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A comparison of environmental and energetic performance of European Countries: a Sustainability Index

Federica Cucchiella[1], Idiano D'Adamo[1,*], SC Lenny Koh[2] Massimo Gastaldi[1] and Paolo Rosa[3]

1 Department of Industrial and Information Engineering and Economics, University of L'Aquila, Via G. Gronchi 18, 67100 L'Aquila, Italy

2 Advanced Resource Efficiency Centre, The University of Sheffield, Conduit Road, Sheffield S10 1 FL, United Kingdom

3 Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Piazza L. Da Vinci 32, 20133 Milano, Italy

federica.cucchiella@univaq.it; idiano.dadamo@univaq.it; S.C.L.Koh@sheffield.ac.uk; Massimo.gastaldi@univaq.it; paolo1.rosa@polimi.it

* Corresponding author

Abstract

Recently, European countries agreed on a new 2030-pact establishing challenging levels for a set of climate and energy indexes in order to achieve a more competitive, safe and sustainable energy system. In order to evaluate current sustainability performances of European countries from the environmental and energetic perspectives, this research proposes a Multi-Criteria Decision Analysis (MCDA) that, starting from both Eurostat data and the Analytic Hierarchy Process (AHP), allows a direct comparison of nations. To this aim, multiple indexes are taken into account (e.g. Greenhouse gas (GHG) emissions, Government expenditures for environmental protection, Recycled and reused waste from electric and electronic equipments (WEEEs), Recycled and reused waste from end-of-life vehicles (ELVs), Recycled materials from Municipal Solid Wastes (MSWs), Share of renewable energy (RE) in electricity, Share of RE in transport, Share of RE in heating and cooling and Primary energy consumption). This assessment model provides a sustainability value for each European country and the related ranking with the European average. Results show as, even nowadays, twelve out of twenty-eight European countries have a value greater than the European average in 2013. Top four nations (Sweden, Denmark, Finland and Austria) have high indexes of sustainability and Sweden is the best country from both the environmental and energetic perspectives.

Keywords: Energy, Environment, European Union, Multi-criteria decision analysis, Sustainability.

1. Introduction

Recently, European countries agreed on a new 2030-pact (Framework) establishing challenging levels for a set of climate and energy indexes in order to achieve a more competitive, safe and sustainable energy system. New 2030 targets define: (i) 40% cut in GHG emissions, in comparison to 1990 levels; (ii) at least 27% share of RE consumption and (iii) at least 27% energy savings, in comparison with the business-as-usual scenario. After a decade of annual growth rates of about 4%, followed by two years (2012 and 2013) of slowing down to about 1%, emissions from both fossil-fuel combustion and industrial processes worldwide equal to 35.7 billion tonnes of CO_2 in 2014 (+0.5% than the previous year). China is the main country responsible for these emissions (30%), followed by United States (15%), Europe (10%) and India (6.5%) [1].

From one side, renewable energy sources (RES) [2, 3] and energy efficiency [4, 5] are useful and strategic to reach the several energy European goals: the security of supply, the reduction of GHG emissions, lower energy costs, and industrial development led to growth and jobs. From another side, a significant amount of potential secondary raw materials is currently lost and the application of European waste hierarchy aims to have a sustainable waste management (SWM): the reduction of GHG emissions, the counteraction of health problems, and deterioration of landscape, water and air due to landfilling. Furthermore, high recycling rates are able to alleviate European reliance on resource imports, boosting security of supply of some of the critical resources used in new technologies [6, 7].

The development of RES was initially evaluated as an alternative to the depletion of fossil fuels, while currently it represents an optimal solution to the achievement of sustainable energy systems [8, 9]. RE is becoming a widely accepted and used source of energy [10, 11]. International Energy Agency (IEA) report highlights its new capacity of 128 GW installed in 2014 representing 45% of total capacity additions [12]. The transition to a sustainable energy system is often accompanied by a transformation of local communities, in which the development of a shared vision is a factor of strength [13]. As indicated in the existing literature, subsidies allowed the development of the sector and the growing of installed power has produced a reduction of cost making RES competitive [14, 15]. The use of energy in the 21st century can be sustainable and all sectors (e.g. electricity, transport, heating and cooling) aim to have clean, affordable and reliable energy [16-18].

In this new direction, decoupling between the economic growth and GHG emissions is needed, by improving the end-use energy efficiency [19]. These investments worldwide since 1990 have generated 256 EJ of avoided consumption. For the first time, an annual value greater than 20 EJ has been reached in 2014 [20]. Measures outlined in research and policy action plans are almost exclusively technology-oriented, but successful energy management practices require its integration with operational phases [21]. A gap in real practices is represented by an integrated dataset of energy efficiency measures published as linked open data [22], but it is also useful to examine the market barriers to energy efficiency by analysing several dimensions such as social psychology, organizational theory, system perspective and economic concepts [23].

Depletion of resources and deterioration of the environment accelerated the transition towards a circular economy, and in the last years there is increased attention about the integration of end-of-life (EoL) strategies within the value chain [24]. Nowadays, wastes are often seen as a resource, especially from an economic perspective. In the last decades, WEEEs, ELVs and MSWs have attracted an increasing number of industrial actors, policy-makers and researchers [25]. Several directives on these waste streams were delivered, especially in the last decades. The WEEE directive fixes a target on the minimum amount of e-wastes to be collected per capita in each nation. This limit is fixed to 4 kg/inhabitant. The ELV directive does not fixes an explicit amount. In this case, levels are established basing on the average weight of cars. These limits are explicated in terms of percentage of the overall mass that must be reused, recycled and recovered. Precisely, 95% of the mass must be reused and recovered. Instead, 85% of the mass must be reused and recycled. About MSWs, there are explicit limits only about the level of recycling to be reached about municipal wastes and packages. The first one is fixed to 65% and the second one to 75%. All of them must be reached by each nation within 2030. WEEEs are clearly increasing and potential revenues from recycled e-waste are estimated to be equal to two billion Euros in the year 2014 for the European market [26] and sixteen billion of American Dollars in the year 2010 for the Chinese one [27]. Printed circuit boards (PCBs) represent the most complex, hazardous, and valuable component of e-wastes [28]. Economic analysis has already been tested in different industrial contexts. The amount of profits that could be potentially achieved equates four billion six hundred and fifty million Euros in automotive sector [29] and three billion eight hundred and twenty million Euros [30] in e-waste sector in the year 2015 for the European market. Another inevitable product of civilization is represented by MSW and its global market is one hundred sixty billion American Dollars in the year 2013 [31].

The sustainability is characterised by several aspects and so it is not simple to define one representative value [32, 33]. This paper attempts to address this gap and a methodology based on MCDA compares European countries for a specific topic “Environment and energy” as defined in Eurostat database. The uncertainty depend upon two factors: (i) the volatility of input data and (ii) the percentage weight of indexes. A mixed evaluation model based on Eurostat data and AHP is proposed in this paper. We considered values defined by a single source and conducted a survey among researchers and experts in these fields. The aim is to propose a current ranking of European countries in terms of sustainability in environment and energy topics that could be useful as a comparison baseline for future years, by highlighting strengths and weakness of each country.

2. Literature review

Multi-criteria decision-making (MCDM) or MCDA is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments. It is concerned with theory and methodology that can treat complex problems encountered in business, engineering, and other areas of human activity [34]. To that end, MCDM methods have been proposed in recent years as a means for helping decision-makers in selecting the best compromise among alternatives, as well as providing them with a powerful tool towards convincing the public over the optimal resource management strategy [35]. In brief, the key feature of MCDA techniques is its flexibility on the judgement of the decision-making team, which explores the optimal option by assigning performance scores and weights. One of the major drawbacks is uncertainty [36, 37]. For instance, general sources of individual uncertainties could come from data series uncertainties, uncertainty about the future, synergies and idiosyncrasies in the interpretation of ambiguous or incomplete information. In a complex decision-making context, the existence of issues such as interdependence of preferences and double counting presents another type of uncertainty in real-world case studies. Sustainability is a term that, especially in the last decade, has become fundamental for many purposes (e.g. government policies, university research projects, and corporate strategies) [38]. Several sustainability indicators still exists. However, measuring sustainability is not an easy work. It requires competencies about the level of viability of the systems involved and their contribution to sustainability [39]. The United Nations Commission on Sustainable Development (UNCSD) proposed the first set of indicators in 1995, under the name Human Development Index (HDI) [40]. The Environmental Performance Index (EPI), a mix of 25 performance indexes particularly focused on reducing environmental stresses to human health and promoting ecosystem vitality and sound natural resource management, represents an evolution [41]. However, the most referenced sustainability index in the current literature is the Ecological Footprint (EF). Its basic assumption is that each category of goods consumption and waste emission has its counterpart, respectively, the production capacity and absorption capacity of a given land [42]. Finally, a comparison among several indexes is proposed by: ecological footprint, environmental sustainability index, renewability and energy sustainability index. Results define that there is not a completely satisfactory index [43]. Despite this amount of indexes, the term “sustainability’’ still lacks a clear and distinct meaning due to its multidimensional nature. The border between sustainability and unsustainability is fuzzy and it is not possible to determine exact reference values [44]. Different sustainability indicators tend to reflect different or even converse outcomes by countries [45]. This way, misleading results and conclusions inevitably confuse any actor willing to use them.

Several works evaluate sustainable indicators regarding types of environmental and energy topics proposed in section 1 (waste management, energy efficiency, renewables and pollutant emissions) – Table 1. Life cycle analysis (LCA) and MCDA are methodology widely used in this context and the sustainability is evaluated through several parameters (economic, energetic, environmental, political, technological, societal). The comparison among several countries or cities is not typically evaluated. An MCDM tool that measures the sustainability has not been found in the literature and this paper aims to fill this gap. To that aim, the current work wants to propose an innovative – and easier – way to compare the sustainability level of countries, considering only a set of indexes in Environment and energy topic defined by an official European database, like Eurostat.

Table 1. Literature review

Source	Typology	Topic	Methodology	Parameters		Comparison countries	
				Multiple	Single	Yes	No
[46]	Literature review	Waste management	MCDA	x			x
[47]	Case study	Energy efficiency	Decision tree	x			x
[48]	Case study	Pollutant emissions	AHP		x	X	
[49]	Literature review	Renewables	LCA, MCDA	x			x
[50]	Case study	Pollutant emissions	LCA	x			x
[51]	Case study	Renewables	MCA	x			x
[52]	Case study	Waste management	AHP	x			x
[53]	Case study	Energy efficiency	LCA	x			x
[54]	Literature review	Renewables	MCDA	x			x
[55]	Case study	Waste management	LCA	x			x
[56]	Literature review	Renewables	LCA	x			x
[57]	Literature review	Pollutant emissions	LCA		x		x
[58]	Case study	Waste management	MCDA	x			x

[59]	Literature review	Energy efficiency	LCA	x			x
[60]	Literature review	Pollutant emissions	MCDA	x			x
[61]	Case study	Waste management	MCDA	x			x
[62]	Case study	Pollutant emissions	MCDA	x		x	
[63]	Case study	Energy efficiency	LCA	x			x
[36]	Literature review	Renewables	MCDA	x			x
[64]	Case study	Waste management	AHP	x			x
[65]	Case study	Energy efficiency	LCA	x			x
[33]	Case study	Renewables	SEDI	x		x	
[66]	Case study	Energy efficiency	MCDA	x			x
[67]	Literature review	Pollutant emissions	CFP		x		x

An overview of the most popular existing MCDM methods is proposed by [68] and a recent review has defined the AHP as the main technique in MCDM method used in sustainable and renewable energy systems problems [69]. AHP is still widely used today [70]. The term ‘analytic’ indicates that the problem is broken down into its constitutive elements. The term ‘hierarchy’ indicates that a hierarchy of the constitutive elements is listed in relation to the main goal while the term ‘process’ indicates that data and judgments are processed to reach the final result. The main advantages related to the AHP methodology are: (i) the hierarchical structure definition, presenting all the involved variables and their relationships, (ii) the decisional problem is proposed in a structured way, (iii) the technique does not replaces personal evaluations of the interviewed experts, but integrates all their judgments in a structured way, (iv) from a simple choice, the decision is derived through a logical process [46, 71].

3. Materials and methods

MCDA method can analyse several aspects of sustainable performance of a country and it comprises several phases [72]:

1. Definition of the projects (section 3.1).
2. Definition of judgement criteria (section 3.2).
3. Assignment of weight to each criteria (section 3.3).
4. Assignment of value to each criteria (section 3.4).
5. Aggregation of judgements (section 4).
6. Sensitivity analysis (section 5).
7. Discussion (section 6).

3.1 Definition of the projects

The European Union is composed by twenty-eight member states and consequently the number of alternative projects analysed in this paper is chosen based on this value. The aim of MCDA in this study is to define the sustainability value (S) for each alternative project (J). It is calculated by the product of (I) - row vector, that represents the value of each criteria - with (W) - column vector, that represents the weight of each criteria - and it is a dimensionless value.

$$S_J = I_J * W_J * 100 \qquad \text{with } J = \text{project} \qquad (1)$$

3.2 Definition of judgement criteria

The use of effectiveness indicators for evaluating the sustainability of a country is a critical phase of the decision making process [73]. In our research, we analysed a set of indicators proposed by Eurostat for the two specific topics "Environment and energy". Eurostat is a Directorate-General of the European Commission and its main responsibilities are to give statistical information to the institutions of the EU and to favour the harmonisation of statistical methods across its member states.

Database is subdivided into nine topics ((i) General and regional statistics; (ii) Economy and finance; (iii) Population and social conditions; (iv) Industry, trade and service; (v) Agriculture, forestry and fisheries; (vi) International trade; (vii) Transport; (viii) Environment and energy and (ix) Science and technology), which in turn are divided into sub-topics. We have concentrated our attention on a specific topic "Environment and energy" and all subtopics are reported in Table 2. Each subtopic is analysed and an indicator is suitable when five constraints are verified:

i. It is linked to the concept of sustainability;
ii. It is not redundant;
iii. It is characterized by the presence of values for all countries;
iv. It is comparable;
v. It is analysed by current scientific literature.

Table 2. Topic "Environment and energy" [74]

Environment	Energy
√ Emissions of greenhouse gas and air pollutants	√ Energy statistics - Quantities, annual data
√ Material flows and resource productivity	√ Energy statistics - Quantities, monthly data
√ Environmental taxes	√ Energy statistics - Short-term monthly data

√ Environmental protection expenditure	√ Energy statistics - Prices of natural gas and electricity
√ Environmental goods and services sector	√ Energy statistics - Market structure indicators
√ Waste	√ Energy statistics - Heating degree days
√ Water	
√ Biodiversity	
√ Regional environmental statistics	

In this paper we have chosen nine indicators, according to Miller's rule, because the dimension of AHP comparison matrices must be seven ± two [75]:

- Greenhouse gas emissions (GhCo)
  [Emissions of greenhouse gas and air pollutants → Air Emissions Inventories].
- Total general government expenditures for environmental protection actions (GeEp)
  [Environmental protection expenditure → Environmental protection expenditure of general government by COFOG groups and economic transactions].
- Total recycled and reused waste from WEEEs (RrWe)
  [Waste → Waste streams → Waste Electrical and Electronic Equipment].
- Total recycled and reused waste from ELVs (RrEl)
  [Waste → Waste streams → End-of-life vehicles: Reuse, recycling and recovery, Totals].
- Total recycled materials from Municipal Solid Wastes (RmMs)
  [Waste → Waste streams → Municipal waste].
- Share of renewable energy in electricity (ReEl)
  [Energy statistics - Quantities, annual data → Indicators and other data].
- Share of renewable energy in transport (ReTr)
  [Energy statistics - Quantities, annual data → Indicators and other data].
- Share of renewable energy in heating and cooling (ReHc)
  [Energy statistics - Quantities, annual data → Indicators and other data].
- Percentage change of primary energy consumption in a specific period (EfPc)
  [Energy statistics - Quantities, annual data → Indicators and other data].

Once all judgement criteria have been identified, it is possible to define the row vector (I), composed by nine columns (equal to the number of indicators).

$$I = [GhCo \;\; GeEp \;\; RrWe \;\; RrEl \;\; RmMs \;\; ReEl \;\; ReTr \;\; ReHc \;\; EfPc] \quad (2)$$

As highlighted in section 1, sustainability is linked strictly to: (i) reduction of emissions; (ii) EoL management of waste; (iii) renewables and (iv) energy efficiency. Although sustainability includes economic and societal pillars, but this row vector does not present them. In fact, when analysing the indicators proposed by Eurostat for Environment and energy topic, economic and societal indexes are not available.

3.3 Assignment of weight to each criterion

AHP is a theory and process of measurement through pairwise comparisons based upon the judgments of experts to derive the priority scales [76]. The accuracy of analysis depends on the user's knowledge in the area, so we exploited a survey involving twenty researchers with extensive experience – Table 3.

Table 3. Survey participants

N°	Role	Country	H-index
1	Director of Research Centre	United States	31
2	Director of Research Centre	United Kingdom	27
3	Director of Research Centre	United States	25
4	Director of Research Centre	India	32
5	Director of Research Centre	Sweden	31
6	Director of Research Centre	China	35
7	Full Professor	Brazil	27
8	Full Professor	Singapore	34
9	Full Professor	United States	43
10	Full Professor	Saudi Arabia	39
11	Full Professor	Malaysia	28
12	Full Professor	Spain	34
13	Full Professor	Denmark	41
14	Associate Professor	Italy	36
15	Associate Professor	Greece	16
16	Associate Professor	Turkey	17
17	Associate Professor	China	26
18	Associate Professor	Germany	20
19	Associate Professor	Japan	20
20	Associate Professor	Belgium	20

AHP weights can be calculated through Microsoft Excel [77] and literature proposes the use of judgement scale from one to nine – Table 4. These pairwise comparisons were performed for all the considered criteria, until the matrix is completed.

Table 4. Pair-wise comparison scale for AHP preferences [34, 76]

Numerical rating	Verbal judgements of preferences
1	Equally preferred
2	Equally to moderately
3	Moderately preferred
4	Moderately to strongly
5	Strongly preferred
6	Strongly to very strongly
7	Very strongly preferred
8	Very strongly to extremely
9	Extremely preferred

Eighty-one values assigned by each decision maker were aggregated. By considering twenty respondents, it is necessary to evaluate the related geometric means. There are numerous special classes of matrices where the weights vector (W – also called the Eigen vector) can be calculated, as triangular matrices, factorable polynomial equations, nxn matrices and nxm matrices. W is a column vector, composed by nine rows (equal to number of criteria).

$$W = [w_{GhCo}\ \ w_{GeEp}\ \ w_{RrWe}\ \ w_{RrEl}\ \ w_{RmMs}\ \ w_{ReEl}\ \ w_{ReTr}\ \ w_{ReHc}\ \ w_{EfPc}]^T \qquad (3)$$

We used nxm matrices, in fact the sustainability value is obtained multiplying the row vector composed by nine columns (1, 9) and the column vector composed by nine rows (9, 1) – see equation 1. The numerical rating ranges from 1 to 9 (see Table 4) and consequently, the normalizing approach proposed by [78, 79] is required.

The final step involved the calculation of a Consistency Ratio (CR) measuring the consistency of a pairwise comparison matrix [54] and consequently, it does not influence the value of components of column vector W and the calculated results of sustainability. If the CR is lower than 0.10 (or 10%) judgements are trustworthy, because they are far from randomness and the exercise is valuable and must not be repeated [76]. The CR is calculated by dividing the consistency index (CI) by the Random Inconsistency (RI) value that corresponds to the number of factors (n).

$$CR = CI / RI \qquad (4)$$

$$CI = (\lambda_{max}-n) / (n-1) \quad (5)$$

where RI values are defined by [76] in Table 5 and λ_{max} is the inner product of the row vector containing column sums and the Eigen vector matrix.

Table 5. Random Inconsistency values for different number of factors [76]

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.4 Assignment of value to each criterion

The volatility of input data can cause uncertainty and consequently results may be unreliable due to the non-homogeneity of this information [80]. Eurostat aimed to solve this issue and, within the paper, the proposed values comes from this source (2013 is the latest year available, only values for GeEp are referred to 2012) – Table 6. Furthermore, all the indexes must have a comparable unit of measure. From the environment side, RrWe and RmMs are already proposed as unit of weight per capita, while GhCo, GeEp and RrEl present absolute values and they are divided for the number of population; from the energy side ReEl, ReTr and ReHC are proposed as percentage values, while EfPc presents absolute values and are converted as percentage change of last five years.

Table 6. Input data in 2013 [74]

GhCo = Greenhouse gas emissions in 2013 (tons of CO_2 equivalent per capita).

GeEp = Total general government expenditures for environmental protection actions in 2012 (€ per capita).

RrWe = Total recycled and reused waste from WEEEs in 2013 (kilograms per capita).

RrEl = Total recycled and reused waste from ELVs in 2013 (kilograms per capita).

RmMs = Total recycled materials from MSWs in 2013 (kilograms per capita).

ReEl = Share of RE in electricity in 2013 (%).

ReTr = Share of RE in transport in 2013 (%).

ReHc = Share of RE in heating and cooling in 2013 (%).

EfPc = Percentage change of primary energy consumption in 2008-2013 period (%).

* = Estimated.

	GhCo	GeEp	RrWe	RrEl	RmMs	ReEl	ReTr	ReHc	EfPc
Belgium	10.4	228	8.5	11.5	150	12.4	4.3	7.5	-4.7
Bulgaria	6.4	39	4.0	8.0	108	18.9	5.6	29.2	-13.8
Czech Republic	11.4	198	4.7	8.8	65	12.8	5.6	15.4	-6.4

Denmark	10.2	177	10.6	19.9	206	43.1	5.7	34.9	-7.7
Germany	11.6	190	7.5	5.5	284	25.3	6.4	10.6	-3.9
Estonia	16.2	113	2.3	9.6	37	13	0.2	43.2	14.0
Ireland	13.6	287	7.7	17.2	180	20.8	4.9	5.4	-13.0
Greece	9.3	97	3.2	6.6	79	21.2	1	26.5	-23.6
Spain	6.2	179	3.7	13.8	70	36.7	0.5	14.1	-14.8
France	6.8	344	5.7	15.7	111	16.8	7.2	17.8	-3.7
Croatia	4.5	39	3.4	6.8	54	42.2	2.2	37.2	-12.1
Italy	6.8	235	6.4	13.2	122	31.3	4.9	18.1	-13.6
Cyprus	8.9	64	2.1	11.4	81	6.6	1.1	21.7	-21.4
Latvia	5.3	79	2.2	4.1	33	48.8	3.1	49.7	-4.3
Lithuania	3.4	98	3.8	9.6	88	13.1	4.6	37.7	-29.6
Luxembourg	19.9	1064	8.3	3.9	174	5.3	3.8	5.8	-6.5
Hungary	5.4	69	4.4	1.4	81	6.6	5.6	12.6	-15.4
Malta	6.6	242	3.9	2.3	46	1.6	3.5	14.6	0.0
Netherlands	12.0	603	5.8	9.7	126	10	4.6	4.1	-4.3
Austria	8.8	196	7.2	6.6	142	68	7.8	32.7	-1.5
Poland	9.4	56	3.4	9.3	39	10.7	6	14.1	0.2
Portugal	5.3	74	4.1	6.8	57	49.1	0.7	34.5	-10.3
Romania	4.3	51	1.0*	2.1*	11	37.5	4.6	26.2	-18.4
Slovenia	6.5	120	2.1	2.2*	116	33.1	3.5	33.7	-9.3
Slovakia	6.6	123	3.6	5.1	20	20.8	5.3	7.9	-6.5
Finland	7.9	90	9.4	15.1	94	30.9	9.6	50.8	-4.9
Sweden	1.5	148	15.4	21.3	150	61.8	17	67.1	0.2
United Kingdom	8.9	277	5.9*	14.9	132	13.8	4.4	3.8	-7.4
EU 28	8.2	211	5.7*	10.9	128	25.4	5.4	16.6	-7.3

4. Results

The sustainability value (S) for each country is calculated as the product of the row vector (which represents indexes measuring the sustainability for a specific topic namely Environment and energy) and the column vector (which represents the weight that each indicator has in this sustainable mix).

Starting by the column vector (W), an explicative evaluation scale (proposed by one of the interviewees) is reported in Table 7, aiming to define the influence in sustainability terms of one indicator on the others. Then, these values were normalized according to section 3.3 (Table 8). All calculations were made seeking to develop a model that is replicable. Starting from the sum of the GhCo column values equal to 10.67 and taking the 0.33 value of the second row and first column (GeEp vs GhCo), the normalization to 1 of this value is performed as follows:

$$(0.33*1) / 10.67 = 0.03. \quad (6)$$

Later, we calculate the weight of each indicator in the sustainable mix, then we proceed to add up all the values of the indicator line matrix, and divide the result by the number of indicators. For example, the weight of GhCo is obtained as follows:

$$(0.09+0.13+0.12+0.19+0.14+0.10+0.04+0.07+0.14) / 9 = 1.02 / 9 = 0.11 \quad (7)$$

By repeating this operation for all the indicators, we got the following normalized column vector, obtained from the information given by the resulting survey:

$$W = [0.11 \;\; 0.05 \;\; 0.12 \;\; 0.13 \;\; 0.08 \;\; 0.20 \;\; 0.13 \;\; 0.14 \;\; 0.04]^T \quad (8)$$

Table 7. Judgement scale – An example

	GhCo	GeEp	RrWe	RrEl	RmMs	ReEl	ReTr	ReHc	EfPc
GhCo	1	3	1	2	2	0.5	0.33	0.50	3
GeEp	0.33	1	0.33	0.50	0.50	0.25	0.33	0.25	2
RrWe	1	3	1	2	2	0.33	1	1	3
RrEl	0.50	2	0.50	1	3	0.33	2	2	2
RmMs	0.50	2	0.50	0.33	1	0.33	1	1	2
ReEl	2	4	3	3	3	1	1	1	3
ReTr	3	3	1	0.50	1	1.00	1	0.50	3
ReHc	2	4	1	0.50	1	1.00	2	1	3
EfPc	0.33	0.50	0.33	0.50	0.50	0.33	0.33	0.33	1
Total	10.67	22.50	8.67	10.33	14.00	5.08	9.00	7.58	22.00

Table 8. Normalized judgement scale – An example

	GhCo	GeEp	RrWe	RrEl	RmMs	ReEl	ReTr	ReHc	EfPc	Total	Avg
GhCo	0.09	0.13	0.12	0.19	0.14	0.10	0.04	0.07	0.14	1.02	**0.11**
GeEp	0.03	0.04	0.04	0.05	0.04	0.05	0.04	0.03	0.09	0.41	**0.05**
RrWe	0.09	0.13	0.12	0.19	0.14	0.07	0.11	0.13	0.14	1.12	**0.12**
RrEl	0.05	0.09	0.06	0.10	0.21	0.07	0.22	0.26	0.09	1.15	**0.13**
RmMs	0.05	0.09	0.06	0.03	0.07	0.07	0.11	0.13	0.09	0.70	**0.08**
ReEl	0.19	0.18	0.35	0.29	0.21	0.20	0.11	0.13	0.14	1.79	**0.20**

ReTr	0.28	0.13	0.12	0.05	0.07	0.20	0.11	0.07	0.14	1.16	**0.13**
ReHc	0.19	0.18	0.12	0.05	0.07	0.20	0.22	0.13	0.14	1.29	**0.14**
EfPc	0.03	0.02	0.04	0.05	0.04	0.07	0.04	0.04	0.05	0.37	**0.04**
Total	1	1	1	1	1	1	1	1	1	9	**1**

The following step is represented by the evaluation of CR. Firstly, λ_{max} is the inner product of the last row of Table 7 and the last vector of Table 8, as shown below:

λ_{max} = [10.67 22.50 8.67 10.33 14.00 5.08 9.00 7.58 22.00] * [0.11 0.05 0.12 0.13 0.08 0.20 0.13 0.14 0.04]^T = 9.87 (9)

The CI is calculated as follows:

CI = (9.87 – 9) / (9 – 1) = 0.11 (10)

Secondly, RI value corresponds to n. For n = 9 → RI = 1.45 from Table 5. Thus,

CR = 0.11 / 1.45 = 0.075 (11)

This value is smaller than 0.10 (see section 3.3) and it is possible to say that there is a required consistency in the judgement. Consequently, it is not necessary any further discussion with survey's participants to redefine their priorities.

The same phases are repeated for all the twenty interviewees, by defining the percentage weights of nine criteria – Table 9. Furthermore, the CR is always verified – Table 10. Its value ranges from 0.048 to 0.088. Consequently, all pairwise comparison matrix are consistent. However, it should be noted that the numbers (Tables 9 and 10) obtained from each interviewee are not specular of what has been presented in Table 3 (mainly for anonymity reasons).

Table 9. Percentage weights of nine criteria by twenty interviewees

N°	GhCo	GeEp	RrWe	RrEl	RmMs	ReEl	ReTr	ReHc	EfPc	Total
1	0.11	0.05	0.12	0.13	0.08	0.20	0.13	0.14	0.04	**1**
2	0.11	0.08	0.14	0.10	0.10	0.20	0.11	0.11	0.05	**1**
3	0.09	0.08	0.11	0.11	0.12	0.21	0.11	0.12	0.06	**1**
4	0.11	0.11	0.16	0.10	0.11	0.13	0.10	0.12	0.05	**1**
5	0.13	0.06	0.17	0.09	0.12	0.14	0.11	0.13	0.05	**1**
6	0.11	0.06	0.15	0.11	0.11	0.20	0.10	0.12	0.06	**1**
7	0.07	0.07	0.17	0.08	0.12	0.13	0.14	0.12	0.10	**1**
8	0.12	0.07	0.09	0.08	0.08	0.16	0.18	0.12	0.09	**1**
9	0.08	0.07	0.09	0.09	0.10	0.11	0.16	0.19	0.11	**1**

10	0.18	0.06	0.08	0.09	0.10	0.11	0.13	0.15	0.11	**1**
11	0.16	0.07	0.08	0.08	0.08	0.19	0.12	0.14	0.06	**1**
12	0.13	0.07	0.11	0.11	0.13	0.14	0.12	0.12	0.08	**1**
13	0.12	0.09	0.13	0.10	0.12	0.19	0.11	0.09	0.05	**1**
14	0.13	0.06	0.14	0.10	0.12	0.16	0.11	0.11	0.06	**1**
15	0.16	0.09	0.17	0.08	0.10	0.14	0.11	0.08	0.07	**1**
16	0.17	0.08	0.18	0.09	0.11	0.12	0.12	0.08	0.05	**1**
17	0.20	0.09	0.11	0.08	0.11	0.15	0.10	0.09	0.06	**1**
18	0.16	0.05	0.14	0.12	0.08	0.19	0.12	0.09	0.06	**1**
19	0.09	0.04	0.12	0.14	0.07	0.18	0.13	0.13	0.10	**1**
20	0.16	0.05	0.17	0.11	0.08	0.16	0.10	0.10	0.07	**1**

Table 10. Consistency Ratio by twenty interviewees

n	1	2	3	4	5	6	7	8	9	10
CR	0.075	0.087	0.078	0.074	0.064	0.068	0.085	0.086	0.077	0.071
n	11	12	13	14	15	16	17	18	19	20
CR	0.048	0.066	0.073	0.067	0.061	0.071	0.088	0.058	0.064	0.061

Starting by the percentage weights obtained from all the twenty interviewees (Table 9), and through the geometric mean, the vector W used in this work is obtained – Table 11. For example, the product of weights attributed to the GhCo indicator is equal to $9.2*10^{-19}$ and the twentieth root of this last value is equal to 0.13:

$$(0.11*0.11*0.09*0.11*0.13*0.11*0.07*0.12*0.08*0.18*0.16*0.13*0.12*0.13*0.16*0.17*0.20*0.16*0.09*0.16)^{\wedge}(1/20) = 9.2*10^{-19}{}^{\wedge}(1/20) = 0.13 \quad (12)$$

The statistical analysis of these pairwise comparisons is defined as:

- The normalized arithmetic mean has values near the geometric ones.
- The range of the standard deviation varies in a non-significant way (equal to 0.3 for GhCo, RrWe, ReEl and ReHc indicators and 0.2 for GeEp, RrEl, RmMs, ReTr and EfPc indicators).

Table 11. Normalized column vector

GhCo	GeEp	RrWe	RrEl	RmMs	ReEl	ReTr	ReHc	EfPc	Total
0.13	0.07	0.13	0.10	0.10	0.16	0.12	0.12	0.07	**1**

The AHP assessment shows that five "environmental" indicators have a higher weight than four "energy" ones (53% vs 47%) and half of the interviewees believed that ReEl is the indicator with the greatest impact on sustainability, often reaching a value equal to 16%. Electricity is the sector contributing more in reducing the share of fossil fuels in the global energy mix, but a lot of importance is given also to the role of renewables in the heat and in transport sectors (ReTr and ReHc both equal to 12%). Together with low-carbon technologies, energy efficiency is playing an increasingly prominent role in national energy strategies. This indicator has a lower weight (7%), but it is the same one used to measure the EU's 20-20-20 goals. In addition, a significant percentage reduction can be caused by an economic crisis and, therefore, it would be more appropriate to assess this indicator together with the national gross domestic product.

Often, the reduction of pollutant emissions is considered as the most important goal to be achieved in a sustainable system. However, only two interviewees considered it as the most significant indicator. The absence of a predominant share of industrial activities in national production mix can push towards low values and the same result is obtained by a high presence of the service industry. However, this indicator is the same one used to measure the EU's 20-20-20 goals. Probably, also because of these issues, a sustainability index is considered appropriate when it takes into account reuse and recycling activities. Among the three main sources of waste examined, e-waste had the greatest weight, and six interviewees considered them as the most significant indicator. Normalized column vector highlights that RrWe weight of is the same of GhCo (equal to 13%). The economic amount of embedded value and precious materials within electric and electronic products consumed on a daily basis are very promising. The recycling of e-wastes potentially allows the reduction of environmental pollution and the conservation of virgin resources. Today, these wastes and their harmful substances end up forgotten in a desk drawer or, worse, in a landfill. However, the difference is limited in comparison to RrEl and RmMs (both 10%). Finally, governments must invest in environment protection, but a low significance is given to this indicator by the experts (GeEp 7%), since public investment can finance also inefficient measures.

After the assignment of weights to each criteria through AHP, the authors analysed the indicators by measuring the sustainability for each specific topic, or environment and energy. The homogeneity of the data is required considering that the indicators have different scales of value among them and starting by values proposed in Table 6, it was possible to proceed with the estimation of the normalized row vector (I). Here, each component varies from 0 to 1 [78] – Table 12. The value 1 is assigned to the best sustainable performance, without a direct correspondence with the highest numerical value.

Instead, GhCo and EfPc indicators take the value 1 when reaching the lowest value. A country is more sustainable if it has a low level of pollutant emissions and if, over a time period, lowered its energy consumption. For example, by analysing the GhCo indicator, the first column of the vector I is calculated as follows:

- 1 for Sweden (maximum value equal to 1.5 tons of CO_2 equivalent per capita). (13)
- 0 for Luxembourg (minimum value equal to 19.9 tons of CO_2 equivalent per capita). (14)
- 0.45 for Germany (intermediate value equal to 11.6 tons of CO_2 equivalent per capita) deriving by (11.6-19.9) / (1.5-19.9) = 0.45. (15)

By analysing other seven indicators, the value 1 corresponds to the highest numerical value. For example, by considering the ReEl indicator, the sixth column of the vector I is calculated as follows:

- 1 for Austria (maximum value equal to 68%). (16)
- 0 for Malta (minimum value equal to 1.6%). (17)
- 0.45 for Italy (intermediate value equal to 31.3%) deriving by (31.3-1.6) / (68-1.6) = 0.45. (18)

Table 12. Normalized row vector for all countries

	GhCo	GeEp	RrWe	RrEl	RmMs	ReEl	ReTr	ReHc	EfPc
Belgium	0.52	0.18	0.52	0.51	0.51	0.16	0.24	0.06	0.43
Bulgaria	0.73	0.00	0.21	0.33	0.36	0.26	0.32	0.40	0.64
Czech Republic	0.46	0.15	0.26	0.37	0.20	0.17	0.32	0.18	0.47
Denmark	0.53	0.13	0.67	0.93	0.71	0.63	0.33	0.49	0.50
Germany	0.45	0.15	0.45	0.21	1.00	0.36	0.37	0.11	0.41
Estonia	0.20	0.07	0.09	0.42	0.10	0.17	0.00	0.62	0.00
Ireland	0.34	0.24	0.47	0.79	0.62	0.29	0.28	0.03	0.62
Greece	0.58	0.06	0.15	0.26	0.25	0.30	0.05	0.36	0.86
Spain	0.75	0.14	0.19	0.63	0.22	0.53	0.02	0.16	0.66
France	0.71	0.30	0.33	0.72	0.37	0.23	0.42	0.22	0.41
Croatia	0.83	0.00	0.17	0.27	0.16	0.61	0.12	0.53	0.60
Italy	0.71	0.19	0.38	0.60	0.41	0.45	0.28	0.23	0.63
Cyprus	0.60	0.02	0.08	0.51	0.26	0.08	0.05	0.28	0.81
Latvia	0.79	0.04	0.08	0.14	0.08	0.71	0.17	0.73	0.42
Lithuania	0.90	0.06	0.20	0.41	0.28	0.17	0.26	0.54	1.00
Luxembourg	0.00	1.00	0.51	0.13	0.60	0.06	0.21	0.03	0.47
Hungary	0.79	0.03	0.24	0.00	0.26	0.08	0.32	0.14	0.68

Malta	0.72	0.20	0.20	0.05	0.13	0.00	0.20	0.17	0.32
Netherlands	0.43	0.55	0.34	0.42	0.42	0.13	0.26	0.00	0.42
Austria	0.60	0.15	0.43	0.26	0.48	1.00	0.45	0.46	0.36
Poland	0.57	0.02	0.17	0.40	0.10	0.14	0.35	0.16	0.32
Portugal	0.79	0.03	0.22	0.27	0.17	0.72	0.03	0.48	0.56
Romania	0.85	0.01	0.00	0.04	0.00	0.54	0.26	0.35	0.74
Slovenia	0.73	0.08	0.08	0.04	0.38	0.47	0.20	0.47	0.54
Slovakia	0.72	0.08	0.18	0.19	0.03	0.29	0.30	0.06	0.47
Finland	0.65	0.05	0.58	0.69	0.30	0.44	0.56	0.74	0.43
Sweden	1.00	0.11	1.00	1.00	0.51	0.91	1.00	1.00	0.32
United Kingdom	0.60	0.23	0.34	0.68	0.44	0.18	0.25	0.00	0.49
EU 28	0.64	0.17	0.33	0.48	0.43	0.36	0.31	0.20	0.49

Once defined values (Table 12) and weights (Table 11) of each indicator, it was possible to proceed with the calculation of the sustainability value for all twenty-eight European countries surveyed in this study (Table 13). For example:

$$S_{EU28} = (0.64*0.13 + 0.17*0.07 + 0.33*0.13 + 0.48*0.10 + 0.43*0.10 + 0.36*0.16 + 0.31*0.12 + 0.20*0.12 + 0.49*0.07) * 100 = 37.1 \quad (19)$$

The contribution given by environmental (S_{ENV}) and energy (S_{ENE}) indicators is proposed in Figure 1. Three groups can be identified:

- “Top four”, in which four countries present excellent results in term of sustainability.
- “Higher than EU 28”, in which eight countries have a sustainability value greater than EU 28 one, other four countries already present in previous group.
- “Lower than EU 28”, in which we can find other sixteen countries with a sustainability value lower than the European one.

Table 13. Ranking of EU 28 – Sustainability for “Environment and energy” topic

Ranking	Countries	Sustainability value (S)	Δ EU 28 (S = 37.1)
Top Four			
1	**Sweden**	80.7	+43.5
2	**Denmark**	55.0	+17.9
3	**Finland**	50.8	+13.6
4	**Austria**	50.1	+13.0

Higher than EU 28			
5	**Italy**	42.1	+4.9
6	**France**	39.7	+2.5
7	**Lithuania**	39.6	+2.5
8	**Germany**	38.5	+1.3
9	**Portugal**	38.2	+1.0
10	**Ireland**	38.1	+1.0
11	**Croatia**	37.9	+0.8
12	**Latvia**	37.7	+0.6
Lower than EU 28			
13	**Spain**	35.7	-1.5
14	**Bulgaria**	35.5	-1.7
15	**Slovenia**	33.7	-3.5
16	**United Kingdom**	33.7	-3.5
17	**Belgium**	33.5	-3.6
18	**Romania**	31.6	-5.5
19	**Greece**	29.6	-7.5
20	**Netherlands**	29.6	-7.5
21	**Luxembourg**	27.5	-9.7
22	**Czech Republic**	27.4	-9.7
23	**Hungary**	26.7	-10.4
24	**Cyprus**	26.6	-10.5
25	**Slovakia**	26.0	-11.1
26	**Poland**	24.6	-12.6
27	**Malta**	21.2	-16.0
28	**Estonia**	19.1	-18.1

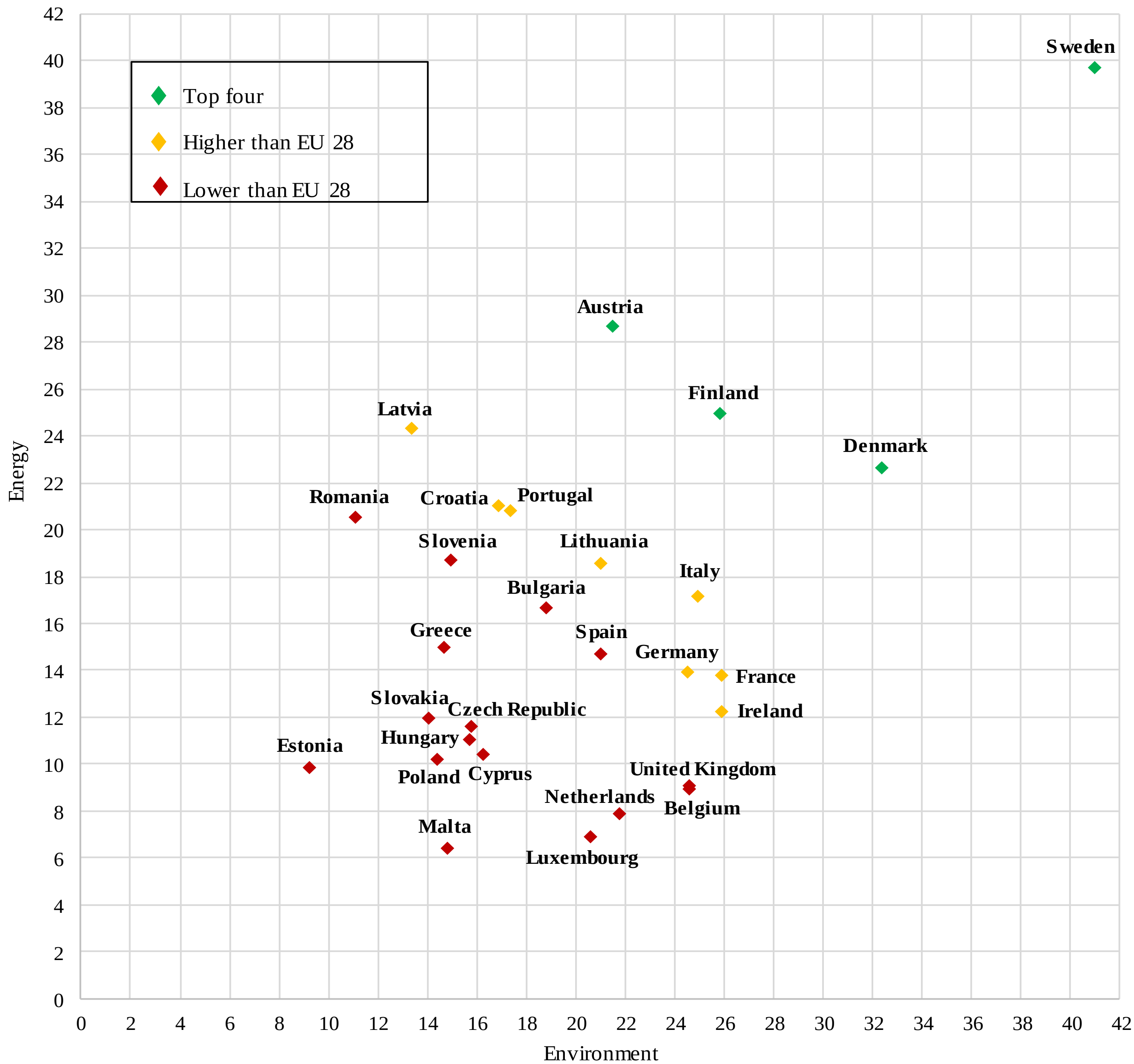

Figure 1. Sustainability Values based on Environment-Energy nexus for all European countries

Benchmark used in this research is represented by the European average (S = 37.1). One alternative could be, for example, the specific target established by each country. Table 13 values show twelve countries have a sustainable value higher than 35.9. Again, Figure 1 defines the ranking of the first six positions in both environment and energy. Results are the following:

- Sweden has S_{ENV} equal to 41, followed by Denmark (32.4), France (25.9), Ireland (25.9), Finland (25.8) and Italy (25), with a European average equal to 22.3.

- Sweden has S_{ENE} equal to 39.7, followed by Austria (28.6), Finland (25.0), Latvia (24.3), Denmark (22.6) and Croatia (21.0), with a European average equal to 14.8.

Sweden is the best nation (S = 80.7) both in environmental and energetic terms. This is an expected result, based on input data proposed in Table 6. In fact, this table shows as the highest value is reached in five cases (GhCo, RrWe, RrEl, ReTr and ReHc) and a second place is reached in the index defined by the experts as the most relevant (ReEl).

In particular, it is interesting to highlight that four countries have high sustainability indexes. By considering the reference value S = 37.1, there were calculated as ΔS of 43.5, 17.9, 13.6 and 13.0 for Sweden, Denmark, Finland and Austria, respectively. Italy, occupying the fifth position, which has a ΔS of 4.9. For this reason, the authors named this group as “Top Four”.

Going ahead with the “Top Four” group, the same weight was associated to both environment and energy related to Finland, with high values in ReTr (2^{nd}), ReHc (2^{nd}) and RrWe (3^{rd}). Denmark and Sweden have the best results on the environmental side (RrWe, RrEl and RmMs (2^{nd}), while Austria on the energy one (ReEl (1^{st}) and ReTr (3^{rd}). Sweden, Finland and Denmark exceed the European average on both perspectives, while Austria only on the energy one.

The second group “Higher than EU 28” is not homogeneous. By assessing individually the environmental and energy indicators, beyond the “Top Four” group, only Italy stands above the European average. Other countries have either an environmental (Latvia, Croatia, Portugal and Lithuania) or energetic performance (France, Ireland and Germany) lower than the European average.

The third group “Lower than EU 28” have a considerable sustainability gap, despite some positive performances. For example, this is the case of United Kingdom and Belgium when considering the environmental indicators, or the case of Romania, Slovenia, Bulgaria and Greece when considering energetic indicators. Consequently, also this group is not homogeneous. Finally, Malta and Estonia have the worse results. Their sustainability value is 16 points lower than the European average.

5. Sensitivity analysis

The results are based on assumptions of a set of input variables. The sustainability value is derived from the product of two vectors. Two changes are proposed in this section.

5.1 Variation of the row vector

The variation of the row vector is proposed in this first subsection, where older historical values are chosen. They are referred to 2012 (2011 for GeEp and 2007-2012 for EfPc – see section 3.4). Also, in this part of the work the reference is Eurostat [74]. Table 14 proposes the change of each indicator in European countries and results define an increase of performances. In fact, concerning renewables indicators twenty-five countries have increases for the share of RE in electricity (Estonia, Netherlands and Poland are the exceptions) and in heating and cooling (Spain, Hungary and Slovakia are the exceptions). Other positive performances in European countries are the following: the reduction of greenhouse gas emissions (n° 19), the increase of the share of RE in transport (n° 18), the increase of total recycled and reused waste from ELVs (n° 17) and WEEEs (n° 15) and the percentage reduction of primary energy consumption (n° 16).

Table 14. Increases and decreases of indicators in EU 28

	GhCo	GeEp	RrWe	RrEl	RmMs	ReEl	ReTr	ReHc	EfPc
Belgium	↑	↓	↑	↓	↓	↑	↓	↑	↑
Bulgaria	↓	↑	↓	↑	↑	↑	↑	↑	↓
Czech Republic	↓	↓	↑	↑	↑	↑	↑	↑	↑
Denmark	↑	↑	↓	↑	↑	↑	↑	↑	↑
Germany	↑	↓	↑	↑	↓	↑	↓	↑	↑
Estonia	↑	↑	↓	↑	↓	↓	↓	↑	↑
Ireland	↓	↓	↑	↓	↓	↑	↑	↑	↑
Greece	↓	↓	↑	↑	=	↑	=	↑	↓
Spain	↓	↓	↑	↑	↓	↑	↑	=	↓
France	↑	↑	↑	↑	↑	↑	↑	↑	↓
Croatia	↓	=	↓	↓	↑	↑	↑	↑	↓
Italy	↓	↓	↓	↑	↑	↑	↓	↑	↓
Cyprus	↓	↓	↓	↓	=	↑	↑	↑	↓
Latvia	↑	↑	↑	↓	↓	↑	=	↑	↑
Lithuania	↓	↑	↑	↑	↑	↑	↓	↑	↓
Luxembourg	↓	↑	↑	↓	↓	↑	↑	↑	↓
Hungary	↓	↓	↑	↑	↓	↑	↑	↓	↓
Malta	↓	↑	↑	↓	↓	↑	↑	↑	=
Netherlands	=	↓	↓	↑	↓	↓	↑	↑	↓
Austria	↑	↑	↓	↑	↑	↑	=	↑	↑

Poland	↓	↓	↓	↑	↑	=	=	↑	↓
Portugal	↓	↓	↑	↓	↑	↑	↑	↑	↑
Romania	↓	↓	=	=	↑	↑	↑	↑	↓
Slovenia	↓	↓	↓	=	↓	↑	↑	↑	↓
Slovakia	↓	↓	↓	↑	↓	↑	↑	↓	↓
Finland	↑	↑	↑	↓	↓	↑	↑	↑	↑
Sweden	↓	↑	↑	↑	↑	↑	↑	↑	↓
United Kingdom	↓	↑	=	↑	↑	↑	↑	↑	↑
EU 28	↓	↓	↑	↑	↓	↑	↑	↑	↓

Results of variation of the row vector are proposed in Table 15. $\Delta_{Bas\text{-}Alt}$ S measures the variation of sustainability values between the baseline scenario and the alternative one. In fact, the baseline scenario shows an actual value, while the alternative scenario proposes a past value. For example, Austria has a sustainability value equals to 46.1 and is the third country among the European ones in an alternative scenario with values referred to 2012. However, this value becomes 50.1 in a baseline scenario, with an increase of 4 points ($\Delta_{Bas\text{-}Alt}$ S). Furthermore, Finland exceeds Austria and so one position is lost in ranking terms ($\Delta_{Bas\text{-}Alt}$ Ranking).

Table 15. Sensitivity analysis – Row vector

Ranking	Countries	Sustainability value (S)	$\Delta_{Bas\text{-}Alt}$ S	$\Delta_{Bas\text{-}Alt}$ Ranking
1	**Sweden**	72.2	+8.5	0
2	**Denmark**	56.1	-1.1	0
3	**Austria**	46.1	+4.0	-1
4	**Finland**	45.4	+5.4	+1
5	**Ireland**	42.9	-4.8	-5
6	**Italy**	42.8	-0.7	+1
7	**Lithuania**	41.8	-2.2	0
8	**France**	40.9	-1.2	+2
9	**Germany**	39.8	-1.4	+1
	EU 28	37.0	+0.1	
10	**Belgium**	36.5	-3.0	-7
11	**Portugal**	35.9	+2.3	+2
12	**Latvia**	35.7	+2.0	0

13	**Croatia**	34.6	+3.3	+2
14	**United Kingdom**	34.6	-0.9	-2
15	**Spain**	34.1	+1.6	+2
16	**Netherlands**	33.6	-3.9	-4
17	**Slovenia**	31.0	+2.7	+2
18	**Luxembourg**	30.8	-3.3	-3
19	**Czech Republic**	28.9	-1.5	-3
20	**Bulgaria**	28.6	+6.9	+6
21	**Romania**	28.5	+3.2	+3
22	**Hungary**	28.0	-1.2	-1
23	**Greece**	26.9	+2.7	+4
24	**Cyprus**	26.4	+0.2	0
25	**Slovakia**	25.2	+0.8	0
26	**Poland**	22.9	+1.7	0
27	**Estonia**	21.7	-2.6	-1
28	**Malta**	20.2	+1.0	+1

From our analysis, it shows that nine out of twenty countries have achieved a sustainability value greater than the European average in this alternative scenario: Sweden, Denmark, Austria, Finland, Ireland, Italy, Lithuania, France and Germany. The trajectory of this value towards a 2020-2030 period allows further analysis of positive or negative deviations. From one side, the greatest increases are 8.5, 6.9, 5.4 and 4.0 for Sweden, Bulgaria, Finland and Austria respectively. From the other side, the greatest decreases are 4.8, 3.9, 3.3 and 3.0 for Ireland, Netherlands, Luxembourg and Belgium respectively. These results depend not only on the value of each country, but also on the maximum values due to normalization. A direct comparison with existing literature is not possible, considering the absence of a comparable indicator. Section 2 defines the novelty of this paper and furthermore, future works can evaluated the change of sustainability value during the following years. In this way, a direct comparison is reached (as that proposed in Table 15).

5.2 Variation of the column vector

The distribution of weights is a critical phase and its variation is evaluated in this subsection. In baseline scenario, we preferred to apply the AHP technique to calculate the relevant importance of weights because it is the most common approach in the literature (see section 2). The AHP is the main technique in MCDM method [69] and is still commonly used today to check the sentiment of the experts [70], especially in terms of sustainable and renewable energy systems and waste management issues (see Table 1). The additional use of a consistency ratio allows the validation, from a purely mathematical point of view, of the answers of the experts (see Table 10). Other three alternatives for the selection of different weights were evaluated: (i) a new survey with alternative experts and (ii) a mathematical variation in function of the standard deviation. From the first side, a new survey with different stakeholders (e.g. politicians and managers) could be a way to further validate the weights given to different indexes. However, it should be redundant within this paper and it could be done in a future work. From the second side, the standard deviation of indexes is very limited (see section 4). In fact, the range of the standard deviation is similar for all the indicators and consequently it varies in a non-significant way. Finally, the third alternative is presented by a simple approach, in which all criteria have the same relevance. As shown in Figure 2, the difference between an equal distribution of weights and a weighted one influences the great part of the indexes. Seven out of nine increase their importance and only two decrease (precisely, the percentage of primary energy consumption in a specific period and the governmental expenditures in environmental protection actions).

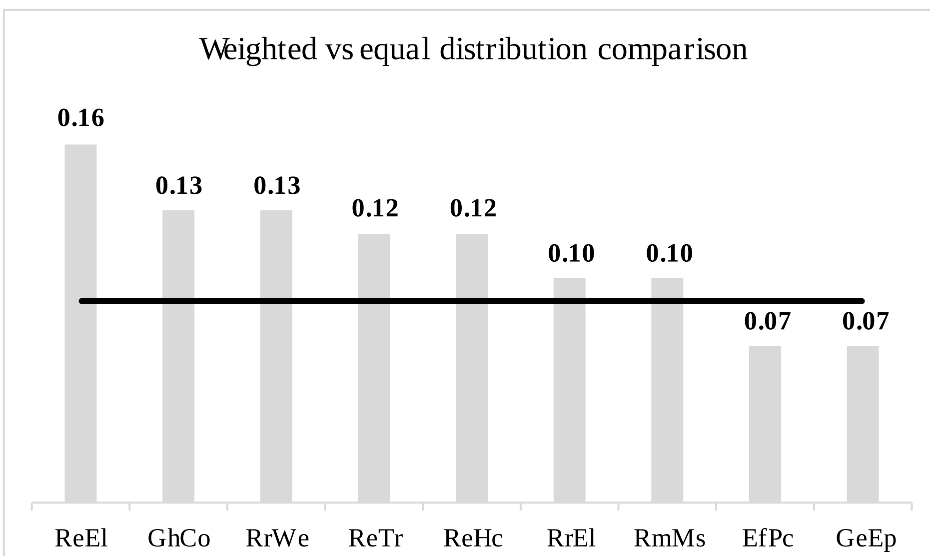

Figure 2. Comparison of different weights distributions

Results of variation of the column vector are proposed in Table 16. $\Delta_{Bas\text{-}Alt}$ S measures the variation of sustainability values between the baseline scenario and the alternative one. In fact, the baseline scenario shows a sophisticated method (AHP), while the alternative scenario proposes a simple method 8equal distribution). For example, Lithuania has a sustainability value equals to 42.4 and is the sixth country among the European ones in an alternative scenario with values referred to 2012. However, this value becomes 39.6 in a baseline scenario, with a decrease of 2.8 points ($\Delta_{Bas\text{-}Alt}$ S). Furthermore, France exceeds Lithuania and so one position is lost in ranking terms ($\Delta_{Bas\text{-}Alt}$ Ranking).

Table 16. Sensitivity analysis – Column vector

Ranking	Countries	Sustainability value (S)	$\Delta_{Bas\text{-}Alt}$ S	$\Delta_{Bas\text{-}Alt}$ Ranking
1	**Sweden**	76.0	+4.7	0
2	**Denmark**	54.6	+0.4	0
3	**Finland**	49.5	+1.3	0
4	**Austria**	46.6	+3.6	0
5	**Italy**	43.0	-0.9	0
6	**Lithuania**	42.4	-2.8	-1
7	**France**	41.1	-1.4	+1
8	**Ireland**	40.8	-2.7	-2
9	**Germany**	38.9	-0.4	+1
	EU 28	37.7	-0.6	
10	**Croatia**	36.6	+1.3	0
11	**Spain**	36.5	-0.8	-2
12	**Portugal**	36.4	+1.8	+3
13	**Bulgaria**	36.2	-0.7	-1
14	**United Kingdom**	35.8	-2.1	-2
15	**Latvia**	35.1	+2.6	+3
16	**Belgium**	34.9	-1.3	-1
17	**Luxembourg**	33.4	-5.9	-4
18	**Slovenia**	33.2	+0.5	+3
19	**Netherlands**	33.0	-3.3	-1
20	**Greece**	31.8	-2.2	+1
21	**Romania**	31.1	+0.5	+3
22	**Cyprus**	29.9	-3.3	-2
23	**Czech Republic**	28.7	-1.3	+1
24	**Hungary**	28.0	-1.3	+1
25	**Slovakia**	25.9	+0.1	0
26	**Poland**	24.7	-0.1	0

27	**Malta**	22.1	-0.9	0
28	**Estonia**	18.6	+0.5	0

From our analysis, it shows that nine countries have achieved a sustainability value greater than the European average in this alternative scenario. They are the same revealed in section 5.1. From one side, the greatest increases are 4.7 for Sweden and 3.6 for Austria. From the other side, the greatest decreases are 5.9 for Luxembourg and 3.3 for Netherlands and Cyprus.

6. Discussion

Sustainability value in the environment and energy nexus is not well understood and harmonised in the literature. Consequently, comparison of values obtained in this paper with other methods proposed by the experts is not possible (see section 2). However, several aspects of sustainability were widely analysed by the literature and national case studies were proposed (see section 1). This paper seeks to describe a tool comparing several indicators and rank of European countries is of great significance for their sustainable development. The purpose of this work is not to illustrate in granularity the correct methods for a sustainable management of natural resources in Europe, but to focus on the end of this process, by providing a clear description of the current situation. The final goal is to point out the role of sustainability in each country from different perspectives (e.g. the environmental and energetic policy) and, at the same time, compare European nations to support future strategic choices. This analysis is therefore, useful as a decision-making tool. Moreover, the application of the MCDA methodology allows providing a judgment that reduces the degree of subjectivity in the choices. Calculations were made in MS Excel to ease the repeatability of this model.

The analysis of the European ranking highlights, from one hand, that Northern countries (Sweden, Finland and Denmark), together with Austria, are leaders in sustainability. From the other hand, most populated countries (the ones with more than fifty million people) have moderately positive results, like Italy (5th), France (6th) and Germany (8th). Spain (13th) is just above the European average, and better than United Kingdom (16th). Furthermore, only four countries (Sweden, Finland, Denmark and Italy) have both an environmental and energetic performance greater than the European average. Sustainability values obtained in this paper only define performances for a specific topic, environment and energy. Strengths and weakness of each country are highlighted for all the European countries – Table 17.

Table 17. Main findings from the sustainability model

Baseline scenario
• **Sweden**, **Denmark**, **Finland**, **Austria**, **Italy**, **France**, **Lithuania**, **Germany**, **Portugal**, **Ireland**, **Croatia** and **Latvia** have a sustainability value higher than the European average. • **Sweden**, **Denmark**, **Finland** and **Austria** represent the "Top Four" group. • **Sweden**, **Denmark**, **Finland** and **Italy** exceed the European average in both the topics.
Alternative scenarios
• **Sweden**, **Denmark**, **Austria**, **Finland**, **Ireland**, **Italy**, **Lithuania**, **France** and **Germany** have a sustainability value higher than the European average.

Europe has the priority to work towards a circular economy, where wastes will be recognized increasingly as resources. It is clear that such an effort makes good sense when translated in economic terms. Europe reduced its dependence on imported fossil fuels thanks to the application of renewable technologies, making its energy production more sustainable. Future applications could be related to monitoring of the trend of the indicators over time and applied to different countries (a comparison on a global scale) or locally (a comparison on a national scale). In this direction, the identification of new indicators could be useful, by providing additional information not contained in the nine examined in this research. For example, economic and societal aspects could be added, and a new survey confirming the degree of the proposed judgments could be implemented. Both industrial actors and politicians could exploit these results.

The current literature is lacking of indexes measuring both the energetic and environmental aspects at the same time. Energy and environment are, like expressed in sections 1 and 2, the two pillars for a sustainable development of humanity. This work considers that what exposed by the 2030 agenda for Sustainable Development is of extremely importance in this direction. Countries must consider this plan as the starting point of their policies in the near future. Having in mind these goals, they should continuously review their progresses through a continuous activity of quality, accessible and timely data collection. What presented within this paper could be interpreted as a way to direct governmental decision-making processes in this way.

7. Conclusions

Linking the ecosystem change with economic opportunities and social wellbeing has always been a challenging work. Understanding and quantifying sustainability drive this pathway. Europe, through a set of specific directives, is trying to cope with this challenge, by pushing nations towards even higher targets. However, not all of the member states are ready to accept these guidelines and reach these levels.

Together, the use of AHP and Eurostat data allow the reduction of uncertainty in these estimations and represent an approach that improves the repeatability of the calculations. A model in MS Excel is proposed in this work and the MCDA method defines the sustainability ranking of European countries for a specific topic, that is environment and energy nexus.

The paper gives a clear view of the current state of European nations under several sustainability performance terms (e.g. renewable energy sources and recycling wastes), by offering a direct comparison and defining the top four ranking (Sweden, Denmark, Finland and Austria). However, this is not a surprising finding. In fact, these four nations are re-known for their strong focus towards environmental defence actions. In particular, Sweden embeds an excellent value of sustainability. The more interesting findings are the demonstration of the twelve nations (the previous ones plus Italy, France, Lithuania, Germany, Portugal, Ireland, Croatia and Latvia) out of twenty-eight which have a sustainability value greater than the European average. It is important to emphasise that we must interpret these findings with care, due to their limitations, as outlined above. However, this study evidences the positive effect from the European Directives during the last years, and it presents opportunities for future research and investment considerations to improve the ranking and the sustainability value. A circular economy could be a possible future solution to the global resource security dilemma.

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