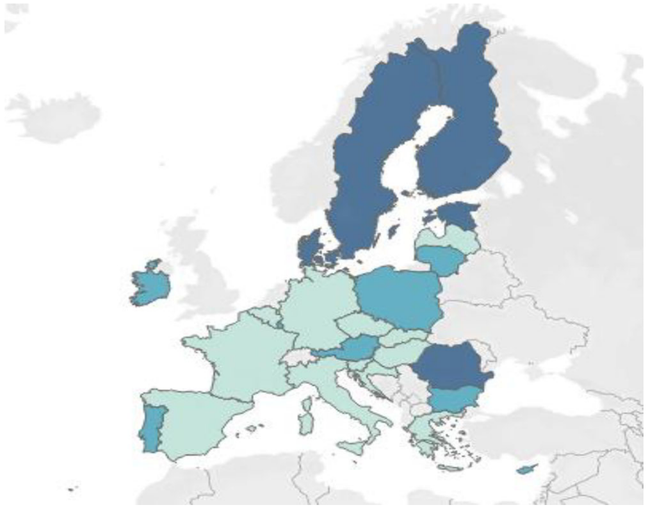

Figure 5. European countries according to domestic material consumption.
Source: authors

Table 7. Correlation matrix.

Correlations

		Material consumption	Direct investment	Global Innovation Index	IESE
Material consumption	Pearson Correlation	1	−0.115	0.166	−0.301
	Sig. (2-tailed)		0.568	0.407	0.127
	N	27	27	27	27
Direct investment	Pearson Correlation	−0.115	1	−0.200	0.069
	Sig. (2-tailed)	0.568		0.317	0.733
	N	27	27	27	27
Global Innovation Index	Pearson Correlation	0.166	−0.200	1	0.198
	Sig. (2-tailed)	0.407	0.317		0.322
	N	27	27	27	27
IESE	Pearson Correlation	−0.301	0.069	0.198	1
	Sig. (2-tailed)	0.127	0.733	0.322	
	N	27	27	27	27

Source: authors.

5. Discussions and conclusions

In the paper, we highlighted the connection between efficiency from an ecological perspective and the resilience of socially ecological systems. At the same time, we have identified the extent to which technological progress through investments can sustain and develop ecological efficiency and develop a robust resilience in the medium and long term.

We started from the following considerations:

- human activity involves resource consumption and has effects on environmental factors and sustainable development and therefore measuring ecological efficiency through a composite index will allow a good analysis of interdependence to ensure economic resilience

- there is a bidirectional but not symmetrical correlation between ecological efficiency and resilience; ecological efficiency does not automatically ensure resilience, but resilience can sustain a positive dynamic of eco-efficiency
- ecological efficiency is measured in various forms and using partial or, more recently, composite indicators - we are actually witnessing an emerging process of developing complex indicators that measure the various dimensions of efficiency in the ecological field; in the paper we have also developed an indicator that takes into account components of resources and results because any economic, social, cultural system to be sustainable must, at the same time, ensure economy in the consumption of resources but without compromising the quality of results and to limit negative externalities.
- financing resilient and ecological development involves resource consumption (significant material and financial) for smart investments, but there are significant differences between countries in support policies and the ability to attract funds, depending on the level of development.

Research focused on various aspects of eco-efficiency and resilience has partially and dispersed highlighted the push factors of resilience. Biggs et al. (2015) consider seven principles for building resilience in social-ecological systems, without referring to ecological efficiency but taking into account ecological diversity. Korhonen and Seager (2008) consider that 'eco-efficiency optimization rarely results in improved diversity or adaptability and consequently may have perverse consequences to sustainability by eroding the resilience of production systems'. Moreover, the experience of recent crises (since 2008 and the pandemic one) have refined research by identifying the need for robust and resilient recovery, respectively 'building back better' and considering climate resilience one of the fifth key dimensions (OECD, 2020).

Our research started from the question of whether eco-efficiency is a stimulating or restricting factor for resilience, and we analyzed the interdependence between the two. The results showed that the resilience is determined by our index, therefore ecological efficiency conduce to resilience.

Starting from the awareness of the need for financing for resilient, robust and sustainable recovery and from the efforts at EU level to finance countries to overcome the Covid-19 crisis (through NextGeneration EU recovery instrument), in the paper we followed the analysis of the relationship between ecological efficiency and material consumption, direct investments and the national innovation index. The obtained results highlighted the link between these indicators is weak. Also our results are consistent with other experts' opinion that after the last financial crisis an underinvestment trend for long-term investments in environmentally friendly development was registered, limiting the sustainable green growth. Innovation for green goods and services with increased resource efficiency is a key determinant to manage climate risks and deliver long-term climate resilient growth. Based on 32 countries and of 1990-3013 period analysis Fernandes et al. (2021) shows that 'sustainable technology transfer and sustainable innovation promote green growth, which in turn positively impacts economic growth'. A climate-friendly development pathway is associated to a 'decisive transition' toward resilient investments in low-emission technology and for limiting the physical and economic damage from climate change, and public policy support 'for mobilising investment in low-carbon infrastructure and technologies' (OECD, 2017).

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In order to promote technologic transfer to increase investment and improve ecological efficiency, several measurements should be politically supported:

- enhancing technology transfer efficiency and bringing knowledge spillovers to industries green transition (Danquah et al., 2018)
- new products and services based on green technological innovation, the efficient use of renewable and non-renewable energy (Lanjouw & Mody, 1996)
- wider cooperation between universities/research centers and business sector for technological transfer
- FDI associated with technology transfer with at least zero environmental impact (Khan & Ulucak, 2020; Peng et al., 2022)
- attracting funding sources at EU level- structural funds and more recently funds from national recovery and resilience plans.

Additionally, based on our own research results, we can conclude the following:

a. it is necessary to define and measure eco-efficiency through a composite index, taking into account the increasing complexity of the concept and the need to capture through a synthetic value the essential aspects of effort and effect;
b. the increase of the ecological efficiency does not determine a positive evolution on the development and preservation of the resilience of the socio-eco-economic systems and, therefore, it is necessary to consider the dynamics of the relationship between them as a warning tool for adjusting public policies;
c. short-term resilience does not ensure a robust and sustainable recovery, and the return is made through other correlations-balances, which absorb the new transformations of the society and of the environment. Therefore, the financing for maintaining the resilience of the socio-eco-economic systems is the responsibility of the states, from both public and private sources;
d. the countries with lower level of development are the ones that have the most needs for financing resilient development and, therefore, facilities are needed - special funds from regional/international sources, the support of banks for affordable interest rates, etc.

As future research, we aim to develop the analysis of the eco-efficiency-resilience relationship by testing the developed indicator on a larger number of countries, and on a wider time horizon.

Disclosure statement

No potential conflict of interest was reported by the authors.

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