sustainability

MDPI

Article

Economic and Human Features for Energy and Environmental Indicators: A Tool to Assess Countries' Progress towards Sustainability

Marco Filippo Torchio *,†, Umberto Lucia † and Giulia Grisolia †

Dipartimento Energia "Galileo Ferraris" Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy; umberto.lucia@polito.it (U.L.); giulia.grisolia@polito.it (G.G.)

* Correspondence: marco.torchio@polito.it; Tel.: +39-011-090-4501

† These authors contributed equally to this work.

Received: 22 October 2020; Accepted: 17 November 2020; Published: 21 November 2020

check for updates

Abstract: Energy and environmental data represent fundamental information for the analysis of sustainable development. On the other hand, these aspects should be associated with economic and human dimensions in order to obtain a more holistic vision. From this perspective, some indicators are discussed and analyzed in this paper in order to assess the performance of a country. As regards the energetic aspects, the data of total primary energy supply and exergy losses were considered. The environmental aspects were taken into account by considering the greenhouse gas emissions and the particulate matter emissions. These energy and environmental data were put in relation to the GDP (gross domestic product) and HDI (human development index, a multidimensional index proposed by United Nations), respectively. So, two sets of indicators were introduced—the set E for economic properties and the set H for human aspects. A case study was conducted by analyzing a group of countries that meet two criteria: the same macro-geographical area and comparable numbers of citizens. The European area—in particular, its six most populous countries—was chosen. From the results obtained, it is possible to point out that some countries present different rankings depending on whether set E or set H is considered. Another important aspect discussed is the temporal evolution of the indicators (the interval from 1990 to 2017 was considered). Political decision-makers can be supported by the use of the indicators of set H in order to evaluate well-being related to their choices on actions related to the energy and environment. These indicators can be used both to analyze the trends of a country and to compare them with the performance of some other similar countries.

Keywords: sustainability; indicators; energy indicators; irreversibility; exergy loss; human well-being

1. Introduction

Indicators are quantitative or a qualitative measurements [1], and they represent the main tool usually adopted:

- To monitor the performance of a country in a certain time interval;
- To determine priorities and choices for policy-making in relation to available data.

Nowadays, moving towards sustainability is becoming a continuous and compulsory requirement [2] to assure human well-being for the present and future generations. Sustainability indicators are needed in order to capture quantitative and qualitative information about the underlying asset base, which must be sustained [3]. Despite the fact that the debate on the proper definition of sustainable development still remains alive [4,5], every facet of this complex topic has its roots in long-term human well-being. Indeed, sustainability has to be focused not only on maintaining every key environmental function, but also, in a more general socioeconomic view, on maintaining the ability to provide a non-declining well-being over time [6].

1.1. Efforts for Going towards Sustainable Development—History in Brief

The concept of sustainable development was initially promoted at the beginning of 1970s in order to achieve suitable environmental conditions during the development of societies and technologies [7]. The work "The Limits to Growth" [8] is considered a precursor of this topic [9,10], putting the spotlight on the finite capacity of the biosphere of being able to meet human needs at that rate of exploitation. In "The Limits to Growth" is presented a dynamic model of prediction ("World3"), which considers the interactions between humans and Earth in relation to the exponential growth of five main interacting variables [11–13]:

- Food production, related to economic, demographic, and environmental conditions;
- Industrialization, considering the related economic growth, which is affected by other factors, such as demographic growth;
- Non-renewable resources, represented by the availability of natural resources required to produce goods and services;
- Pollution, considering the outputs due to industrial, agricultural, and service production that could affect the ecosystem, including agricultural systems and human health;
- Population, considering the demographic effects of social, economic, and environmental aspects that affect human birth and death rates.

The results of this model indicate that the exploitation of natural resources at the current rate, without any change in human activities and social behavior, would result in a "death time" for resources themselves, as well as, finally, for humans. Therefore, just fifty years ago, the failure of integrating conservation with development was noticed, and, consequently, the recognition of the need to act urgently for a more sustainable management of the use of the Earth's limited resources emerged.

In 1980, the term "sustainable development" was first introduced in the *World Conservation Strategy Report* with the subtitle "Living Resource Conservation for Sustainable Development" [14]; indeed, a global approach was pointed out to be required for the administration of resources, which human life and development depend on. Two main issues were examined:

- The conservation of global ecosystems;
- The interrelations between actions on the local and global levels, highlighting the ramifications of those on the local level for the global one, as well as the awareness of human actions.

The most often cited definition of sustainable development [15], indicating development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" [16], was introduced in the *Brundtland Report* in 1987 by the World Commission on Environment and Development (WCED). After the publication of this report, the attention on sustainable development and on its implications grew in the international policy framework, too [17], and in scientific literature [18]. The *Brundtland Report* put the spotlight on the need to integrate economic growth with social (focused on equity) and environmental issues, which has been translated into sustainable development [18].

In 1992, the United Nations Conference on Environment and Development (UNCED), commonly known as the "Rio Earth Summit", was held in Rio de Janeiro, and it represented the largest meeting of world's leaders ever organized [9], with the aim of beginning an international partnership in order to achieve the target of sustainable development for all of Earth's inhabitants [19]. During this conference, five main documents were produced, suggesting a new viewpoint for approaching sustainability and human activities:

- *The Rio Declaration of Principles*, which contains a list of 27 principles with the aim of establishing a "new and equitable global partnership" [20], moving in the direction of international agreements, safeguarding the integrity of both environmental and developmental systems, and integrating legislative instruments to pursue environmental issues in each country.

- *The United Nations Framework Convention on Climate Change* (UNFCC) [21], which is an international treaty on environment, with the aim of fixing the amount of greenhouse gases concentrations in the atmosphere to the 1990 levels, preventing a human interference with natural climate system.
- *The Convention on Biological Diversity* (CBD) [22], an international treaty with three main aims: "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources", highlighting the finite amount of natural resources and the need for all to preserve them.
- *The Statement on Forest Principle* [23], a document which contains principles to manage and preserve the forests reserves, using them in a sustainable way.
- *Agenda 21* [24], which represents a global action plan (both analyses and recommendations [19]) with the aim to integrate issues related to environment and development, in order to improve living standards and to guarantee a better future for all the people with a particular attention to the ecosystem. All these issues are considered the challenges of XXI Century and is highlighted the central role of multiscalar cooperation from an international level to a local one [25]. Indeed, the need to bring the Agenda at a local level within each Nation has led to a program called *Local Agenda 21* (LA21) in which local communities are recognized as the core for the implementation and control of the planning for actions towards sustainable development.

Substantially, in *Agenda 21*, the use of indicators was proposed as the main tool to monitor and address the proper measures and actions towards sustainable development.

After the "*Rio Earth Summit*", the Commission to Sustainable Development (CSD) was created in order to follow-up the progresses of *Agenda 21* and, in 2000, the *United Nations Millennium Development Goals* (MDGs) were introduced in order to implement its targets up to 2015. In particular, MDGs have put the spotlight on a powerful approach, to achieve social priorities worldwide [26], including crucial topics such as energy, health, poverty, gender inequality, schooling and environmental degradation. The eight MDGs main targets were focused specially on poor countries, while the richer countries had to support them, by finance and technology. The main criticism related to the MDGs has been the difficulty of their objective measurement, due to the low amount of data [27], which can be collected only in some regions of the globe, and not worldwide [28]. Moreover, MDGs have been also highlighted to have promoted a decision making system about equitable well-being and social issues, based on an economistic perspective of development [29].

In 2012, the "*UN Rio + 20 Summit*"was held in Brazil, with the aim to create a new set of goals, in order to carry forward the targets of MDGs until 2030 [30]. A new ambitious UN plan for action, called *2030 Agenda for Sustainable Development*, has been presented in 2015. Thus, the 17 Sustainable Development Goals (SDGs), and their 169 related targets, were introduced as a global challenge, in order to achieve them until 2030. In this context, the nexus approach has been introduced [31] in order to highlight the lever effect of the economic activities in order to achieve the SDGs, and to evaluate the related difficulties in assessments. The goals have been set to stimulate universal action, for human well-being on the following interlinked main areas: People, Planet, Prosperity, Peace, Partnership.

The achievement of SDGs implies a well defined government decision-making process, which had to be understood by means of introducing proper tools, such as the indicators.

1.2. Indicators of Sustainable Development

The present days are characterised by some issues—such as the biodiversity loss, the global change, etc.—that depend on human behaviours, so much that the *Anthropocene* (human-dominated geological epoch) has been introduced in order to describe the period in which we are living [32–34]. This issues (and all those derived from them) highlight how the transition to sustainability must occur [35]. In order to monitor and to assess the performance of sustainability policies, indicators are needed [36], as reported in Agenda 21 'indicators of sustainable development need to be developed to provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development systems' [24]. Moreover, Meadows [37] has also highlighted that 'what is needed to inform sustainable development is not just indicators, but a coherent information system from which indicators can be derived'.

Therefore, to support decision-making towards sustainable development, organizations and researchers have proposed indexes and indicators for sustainable development. In 1989, Cobb [38] introduced the Index of Sustainable Economic Welfare (ISEW) as an alternative to the Gross Domestic Product (GDP); ISEW has subsequently been modified by the same author [39] in order to give a more reliable monetary indicator of welfare and sustainability. It has been criticised for the ambitious attempt to enclose too many different information into a single index [40].

Another sustainability indicator proposed in the 1990s was the ecological footprint (EF) [41], which considers the area of biologically productive land required to support a given population [42] at its current level of consumption [43]. Recently, this indicator has been used to build assessments of performances on environmental sustainability [44–48]. Its widespread has been promoted by its clear calculation and its intuitive definition, which represent also the bases of any criticisms against it [49].

The Genuine Savings Indicator (GS) has been presented as a measure of the change of the annual total capital stock of a country [50], including the wealth accounting [51], and, recently, some improvements have been introduced [52].

The Environmental Sustainability Index (ESI) is a composite index to assess sustainability, by using environmental and socio-economic indicators. This index encloses twenty different indicators, which are combined with two to eight variables [53]. Then, this composite index has been modified, by adding some indicators regarding human health and environmental issues, designing the Environmental Performance Index (EPI). The latter identifies economic and social driving forces, and environmental pressures, assesses the impacts on human health, and on the environment [54].

Since 1990, the United Nations Development Programme (UNDP) has proposed the Human Development Index (HDI) [55,56] as a multidimensional index to measure the development of a country from a socio-economic viewpoint, with a specific focus on the human well-being. This index has been introduced to switch the focus from a pure economic development viewpoint to a more human-centred one, considering some crucial parameters of social development [56,57]. This indicator combines three dimensions together: the long and healthy life (life expectancy of birth), the knowledge (years of school) and a decent standard of living (the gross national income *per capita*). Since 2010, HDI has been improved in relation to the new needs emerged in relation to sustainability, as deeply analysed in Refs. [57–59].

In Table 1, the indicators considered in this Section, are summarised in relation to their chronological introduction.

Table 1. Main indicators of sustainability introduced in Section 1.2.

Year	Indicator	References
1989	Index of Sustainable Economic Welfare (ISEW) first version	[38]
1990	Human Development Index (HDI) first version	[55,56]
1992	Ecological Footprint (EF)	[41–49]
1994	Index of Sustainable Economic Welfare (ISEW), updated version: Green National Product	[39,40]
2007	Environmental Sustainability Index (ESI)	[53]
2010	Human Development Index (HDI) updated version	[57–60]
2013	Environmental Performance Index (EPI)	[54]
2014	Genuine Savings Indicator (GS)	[50–52]

1.3. This Study

From the Brundtland definition of sustainability emerges the achievement of a balance between human requirements and environmental integrity [35], considering *intra-* and *inter-*generational equity. Social and economic development are needed in order to make sustainability really effective. However, these developments are mutually interconnected with the environment in which occur (nature). Thus, the sustainability can be described as three inter-related dimensions [5,61]:

- Environment;
- Society;
- Economy.

These pillars can be analytically expressed by changing the only financial and economical quantities into socio-economic ones, considering that all human actions entail an interaction with the environment, as a consequence there is always irreversible footprint. The fundamental problem is to identify the proper quantities. A great number of models have been proposed, but each of them presents limits of application in obtaining a comprehensive description of sustainability.

In order to try to respond to this problem, in this paper, we develop some considerations on the different results obtained by using a more economic versus a more human oriented approach. To do so, we have built two different sets of indicators:

- An economic set, based on Gross Domestic Product, as usually done in all economic assessment in literature;
- A more human-centred set, which has been related to the UN's Human Development Index, in order to take into account human well-being.

Therefore, the aim of this paper is to develop some considerations on the current state of sustainability, by introducing an analysis that points out the needs of the human being, in order to show the difficulty of find a unique way to respond quantitatively to a fundamental open problem: does the actual technical and economical state agree with the human equality? This question is crucial, because just *human equality* is one of the fundamental milestones of the sustainability concept itself. In this paper, we will develop the analysis of two sets of indicators in order to highlight that each approach allows us to obtain different considerations of the current state of development in relation to sustainability. Consequently, we can highlight that it could be better consider integration between different approaches rather than mutual exclusion of them.

2. Materials and Methods

In this section, we develop an analysis of the current state of the art, related to the socio-economic development, in order to introduce some considerations on the human well-being.

In order to do so, we analyse two different sets of indicators, which present different reference indicators:

- Economic indicators, usually used for decision-making;
- Human indicators, introduced for the assessment of the human well-being.

To do so, we consider four different sets of data for each country:

1. The Total Primary Energy Supply ($TPES$), which is the total amount of energy available for a country;
2. The Exergy Losses (W_λ) in the energy chain;
3. The amount of GreenHouse Gases (GHGs) emitted;
4. The amount of particulate matter (PM) emitted.

The first parameter has been chosen because the access to energy and its availability represent a key quantity for human well-being, and are essential for human development.

The exergy losses, here considered, are the ones directly involved in the country energetic chain, and they are directly related to the technological development [62].

The amount of greenhouse gases represents an environmental issue at global scale, contributing to the greenhouse effect, and the related increase of Earth's mean temperature. Moreover, the particulate matter is a useful parameter to assess environmental pollution, directly related to air quality, which can have negative effects on human health [63].

So, all these data have been put in relation respectively with two main indicators used to assess performances of a country:

- The Gross Domestic Product (GDP) [$] [64]:

$$GDP = C + In + G + (X - M) \tag{1}$$

  where C is the consumption [$], In are the investments [$], G are the government spendings [$], X are the imports [$] and M are the exports [$].
- The Human Development Index (HDI) [60]:

$$HDI = \left(I_{health} \cdot I_{education} \cdot I_{income} \right)^{1/3} \tag{2}$$

  where I_{health} is the normalized Life Expectancy Index, which is the life expectancy at birth [yr], $I_{education}$ is the normalized Education Index which considers two different indicators equally weighted (by their mean arithmetic value): the mean years of schooling and the expected years of schooling [yr] and, I_{income} is the normalized Gross National Income *per capita* at purchasing power parties $GNI_{pc,PPP}$ [$ *per capita*]. The GNI *per capita* 'is the sum of value added by all resident producers in the economy plus any product taxes (less subsidies), not included in the valuation of output plus net receipts of primary income (compensation of employees and property income) from abroad, divided by midyear population. Value added is the net output of an industry after adding up all outputs and subtracting intermediate inputs' [58]. All the values of indicators that appear in Equation (2) are normalized ones by using their minimum and maximum values in the following way:

$$I = \frac{I_{actual} - I_{min}}{I_{max} - I_{min}} \tag{3}$$

  where I_{actual} is the actual value of the indicator, I_{min} is its minimum value and, I_{max} is the maximum value of the indicator. In the case of the $GNI_{pc,PPP}$ the natural logarithms are applied to the normalization formula (Equation (3)) in order to consider that higher incomes have a declining contribution to human development [60]. In Table 2, the values used for the normalization—since 2010—have been reported. The aim of the normalization is to obtain a non dimensional value in the range between 0 and 1.

Table 2. Values used by the United Nations [60] to normalize (Equation (3)) the indicators which are useful to calculate the Human Development Index.

Indicator	Maximum Value	Minimum Value
Life Expectancy Index [yr]	85	20
Mean Years of Schooling [yr]	15	0
Expected Years of Schooling [yr]	18	0
$GNI_{pc,PPP}$ [PPP 2011 $]	75,000	100

So, HDI is the result of the geometric mean of these normalized indicators. Thus, the Human Development Index considers three fundamental dimensions of human development: a long and healthy life, access to education and a decent standard of life [65].

These indicators allow us to compare the results obtained from two different viewpoints:

- The classical economic approach;
- A more social-related one.

Therefore, we have considered the two following different sets of indicators. The first set has been named *set E* , which is characterised by considering as a reference quantity a purely economic one: the gross domestic product *per capita*, GDP_{pc} (at purchaser's prices in constant 2011 US$ [66]). The *set E* is represented by the following equations (Equations (4)–(7)):

$$E1 = \frac{TEPS_{pc}}{GDP_{pc}} \quad (4)$$

where $TEPS_{pc} = TEPS/pop$ is the total primary energy supply *per capita*, which is calculated as the amount of energy, $TEPS$ [toe], available for a country, divided by the considered country population (pop). This indicator provides the total amount of primary energy that a country has at their disposal in relation to its gross domestic product;

$$E2 = \frac{W_{\lambda,\ pc}}{GDP_{pc}} \quad (5)$$

where $W_{\lambda,\ pc} = (TEPS - AFC)/pop$ are the exergetic losses related to the energy chain of the country considered *per capita*, calculated as the difference between the total primary energy supply, $TEPS$, and the energy available for energy consumption, AFC [toe]. This indicator provides the total amount of the exergetic losses related to the energy chain that occur in each country, in relation to its gross domestic product;

$$E3 = \frac{CO_{2,eq\ pc}}{GDP_{pc}} \quad (6)$$

where $CO_{2,eq\ pc} = CO_{2,eq}/pop$ is the amount of carbon dioxide equivalent [ton] *per capita* emitted in the atmosphere, due to the anthropic activities. This indicator provides the total amount of carbon dioxide equivalent emissions of a country, in relation to its gross domestic product;

$$E4 = \frac{PM_{pc}}{GDP_{pc}} \quad (7)$$

where $PM_{pc} = PM/pop$ is the amount of particulate matter emissions [ton] *per capita* emitted in the atmosphere, due to the anthropic activities. This indicator provides the total amount of particulate matter emissions of a country, in relation to its gross domestic product;

The second set of indicators has been named *set H*. It is analogous to the previously introduced *set E*, with the difference that, all the variables above considered—the total primary energy supply ($TEPS$), the exergetic losses due to the energetic chain ($W_{\lambda,\ pc}$), the greenhouse gases emissions ($CO_{2,eq\ pc}$) and the particulate matter emissions (PM_{pc})—have been divided by the Human Development Index, HDI. In this way, the reference indicator (HDI) is directly related to human well-being and is not a purely economic reference indicator. Thus, the *set H* can be written as follows:

$$H1 = \frac{TEPS_{pc}}{HDI} \quad (8)$$

$$H2 = \frac{W_{\lambda,\ pc}}{HDI} \quad (9)$$

$$H3 = \frac{\mathrm{CO}_{2,eq\ pc}}{HDI} \tag{10}$$

$$H4 = \frac{PM_{pc}}{HDI} \tag{11}$$

In relation to this two sets of indicators, we wish to stress that they represent two different viewpoints for the same quantities. Here, we wish to show how two different approaches for the same quantity bring to two different results: one in relation only to the economic approach, while the other results more social-need oriented. In Figure 1, are summarised the indicators and the relative quantities involved in the two sets of indicators considered in this paper to develop our study, in relation to the economic and human-oriented approach.

		Energy/Exergy		Environmental	
		$TEPS_{pc}$	$W_{\lambda,pc}$	$CO_{2eq\,pc}$	PM_{pc}
Economic viewpoint	GDP_{pc}	***E1***	***E2***	***E3***	***E4***
Human Development viewpoint	*HDI*	***H1***	***H2***	***H3***	***H4***

Figure 1. Summary of the indicators used in the present paper.

In relation to our previous considerations on sustainability, the indicators H represent the quantity which allow us to express analytically the pillars of sustainability. Therefore, we wish to suggest that the set H proposed allows us to develop an analysis towards the requirement of sustainability.

Starting from this hypothesis we wish to highlight:

- $E1$ and $H1$ allow us to evaluate the country energy consumption,
- $E2$ and $H2$ allow us to evaluate country technological level,
- $E3$ and $H3$ allow us to evaluate country GHGs emissions,
- $E4$ and $H4$ allow us to evaluate country PM emissions,

respectively in relation to the economic and human viewpoint, obtaining a way to point out if the policy makers can achieve sustainable decisions by using only economic approaches, or if a change in the standpoint is required. In relation to the different requirement of decision, depending on the social and human conditions of the country considered, it could emerge the unsuitability of the GDP, just related to sustainability; if it is the case a new approach [67], which links economics to engineering, is required.

3. Results

In this paper, we have introduced two sets of indicators, in order to show two different approaches: a more economic-centred one, and a more human well-being centred one. Indeed, the parameters considered are always the same, but the reference quantities are different for any set of indicators.

In particular, we have focused our first analysis by choosing a group of countries that meet the following criteria:

- Countries which belong to the same macro geographical area;
- Countries with comparable number of inhabitants.

Therefore, we have considered the overall data of the European Union and the six more populated European countries in 2017 [68]:

- Germany;
- France;

- United Kingdom;
- Italy;
- Spain;
- Poland;

It has to be highlighted that, the United Kingdom left the European Union on 31 January 2020, however the UK was still a member during the period of time analysed.

We have compared the trends of the two indicators, evaluated between 1990 and 2017. The demographic behaviour is represented in Figure 2; we can highlight that in this period of time there has been a population growth of:

- ∼4% for Germany;
- ∼15% both for France and United Kingdom;
- ∼7% for Italy
- ∼20% for Spain;
- approximately unchanged for Poland,

while, the overall population growth for the European Union, between 1990 and 2017, has been ∼8%.

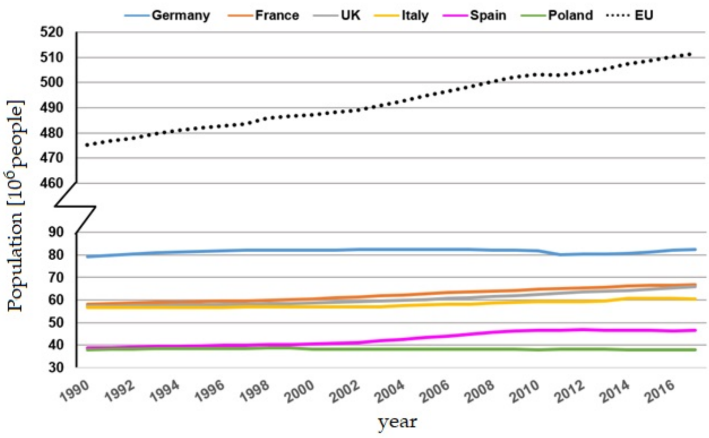

Figure 2. EUROSTAT population data from 1990 to 2017 [68].

In Figure 3, the trends of the four main parameters involved in the analysis are shown for the selected countries (including the overall EU values) from 1990 to 2017 and, in Figure 4, are represented their relative variations, comparing their values in 1990 with those of 2017. We can point out the following considerations:

- The Total Primary Energy Supply *per capita* $TPES_{pc}$ (Figure 3a) presents different trends among the European countries. Spain and Italy have shown a relevant increase in $TPES_{pc}$ until 2005, followed by a reduction in the subsequent years, while, as regards the UK and Germany, their decreasing trend in $TPES_{pc}$ can be highlighted. On the contrary, for France and Poland, a stable trend in $TPES_{pc}$ can be noticed. The overall variation from 1990 to 2017, presented in Figure 4, highlights that: the UK, Germany and France have reduced their total Primary Energy Supply, compared with the 1990's values, respectively of 26%, 15% and 3%, while, for Italy and Poland, this quantity has remained almost constant and, an increase of 21% has occurred in Spain. As concerns the overall $TPES_{pc}$ of EU during the same reference time, it has shown a reduction of 8%;
- The Exergy Losses related to the energy chain *per capita* (Figure 3b) present similar shapes if compared with the $TPES_{pc}$ ones, with an overall reduction (Figure 4) of 21% for Poland, 27% for Germany, 42% for the UK, while an increment for France, Italy and Spain relatively of 4%, 4% and 31% can be identified. For the European Union an overall reduction trend of 15% in $W_{\lambda,pc}$ has been verified;

- The Greenhouse Gases emissions *per capita* (Figure 3c) have been reduced in the UK of 46%, in Germany of 30%, in France of 26%, in Italy of 23% and in Poland of 10%. On the contrary, in Spain an increase of 1% of the greenhouse emissions has been shown. The overall European Union GHGs emissions reduction has been of 28%;
- The Particulate Matter emissions *per capita* (Figure 3d) present a decreasing trend for all the countries involved in the analysis. Their reduction between 1990 and 2017 (Figure 4) has been: of 61% in the UK, of 60% in France, of 44% in Germany, of 37% in Italy, of 35% in Spain and of 22% in Poland. Moreover, the overall reduction of the European Union has been relevant (48%).

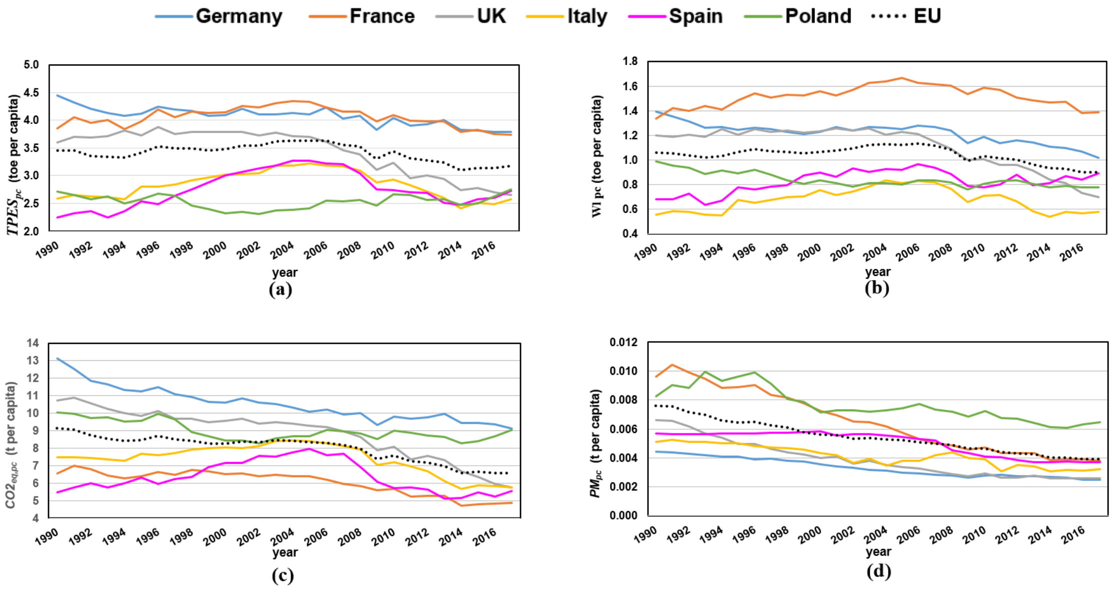

Figure 3. Trends of the four main parameters used for the period from 1990 to 2017: (**a**) Total Primary Energy Supply [69] *per capita*, (**b**) Exergy Losses *per capita*, (**c**) Greenhouse Gases [70] *per capita*, (**d**) Particulate Matter [71] *per capita*.

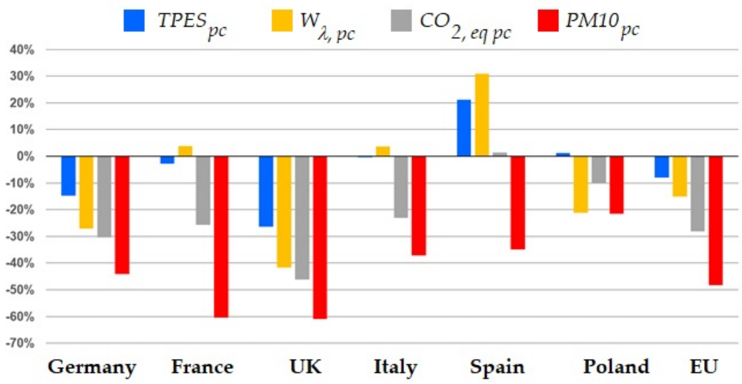

Figure 4. Variation for the selected reference quantities from 1990 to 2017 for each country, including the overall EU data.

In Figure 5a,b the trends, between 1990 and 2017, of the GDP_{pc} and of the HDI have been plotted. As concerns the GDP_{pc}, for all countries, it can be shown an increase until 2008, whereupon, due to the important global financial crisis, a subsequent reduction of the GDP_{pc} in the European Union can be noticed. It can be observed that some countries (Italy and Spain) have suffered the crisis more than others, with consequent reductions during the subsequent years. As concerns the HDI, it can be observed an overall growth of this indicator during the period between 1990 and 2017.

It can be noticed that the ranking of countries with respect to the GDP_{pc} is, in some cases, different from that of the HDI. For example, in 1990 the ranking of the top three countries for GDP_{pc} was: France, Germany and Italy, while for the HDI it was: Germany, France and the UK. While, in 2017, the top three countries in the ranking were: Germany, UK and France for GDP_{pc}, and Germany, UK and Spain for HDI.

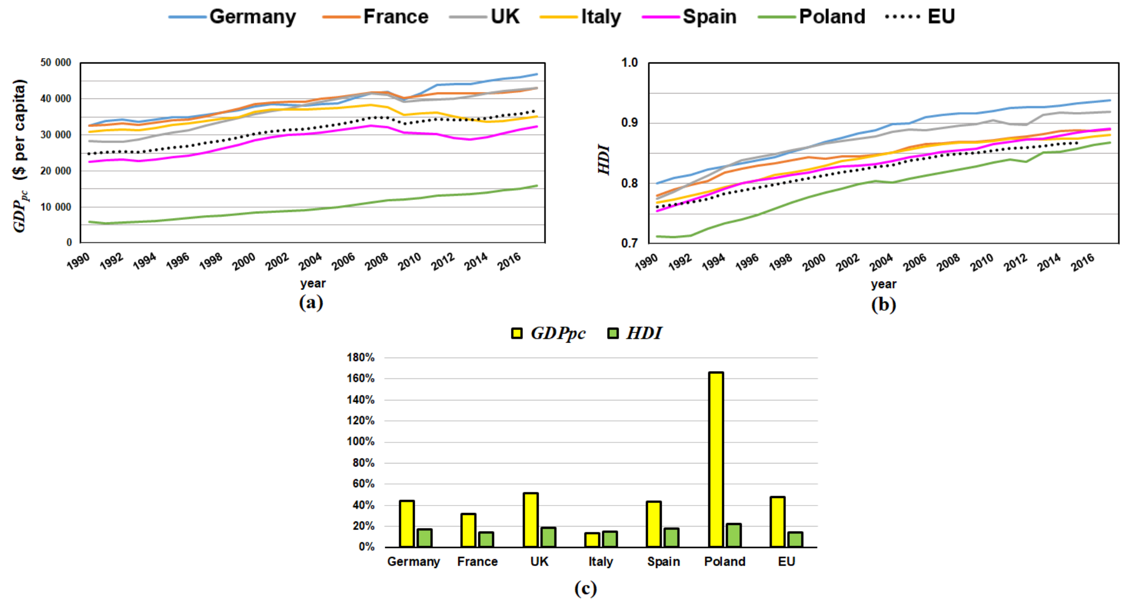

Figure 5. For each country analysed, including the EU overall data: (**a**) Trends of the Gross Domestic Product *per capita* between 1990 and 2017 (**b**) Trends of the Human Development Index between 1990 and 2017. (**c**) Percentage variation of the GDP_{pc} and HDI between 1990 and 2017.

In Figure 5c, the percentage variations, both of GDP_{pc} and HDI, between 1990 and 2017, are shown for the six countries examined (including also the overall EU data): positive variations are observed in all cases. A very high improvement on GDP_{pc} can be observed for Poland, although the increase of HDI has not noticed a similar value. Italy results the country that has had the smallest improvement in terms of both GDP_{pc} and HDI. In particular, the GDP_{pc} variation noticed in Poland has been of ∼166%, while Italy is the country that had the lowest increase. In relation to HDI, we can highlight that its value has grown for all countries, and its range is ∼14–22%. It can be also be observed that the European Union has shown relevant improvements both in GDP_{pc} and HDI, respectively of 48% and 14%.

The proposed indicators have been built as reported in Equations (4)–(11), and their comparison is represented in Figure 6, where the attention has been focused on the two extreme years of the analysed period: 1990 and 2017.

As regards indicator $E1$ (Figure 6a), in 2017 the UK was the best performing country (while in 1990 Italy presented the best value); all the countries considered have improved this indicator. Although Poland is the country with the worst value in both years analysed, it has however narrowed the gap with respect to other countries, in fact during the time interval analysed, the indicator has shown a significantly reduction (−62%) and, this is due to the strong growth of its GDP_{pc}, while its energy consumption has been stable. Italy is the country that has had the lowest improvement (−12%), essentially due to a modest increase in the GDP_{pc}. Considering the overall EU data, it can be observed a good improvement on the $E1$ indicator, equal to −38%.

As regards indicator $H1$ (Figure 6b), in 2017 also for this indicator the UK was the country with the best performances, having undergone a significant reduction compared to 1990 (−38%). It should be noted that Spain, which had the best value in 1990, did not undergo significant changes in 2017 because the improvement in HDI was offset by an increase in energy consumption. Germany and France, on the other hand, were the countries that had a worse value both in 1990 and in 2017. The overall EU value of $H1$ has shown a reduction (−20%) due both to a $TPES_{pc}$ reduction and to a HDI increase.

As concerns indicator $E2$ (Figure 6c) the best performing countries in 2017 were Italy and the UK, but while Italy had a modest improvement compared to 1990 (−9%), the United Kingdom had a significant improvement (−62%). The worst value is that of Poland, although compared to 1990 it has made a significant step forward. The overall EU value has shown a relevant improvement, equal to −43%.

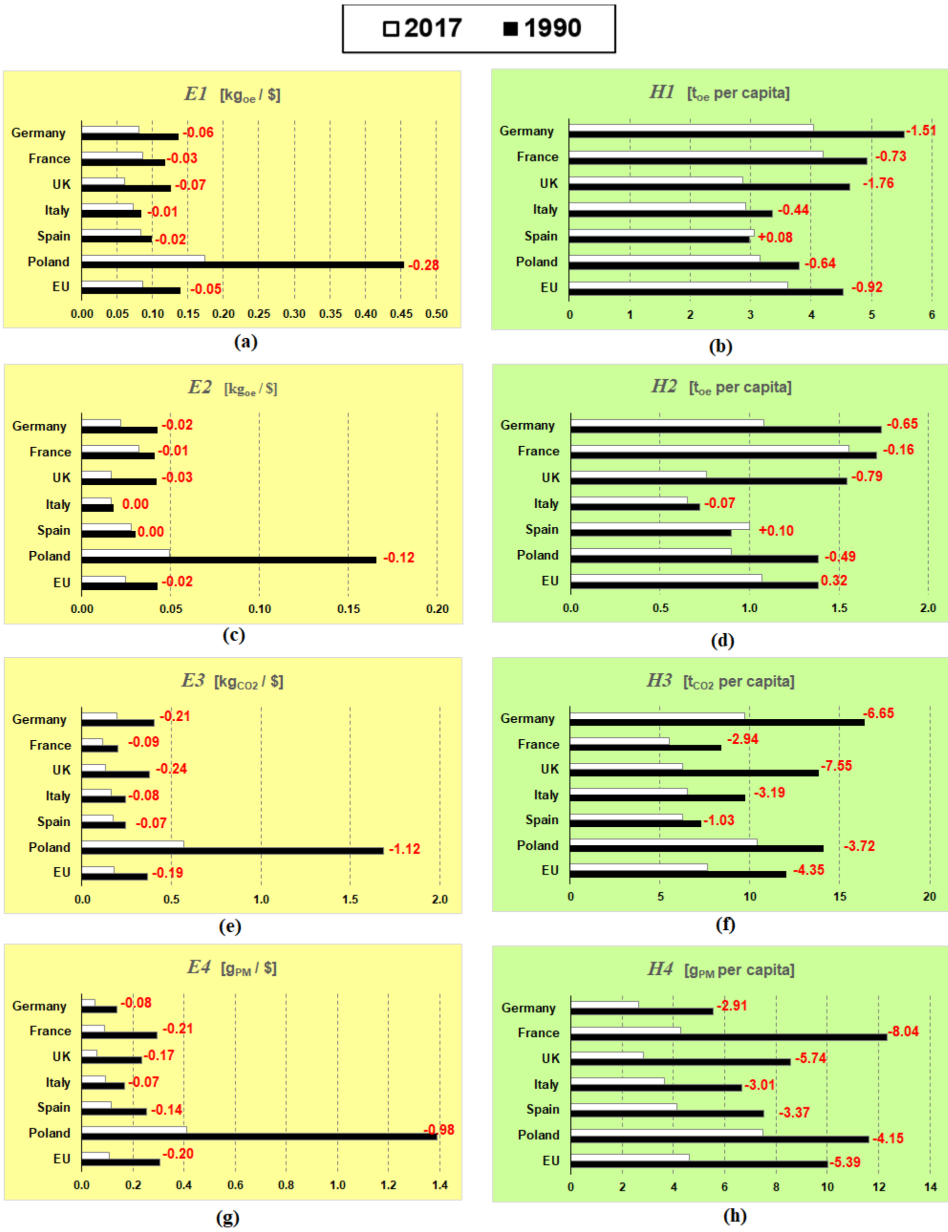

Figure 6. The two sets of indicators: those presented with a yellow background (**a**,**c**,**e**,**g**) are the graphs related to set E, while those with a green background (**b**,**d**,**f**,**h**) are the indicators of set H. For each country are reported: the 1990 values (black bars), the 2017 values (white bars) and their difference (red numbers).

As concerns indicator $H2$ (Figure 6d), Italy maintains the best value of the indicator in both years, France in 2017 presented the worst value. It should be noted that Spain is the only country where this indicator worsened between 1990 and 2017 (+10%). As concerns the overall EU data, an improvement of −23% can be noticed.

For indicator $E3$ (Figure 6e), France is confirmed as the country that has the best value in both years, in particular thanks to the fact that it has both low emissions and high GDP_{pc}. This indicator for Poland is still far from that of the other countries, but it achieved a significant reduction (−66%) between 1990 and 2017, mainly thanks to the growth of GDP_{pc}. The overall EU value has shown an important reduction (−51%).

For indicator $H3$ (Figure 6f), in 2017 France had the best value, followed by the United Kingdom which obtained a high reduction between 1990 and 2017 (−55%) while the worst values are those of Poland and Germany, due to their high GHG emissions. For the EU, the $H3$ indicator improvement has been equal to −36%.

For indicators $E4$ and $H4$ (Figure 6g,h), Germany shows the best value in both periods followed by the UK. Also for these two indicators, Poland had the worst values. A significant improvement can be observed for all countries, both for $E4$ (from −45% to −74%) and for $H4$ (from −36% to −67%). For the EU the $E4$ and $H4$ indicators have shown a relevant reduction: −65% and −54% respectively. All these results can be also directly linked to the generalized reduction of PM emissions between 1990 and 2017.

4. Discussion

The requirement to dispose of information and data availability, regarding the conditions of each single Country, is set in Chapter 40 of *Agenda 21*. This has led to the requirement of defining indicators of sustainability, in order to “provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development systems” [24].

A first set of 134 sustainable development indicators, and their relative methodologies, were provided in 1995 by the CSD [72]. Those were grouped into four main domains:

1. Social;
2. Economic;
3. Environmental;
4. Institutional.

In order to classify them, the CSD initially used the “Pressure-State-Response”framework [73] which was already been introduced by OECD [74] for Environmental Indicators. But, this approach was not suitable at all for social and economic aspects. So, it was modified into “*Driving force-State-Response*”and, after its test, it was further changed into “*Policy issues*”, collecting them into main themes and sub-themes [75].

In this paper, in order to assess the sustainability of a macro system such as a country, the energy and environmental dimensions were preliminarily examined through four indicators: the total primary energy supply, the exergetic losses, the greenhouse gases emitted and the particulate matter emitted (al values adopted are *per capita* ones).

The choice of this four main parameters has been taken due to their direct link to sustainability, because they cover and represent the crucial domains of sustainable development, useful to build a concise set of indicators, that means providing a general overview of the behaviour of the system [76].

Indeed, a fundamental requirement to enable human well-being is energy: human development and access to energy have always gone hand in hand and, this clearly emerges specially in the history of the two last centuries, from the industrial era up to now [77]. The exergy losses (or the dissipated available energy) are proportional to the entropy generation [78,79], and can be linked to the technological development [80] that is another fundamental dimension in sustainability. The primary driver for climate change are the greenhouse gases emissions: from 1990 to 2018, the global carbon dioxide emissions have registered an increase of about 65%, passing from 22.18×10^6 t to 36.57×10^6 t [81], and achieve their rapid reduction is crucial, as highlighted in *The Paris Agreement* [82]. Conversely, the particulate matter emissions are directly linked to human wealth [83].

Then, an economic dimension has been introduced through the GDP *per capita*, and from the combination of energetic, environmental and economic aspects, a set of indicators, called *set E* was generated: Equations (4)–(7). Among these indicators, $E1$, $E3$ and $E4$ (Equations (4), (6) and (7)) have usually been adopted in literature, while $E2$ (Equation (5)) is less used but, it gives the dissipated energy associated to the GDP and, it can be an useful sustainability indicator.

Since purely economic aspects are considered to be too limited, a more holistic set of indicators has been proposed. It is based on the index introduced by the United Nations, called Human Development Index, which tries to quantify human well-being in a multidimensional way. Indeed, this index was introduced in order to consider that the ultimate criteria to assess development must reflect human well-being and not the economic growth alone. From a thermoeconomic point of view, GDP can be seen as a flow (financial flow), while HDI is analogous to a state variable, describing the state of the system at a certain time. Consequently, these two indicators represent the analytical expression of two different approaches, and, we argue, possible complementary. Therefore, the second set of indicators has been defined as *set H* (Equations (8)–(11)), taking into account human well-being. The case study discussed in this paper has been focused on European area and on its six more populated countries. As can be observed in Figure 5, the GDP_{pc} and HDI trends are quite different and, these trends have an impact in the respective sets of indicators. Indeed, some countries present a different ranking depending on whether considering *set E* or *set H*. For example, in the comparison of dissipation indicator ($E2$ and $H2$), it can be observed that, while for $E2$ is the UK that leads the ranking, for $H2$ Italy presents the first value in this ranking. Even the last position in the two rankings is different: for $E2$ the last position is covered by Poland, while for $H2$ is covered by France.

Another important aspect is how an indicator has evolved over time and how much it has improved over a significant period of time considered in this work: between 1990 and 2017. For example, Poland is the country which presents the worst values for all four indicators of *set E* and for two of the indicators of *set H*. However, it emerges that Poland has made significant improvements: in 1990 it had a large gap compared other countries, while in 2017 the gap was often reduced.

It is believed that political decision makers can find in the indicators of *set H* a help to understand if the choices made are bringing benefits. These indicators can be used both to analyse the trends of the country that they are governing, and to compare that country with the performance of similar countries.

5. Conclusions

In this paper, we have developed an analysis of two different approaches to sustainable development: one more economic-oriented and the other one, more human-oriented. We have developed this study to show the difficulty to find a unique response to one of the pillars of sustainability: the human equity.

At one glance, everyone could be induced to prefer a human-oriented indicator, just for the way used to build it. After a deeper consideration of the analysis developed, it emerges that the choice of the indicator must be related to the target and the aim of the decision to be made. Consequently, the conclusion we have achieved is that an integration of the two approaches is more useful for sustainability than a mutual exclusion of them.

Last, it is possible to argue that these two approaches do not consider the technological level of the system used in power and industrial sectors. Consequently, a possible new choice is to develop a more thermo-economic approach to sustainability, because this field of investigation allow us to link economics and optimization methods for systems, but it requires the introduction of human-oriented quantities in thermodynamic indicators. So, we conclude that this paper suggests new frontiers of research, based on an interdisciplinary approach. Thus, further analysis may be carry out in the following directions:

- The two sets of indicators proposed could be applied to other countries with different population dimensions both in Europe and in other aggregated macro-regions (such as: America, Asia, Africa, etc.);

- Many other alternatives to HDI have been proposed, in order to measure the development of a country from a socio-economic viewpoint, therefore new sets of indicators could be introduced, analysed and compared;
- Although two important pollutants were chosen in this work (one with global impact and the other with local impact) it would be interesting to introduce other environmental indicators that could be useful to policy makers.

Author Contributions: Conceptualization, M.F.T., U.L. and G.G.; methodology, M.F.T., U.L. and G.G.; software, M.F.T., U.L. and G.G.; validation, M.F.T., U.L. and G.G.; formal analysis, M.F.T., U.L. and G.G.; investigation, M.F.T., U.L. and G.G.; resources, M.F.T., U.L. and G.G.; data curation, M.F.T., U.L. and G.G.; writing—original draft preparation, M.F.T., U.L. and G.G.; writing—review and editing, M.F.T., U.L. and G.G.; visualization, M.F.T., U.L. and G.G.; supervision, M.F.T., U.L.; project administration, M.F.T., U.L.; funding acquisition, M.F.T., U.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AFC	Energy available to final consumption
C	Consumption
$CO_{2,eq}$	Carbon dioxide equivalent, total amount of greenhouse gases emissions
E	This letter has been used to identify the first set of indicators, with reference to economy aspects (GDP_{pc})
$E1$	$TEPS_{pc}/GDP_{pc}$
$E2$	$W_{\lambda,pc}/GDP_{pc}$
$E3$	$CO_{2eq,pc}/GDP_{pc}$
$E4$	PM_{pc}/GDP_{pc}
EU	European Union
G	Government spendings
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GNI	Gross National Income
H	this letter has been used to identify the first set of indicators, with reference to human aspects (HDI)
HDI	Human Development Index
$H1$	$TEPS_{pc}/HDI$
$H2$	$W_{\lambda,pc}/HDI$
$H3$	$CO_{2eq,pc}/HDI$
$H4$	PM_{pc}/HDI
I	Indicator
IEA	International Energy Agency
In	Investments
M	Exports
PM	Particulate Matter
SDI	Sustainable Development Index
SDGs	Sustainable Development Goals
$TPES$	Total Primary Energy Supply
W	Exergy (Available work)
X	Imports
pop	Population, total number of inhabitants of a country/region
Subscripts	
max	Maximum value
min	Minimum value
pc	*Per capita*
λ	Lost

References

1. Nardo, M.; Saisana, M.; Saltelli, A.; Tarantola, S.; Hoffmann, A.; Giovannini, E. *Handbook on Constructing Composite Indicators: Methodology and User Guide*; OECD Publishing: Paris, France, 2008.
2. Lucia, U.; Grisolia, G. Unavailability percentage as energy planning and economic choice parameter. *Renew. Sustain. Energy Rev.* **2017**, *75*, 197–204. [CrossRef]
3. Garrett, R.D.; Latawiec, A.E. What are sustainability indicators for? In *Sustainability Indicators in Practice*; Latawiec, A.E., Ed.; DeGruyter: Berlin, Germany, 2015; Chapter 1, pp. 12–22.
4. Roberts, P.; Jalal, K.; Boyd, J. *An Introduction to Sustainable Development*; Earthscan—Glen Educational Foundation: London, UK, 2007.
5. Wu, J.; Wu, T. Sustainability indicators and indices: An overview. In *Handbook of Sustainability Management*; World Scientific Publishing: Singapore, 2012; Chapter 4, pp. 65–86._0004. [CrossRef]
6. Neumayer, E. *Sustainability and Well-Being Indicators*; Report; UNU-WIDER: Helsinki, Finland, 2004.
7. Asr, E.T.; Kakaie, R.; Ataei, M.; Mohammadi, M.T. A review of studies on sustainable development in mining life cycle. *J. Clean. Prod.* **2019**, *229*, 213–231. [CrossRef]
8. Meadows, D.; Meadows, D.; Randers, J.; Behrens, W., III. *The Limits to Growth*; Potomac Associates—Universe Books: New York, NY, USA, 1972.
9. Basiago, A. Economic, social, and environmental sustainability in development theory and urban planning practice. *Environmentalist* **1999**, *19*, 145–161. [CrossRef]
10. Nørgård, J.; Peet, J.; Ragnardsdóttir, K. The History of The Limits to Growth. *Solut. J.* **2010**, *1*, 59–63.
11. Turner, G. A comparison ofThe Limits to Growthwith 30 years of reality. *Glob. Environ. Chang.* **2008**, *18*, 397–411. [CrossRef]
12. Vermeulen, P. 'Dynamics of Growth in a Finite World'—Comprehensive Sensitivity Analysis. *IFAC Proc. Vol.* **1976**, *9*, 133–145. [CrossRef]
13. Thissen, W. Investigations into the Club of Rome's World3 Model: Lessons for Understanding Complicated Models. Ph.D. Thesis, Industrial Engineering & Innovation Sciences, Technische Hogeschool Eindhoven, Eindhoven, The Netherlands, 1978.
14. IUCN; UNEP; WWF. *World Conservation Strategy Living Resource Conservation for Sustainable Development*; Report; International Union for Conservation of Nature and National Resources; United Nations Environment Programme; World Wildlife Fund; Food and Agriculture Organization; United Nations Educational; Scientific and Cultural Organization; IUCN: Gland, Switzerland, 1980.
15. Schaefer, A.; Crane, A. Addressing sustainability and consumption. *J. Macromarket.* **2005**, *25*, 76–92. [CrossRef]
16. WCED. *Our Common Future*; Oxford University Press: Oxford, UK, 1987.
17. Johnston, P.; Everard, M.; Santillo, D.; Robèrt, K.H. Reclaiming the Definition of Sustainability. *Environ. Sci. Pollut. Res.* **2007**, *14*, 60–66.
18. Castro, C. Sustainable Development: Mainstream and critical perspectives. *Organ. Environ.* **2004**, *17*, 195–225. [CrossRef]
19. Cicin-Sain, B. Earth Summit implementation: Progress since Rio. *Mar. Policy* **1996**, *20*, 123–143. [CrossRef]
20. United Nations General Assembly. *Report of the United Nations Conference on Environment and Development—Annex I: Rio Declaration on Environment and Development*; Report; United Nations: New York, NY, USA, 1992.
21. United Nations General Assembly. *United Nations Framework Convention on Climate Change*; Report; United Nations: New York, NY, USA, 1992.
22. United Nations General Assembly. *Convention on Biological Diversity*; Report; United Nations General Secretary: New York, NY, USA, 1992.
23. United Nations General Assembly. *Report of the United Nations Conference on Environment and Development—Annex III: Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development for All Types of Forests*; Report; United Nations: New York, NY, USA, 1992.
24. United Nations General Assembly. *Report of the United Nations Conference on Environment and Development—Agenda 21*; Report; United Nations: New York, NY, USA, 1992.
25. Norman, E.; Carr, D. Rio summit. In *International Encyclopedia of Human Geography*; Kitchin, R., Thrift, N., Eds.; Elsevier: Oxford, UK, 2009; pp. 406–411.
26. Sachs, J. From Millennium Development Goals to Sustainable Development Goals. *Lancet* **2012**, *379*, 2206–2211. [CrossRef]

27. Attaran, A. An Immeasurable Crisis? A Criticism of the Millennium Development Goals and Why They Cannot Be Measured. *PLoS Med.* **2005**, *2*, 955–961. [CrossRef] [PubMed]
28. Solheim, E. Climate, Conflict and Capital: Critical Issues for the MDGs and Beyond 2015. *IDS Bull.* **2010**, *41*, 100–103. [CrossRef]
29. Vandemoortele, J. The MDG Story: Intention Denied. *Dev. Chang.* **2011**, *42*, 1–21. [CrossRef]
30. Griggs, D.; Stafford-Smith, M.; Gaffney, O.; Rockstrm, J.; Öhman, M.; Shyamsundar, P.; Steffen, W.; Glaser, G.; Kanie, N.; Noble, I. Sustainable development goals for people and planet. *Nature* **2013**, *495*, 305–307. [CrossRef]
31. Van Zanten, J.A.; van Tulder, R. Towards nexus-based governance: Defining interactions between economic activities and Sustainable Development Goals (SDGs). *Int. J. Sustain. Dev. World Ecol.* **2020**, *27*, 1–17. [CrossRef]
32. Steffen, W.; Persson, A.; Deutsch, L.; Zalasiewicz, J.; Williams, M.; Richardson, K.; Crumley, C.; Crutzen, P.; Folke, C.; Gordon, L.; et al. The Anthropocene: From Global Change to Planetary Stewardship. *Ambio* **2011**, *40*, 739–761. [CrossRef]
33. Lewis, S.; Maslin, M. Defining the Anthropocene. *Nature* **2015**, *519*, 171–180. [CrossRef]
34. Keys, P.; Galaz, V.; Dyer, M.; Matthews, N.; Folke, C.; Nyström, M.; Cornell, S. Anthropocene risk. *Nat. Sustain.* **2019**, *2*, 667–673. [CrossRef]
35. Wu, J. Landscape sustainability science: Ecosystem services and human well-being in changing landscapes. *Landsc. Ecol.* **2013**, *28*, 999–1023. [CrossRef]
36. Hák, T.; Moldan, B.; Dahl, A.L. (Eds.) *Sustainability Indicators—A Scientific Assessment*; Island Press: Washington, DC, USA, 2007.
37. Meadows, D. *Indicators and Information Systems for Sustainable Development*; Report to the Balaton Group; The Sustainability Institute: Hartland, WI, USA, 1998.
38. Cobb, C. *The Index for Sustainable Economic Welfare*; Beacon Press: Boston, MA, USA, 1989.
39. Cobb, C.; Cobb, J. *The Green National Product: A Proposed Index of Sustainable Economic Welfare*; University Press of America: Lanham, MD, USA, 1994.
40. Neumayer, E. The ISEW: Not an index of sustainable economic welfare. *Soc. Indic. Res.* **1999**, *48*, 77–101. [CrossRef]
41. Wackernagel, M.; Rees, W. *Our Ecological Footprint*; Birkhouse Publishing: Basel, Switzerland, 1997.
42. Rees, W.E. Ecological footprints and appropriated carrying capacity: What urban economics leaves out. *Environ. Urban.* **1992**, *4*, 121–130. [CrossRef]
43. Moldan, B.; Janoušková, S.; Hák, T. How to understand and measure environmental sustainability: Indicators and targets. *Ecol. Indic.* **2012**, *17*, 4–13. [CrossRef]
44. Kissinger, M.; Sussman, C.; Moore, J.; Rees, W. Accounting for the Ecological Footprint of Materials in Consumer Goods at the Urban Scale. *Sustainability* **2013**, *5*, 1960–1973. [CrossRef]
45. Ghita, S.I.; Saseanu, A.; Gogonea, R.; Huidumac-Petrescu, C. Perspectives of Ecological Footprint in European Context under the Impact of Information Society and Sustainable Development. *Sustainability* **2018**, *10*, 3224. [CrossRef]
46. Chen, G.; Li, Q.; Peng, F.; Karamian, H.; Tang, B. Henan ecological security evaluation using improved 3D ecological footprint model based on emergy and net primary productivity. *Sustainability* **2019**, *11*, 1353. [CrossRef]
47. Shi, X.; Matsui, T.; Machimura, T.; Gan, X.; Hu, A. Toward Sustainable Development: Decoupling the High Ecological Footprint from Human Society Development: A Case Study of Hong Kong. *Sustainability* **2020**, *12*, 4177. [CrossRef]
48. Guo, J.; Ren, J.; Huang, X.; He, G.; Shi, Y.; Zhou, H. The Dynamic Evolution of the Ecological Footprint and Ecological Capacity of Qinghai Province. *Sustainability* **2020**, *12*, 3065. [CrossRef]
49. Fiala, N. Measuring sustainability: Why the ecological footprint is bad economics and bad environmental science. *Ecol. Econ.* **2008**, *67*, 519–525. [CrossRef]
50. Hamilton, K.; Naikal, E. Genuine saving as an indicator of sustainability. In *Handbook of Sustainable Development*; Atkinson, G., Dietz, S., Neumayer, E., Agarwala, M., Eds.; Edward Elgar Publishing: London, UK, 2014; Volume 4, Chapter 22, pp. 336–347.
51. Hamilton, K.; Hepburn, C. Wealth. *Oxf. Rev. Econ. Policy* **2014**, *30*, 1–20. [CrossRef]

52. Boos, A. Genuine Savings as an Indicator for "Weak" Sustainability: Critical Survey and Possible Ways forward in Practical Measuring. *Sustainability* **2015**, *7*, 4146–4182. [CrossRef]
53. Wilson, J.; Tyedmers, P.; Pelot, R. Contrasting and comparing sustainable development indicator metrics. *Ecol. Indic.* **2007**, *7*, 299–314. [CrossRef]
54. Hsu, A.; Lloyd, A.; Emerson, J.W. What progress have we made since Rio? Results from the 2012 Environmental Performance Index (EPI) and Pilot Trend EPI. *Environ. Sci. Policy* **2013**, *33*, 171–185. [CrossRef]
55. UNDP Human Development Report Office. *Concept and Measurement of Human Development*; Human Development Report 1990; UNDP (United Nations Development Programme): New York, NY, USA, 1990.
56. Sagar, A.D.; Najam, A. The human development index: A critical review. *Ecol. Econ.* **1998**, *25*, 249–264. [CrossRef]
57. Hickel, J. The sustainable development index: Measuring the ecological efficiency of human development in the anthropocene. *Ecol. Econ.* **2020**, *167*, 106331. [CrossRef]
58. UNDP Human Development Report Office. *The Real Wealth of Nations: Pathways to Human Development*; Human Development Report 2010; UNDP (United Nations Development Programme): New York, NY, USA, 2010.
59. Liu, G.; Brown, M.T.; Casazza, M. Enhancing the Sustainability Narrative through a Deeper Understanding of Sustainable Development Indicators. *Sustainability* **2017**, *9*, 1078. [CrossRef]
60. UNDP Human Development Report Office. *Training Material for Producing National Human Development Reports*; Occasional Paper; UNDP: New York, NY, USA, 2015.
61. Mensah, J. Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review. *Cogent Soc. Sci.* **2019**, *5*, 1653531. [CrossRef]
62. Lucia, U.; Grisolia, G. Cyanobacteria and microalgae: Thermoeconomic considerations in biofuel production. *Energies* **2018**, *11*, 156. [CrossRef]
63. Torchio, M.F. Comparison of district heating CHP and distributed generation CHP with energy, environmental and economic criteria for Northern Italy. *Energy Convers. Manag.* **2015**, *92*, 114–128. [CrossRef]
64. Mankiw, N. *Principles of Macroeconomics*; Harcourt College: San Diego, CA, USA, 2001.
65. Roser, M.; Human Development Index (HDI). Our World in Data. 2014. Available online: OurWorldInData.org (accessed on 29 September 2020).
66. World Bank. GDP (Constant 2010 US$). 2020. Available online: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD (accessed on 25 August 2020).
67. Lucia, U.; Fino, D.; Grisolia, G. Thermoeconomic analysis of Earth system in relation to sustainability: A thermodynamic analysis of weather changes due to anthropic activities. *J. Therm. Anal. Calorim.* **2020**. [CrossRef]
68. EUROSTAT. Population Change—Demographic Balance and Crude Rates at National Level. 2020. Available online: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_gind&lang=en (accessed on 25 August 2020).
69. EUROSTAT. Simplified Energy Balances. 2020. Available online: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_s&lang=en (accessed on 25 August 2020).
70. EEA. Greenhouse Gas Emissions by Source Sector. 2020. Available online: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en (accessed on 25 August 2020).
71. EEA. PM10. 2020. Available online: https://ec.europa.eu/eurostat/databrowser/view/sdg_11_50/default/table?lang=en (accessed on 25 August 2020).
72. UNDESA; CSD. *Indicators of Sustainable Development, Framework and Methodologies*; Report; United Nations: New York, NY, USA, 1996.
73. Levrel, H.; Kerbiriou, C.; Couvet, D.; Weber, J. OECD pressure-state-response indicators for managing biodiversity: A realistic perspective for a French biosphere reserve. *Biodivers. Conserv.* **2009**, *18*, 1719–1732. [CrossRef]
74. OECD. *OECD Core Set of Indicators for Environmental Performance Reviews*; Report; OECD—Organization for Economic Co-operation and Development: Paris, France, 1993.
75. IAEA; UNDESA; IEA; EUROSTAT; EEA. *Energy Indicators for Sustainable Development: Guidelines and Methodologies*; Report; International Atomic Energy Agency; United Nations Department of Economic and Social Affairs; International Energy Agency; Eurostat; European Environment Agency: Vienna, Austria, 2005.

76. Angelis-Dimakis, A.; Arampatzis, G.; Assimacopoulos, D. Monitoring the sustainability of the Greek energy system. *Energy Sustain. Dev.* **2012**, *16*, 51–56. [CrossRef]
77. Bejan, A. Why we want power: Economics is physics. *Int. J. Heat Mass Transf.* **2012**, *55*, 4929–4935. [CrossRef]
78. Bejan, A. *Advanced Engineering Thermodynamics*; Wiley & Sons: New York, NY, USA, 2006.
79. Lucia, U.; Grisolia, G. Exergy inefficiency: An indicator for sustainable development analysis. *Energy Rep.* **2019**, *5*, 62–69. [CrossRef]
80. Grisolia, G.; Fino, D.; Lucia, U. Thermodynamic optimisation of the biofuel production based on mutualism. *Energy Rep.* **2020**, *6*, 1561–1571. [CrossRef]
81. Ritchie, H.; Roser, M. CO_2 Emissions. 2020. Available online: https://ourworldindata.org/co2-emissions (accessed on 25 August 2020).
82. United Nations. *Paris Agreement*; UNFCC Agreement; United Nations: New York, NY, USA, 2015.
83. Anderson, J.O.; Thundiyil, J.G.; Stolbach, A. Clearing the Air: A Review of the Effects of Particulate Matter Air Pollution on Human Health. *J. Med. Toxicol.* **2012**, *8*, 166–175. [CrossRef] [PubMed]