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Energy sustainability evolution in the Mediterranean countries and synergies from a global energy scenario for the area

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ABSTRACT

Energy supply is essential for the development of any society and search for energy sustainability is a must with poverty reduction and environmental sustainability as the two challenges to consider for any energy scenario. Meanwhile environmental damage receives predominant attention in the energy sustainability analysis, a lack of attention exists to others, such as external dependence for energy supply or availability of enough energy for people. However, these factors also compromise the sustainability of the assumed policies. An analysis considering these three factors has been developed and applied to countries in the Mediterranean area by considering two well-defined zones: the North side with an adequate level of energy consumption, but with excessive CO_2 emissions and high external dependence on energy supply; and, by the contrary, the Middle East and North African countries, with a deficit in energy supply, but without problems in CO_2 emissions and external energy supply. Results show a requirement of a 100% renewable scenario for the countries in the North area, while those in the MENA need to increase drastically their energy demand with a significant contribution from renewable sources. Assuming a global scenario for the entire area, energy sustainability could be reached with less demanding requirements.

1. Introduction

Energy supply is a fundamental element for the functioning of the society in the search for environmental, economic, and social sustainability [1]. In fact, poverty reduction and environmental sustainability are two significant challenges to cope with in the twenty-first century [2–4]. However, there is no consensus on which aspects need to be covered for a comprehensive assessment of energy sustainability [5,6]. While some aspects, such as environmental damage, receive predominant attention, there is a lack of coverage and adequate quantification for others, like the increase of energy demand or the external dependence for the energy supply. In particular, the search for an acceptable level of available energy generates a growing domestic demand, which increases at an average yearly rate of 3%, with higher values for developing countries [7]. This generates another element to consider when envisioning strategies towards a more sustainable energy sector.

Renewable energy plays a significant role in ensuring energy security, improving environment and promoting sustainable economic and social development [8–10]. Due to this potential, renewable energy has an important participation in the energy systems of European Union (EU) member states, in order to support the transition towards a greener, resource-efficient and more competitive, low-carbon EU economy [11–13]. Meanwhile, renewable energy participation in the energy scenario is very marginal in most of the African countries. In particular, countries in the Middle East and North Africa (MENA) region, have the greatest potential for renewable energy generation in the world, especially due to the high solar radiation, and likely are the most vulnerable to the worrisome effects of climate change [14]. Unfortunately, only a few of these countries have tapped into this potential and non-renewable energy, based on their fossil fuel abundance, still dominates their total energy mix [15].

The increasing concern over global warming and energy security has promoted the renewable energy alternative as the most vibrant option for future energy needs. Analysis for the five most populous countries (Ethiopia, South Africa, Nigeria, DR Congo, and Egypt) in Africa indicates that any increase in population, energy

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Nomenclature

Variables

$I_{cons}(t)$	Compliance factor: requirement to cover existing energy needs (%)
$dep(t)$	External dependence factor (%)
$I_{dep}(t)$	Sustainable degree of the external dependence (%)
$I_{CO_2}(t)$	Annual emissions per capita factor (%)
$sost(t)$	Sustainability index of the energy scenario (%)
$S(k,t)$	Sustainability parameters to cover each sustainable goal (%)
$De(i,j,t)$	*Energy demand (toe)*
$FD(t)$	*Fossil demand (toe)*
$FG(t)$	*Fossil generation (toe)*
$CO_2(t)$	*Total CO_2 emissions ($MtCO_2$)*
$CS(k,t)$	*Contribution to the sustainability index evolution (%)*
$INS(t)$	*Sustainability index evolution (%)*
$BS(k,t)$	*Deficits or surpluses for each parameter (%)*

Parameters

$TPC(t)$	*Available annual energy* per capita *consumption (toe/cap)*
TPC_0	*Adequate value for TPC(t) (toe/cap)*
$TPES(t)$	*Total primary energy demand (toe)*
C_{emp}	*Sustainable value of emissions* per capita *(t CO_2/cap)*
$CO_{2p}(t)$	*CO_2 emissions* per capita *for the year under consideration (t CO_2/cap)*
w_{cons}	*Compliance weighting factor (%)*
w_{dep}	*External dependence weighting factor (%)*
w_{CO_2}	*Annual emissions* per capita *weighting factor (%)*
$P(t)$	*Population data (inhab)*
$CO_2S(t)$	*CO_2 emissions from electricity generation (t CO_2/toe)*
$F(j,t)$	*Fossil fuel generation for the different sources (toe)*
$Em(i,j)$	*CO_2 emissivity (t CO_2/toe)*
$SO(k)$	*Sustainable reference parameters (%)*
$w(k)$	*Weighting factor for each energy sustainability objective (%)*

Sets

t	*Time period under consideration*
i	*Index for sectors under consideration, $i = \{1, 2, 3, 4, 5, 6\}$, specifically 1: transport, 2: industry, 3: residential, 4: services, 5: agriculture and fishing, 6: electricity generation*
j	*Index for energy resources under consideration, $i = \{1, 2, 3, 4, 5, 6\}$, specifically 1: coal, 2: oil, 3: natural gas, 4: renewable, 5: nuclear, 6: electricity*
k	*Index for energy sustainability objectives under consideration, $i = \{1, 2, 3\}$, specifically 1: to cover current energy needs, 2: to guarantee the energy supply for the future generations considering energy dependence, 3: to minimize the environmental impact of the chosen energy scenario*

use, electric power consumption and human capital should be determinants for an increase of renewable energy consumption [16]. Studies on the driving factors of renewable energy consumption on African Countries [17] shows that urbanization and economic globalization depress efforts towards renewable energy consumption and the need for some policy action that combines environmental, economic, and social factors in attaining the Sustainable Development Goals is needed. Statistical analysis using databases of the World Development Indicators (WDI) for the period 1990–2015 [18] found direct relationships of the CO_2 emissions with energy consumption, economic growth, urbanization and, even, with foreign direct investments. Main conclusions is to advocate for the consumption of renewable energies like wind, solar, hydro, biomass and biofuels among others in all these aspects. Evidences have been published on the fact that countries emitting more pollutants are less likely to take action to address climate change [19]. Therefore, to address the climate change in Africa, a re-evaluation of current policy actions in relation to renewable energies is needed. Additionally, most of the studies carried out in the northern and southern Africa shows a high increase on energy demand for water supply through desalination [20].

Since the United Nations published “Our Common Future” report (Brundtland Report) in 1987 [21], many indicators have been proposed for energy sustainability quantification. In Ref. [22] more than 57 indexes are mentioned, but all of them were lacking in some aspects and emphasis was mostly put on the economic and stakeholder implication aspects. For instance, in Ref. [23] the indicator includes an integrated approach and analyses various disciplines that influence sustainability assessment including energy, economy, technology, exergy, society, environment, education, and the size of the energy system. Meanwhile, the Sustainable Society Index (SSI), developed in 2006 [24], covers three aspects: economic, social and environmental but does not take explicit consideration of the external dependence. A composite indicator for Sustainable Development of Energy, Water and Environment is introduced in Ref. [25] including energy consumption and penetration, carbon dioxide saving measures and renewable energy potential and utilization. A City Sustainability Index (CSI) based on to maximize socio-economic benefits while meeting constraint conditions of the environment and socio-economic equity on a permanent basis is introduced in Ref. [26].

Our research focuses on the initial concept of sustainability presented in the Brundtland Report [21], which indicates that a sustainable energy scenario should allow three clearly defined objectives to be simultaneously achieved: to cover current energy needs, to guarantee the energy supply for the future generations and to minimize the environmental impact of the chosen energy scenario. Hence, it presents a complete energy sustainability index based on energy availability, external dependence and CO_2 emissions quantification. This index is used for the analysis of the evolution, along the period 1990–2018, of the energy sustainability degree for different countries in the Mediterranean Area. The countries selected for the case study include North European Mediterranean countries and MENA ones, so the energetic comparison between these two types of countries based on the introduced energy sustainability index is addressed. Moreover, the paper presents a novel algorithm for the index extrapolation, which looks for sustainable scenarios, both at an individual level and at a global one for the entire area, deducing the synergies that this global approach could be produced.

Finally, this paper is organised as follows: section 3 details the methodology developed for the sustainability analysis and extrapolation; section 4 presents the evolution in the period 1990–2018 of the sustainability in the different countries of the Mediterranean Area; section 5 details the requirements for full sustainable scenarios and their comparison with Business as Usual

(BAU) scenarios, and section 6 resumes the synergies from a global scenario including all the involved countries.

2. Literature review

The search for an appropriate index that represents energy sustainability for the different countries has been widely addressed in the literature review.

First researches tackled this issue providing single indicators. Latin-American Energy Organization (OLADE), Economic Commission for Latin America and the Caribbean (ECLAC) and German Technical Cooperation Agency (GTZ) proposed in 1997 the earliest set of energy sustainability indicators [27]. In 2000, the Millennium Development Goals (MDGs) presented a battery of 60 single indicators for this issue [28]. More recently, the International Atomic Energy Agency (IAEA) developed 30 indicators regarding energy sustainability [29].

Some researchers carried out particular investigations regarding single sustainability energy indicators. Razmjoo et al. developed new indicators to address this issue and compared their results in 12 countries [30]. Saraswat and Digalwar proposed a final set of 93 indicators, which were filtered from an initial list of 767 indicators [31].

However, later studies demonstrated that tracking progress into large number of single indicators becomes impractical and discouraging, especially for country comparisons or changes identification. Furthermore, some indicators prove dependent and may not be mutually exclusive [32].

In this regard, composite energy sustainability indices were develop to overcome these drawbacks, aiming to synergize the strengths and avoid weakness of individual indicators. Composite indices embrace a low number of unidimensional weighted sub-indices, preferable lower than 4, which reflect the multicriteria behavior of energy sustainability. Their use reduces the quantity of information to analyse, making it more convenient and easy to track results, providing also a uniform scale to compare countries performance in terms of energy sustainability [32,33].

Their multidimensional approach should reflect the complete dimension of energy sustainability, firstly reported in Brundtland Report [21] and verified later by OLADE, ECLAC and GTZ [27]. Brundtland report established that energy sustainability is ensured when current energy needs are covered, energy supply for future generations is guaranteed and environmental impact is minimized. OLADE, ECLAC and GTZ agreed on these requirements and divided them into three different dimensions: social, economic and environmental. In this regard, some authors have presented composite indices to quantify energy sustainability.

Dragos Cîrstea et al. [34] presented an energy sustainability index based on 23 indicators, and 6 sub-indices. Although they included some interesting novel sub-indices, as “Innovation competitiveness”, the number becomes high to track information. Furthermore, neither coverage of energy needs nor energy supply for future generations requirements were evaluated.

Slišāne et al. [35] contemplated a traceable number of sub-indices to determine a sustainability index (3, economic, social and environmental) according to Brundland and OLADE, ECLAC and GTZ reports. However, none of the aspects included in these sub-indices contemplated the energy availability condition.

Iddrisu et al. [32] presented the Sustainable Energy Development Index, based on 5 sub-indices that aimed to filled the gap between sustainable development and energy development. Although the number of sub-indices could be considered acceptable, even high, the main disadvantage of this index relates to its lack of assessment for the established condition of energy supply for future generations.

In line with this last index, the International Energy Agency (IEA) proposed in 2011 the Energy Development Index to better understand the role that energy plays regarding human development. It focuses on the transition of countries or regions to the use of modern fuels [32,33]. Nonetheless, it does not consider the sustainability of this transition based on the 3 previously described requirements. Instead, it quantifies the availability of modern fuels, their consumption, the basic needs supply trough this consumption and human development, distinguishing between energy development at residential and community levels.

Finally, Oxford Poverty and Human Development Initiative Institution (OPHI) presented the Multidimensional Energy Poverty Index [36]. It focuses on depriving modern energy as opposed to accessing energy, and it captures both the incidence and intensity of energy poverty. However, energy sustainability is not assessed with this index, since the six sub-indices comprise basic services of cooking, lighting, appliances, entertainment/education, and communication, but none of the 3 requirements above described.

After this thorough literature review of energy sustainability indexes, none of the current researches provides a complete index that fulfills the stated requirements. Therefore, we consider that the sustainability index presented in our study fills this research gap. Firstly, it addresses energy sustainability quantification answering to the 3 previously stablished dimensions in the literature: to cover current energy needs, to guarantee the energy supply for the future generations and to minimize the environmental impact of the chosen energy scenario. Second, this quantification is represented by means of a composite index, which facilitates the comparison of results and the traceability of the information. And, finally, the number of unidimensional sub-indices that compose the presented sustainability index is adequate for making the process easy to calculate and follow, being all of them directly related to the goals to fulfill.

3. Methodology

A methodology has been developed for the quantification of the degree of compliance with the requirement of sustainability in a particular energy scenario. This quantification is based on the evaluation of the three aspects above mentioned: coverage of the current energy needs, external dependence on the energy supply and environmental impact.

3.1. Sustainability index

According to the original report [21], which introduced the concept of sustainability, a sustainable energy scenario should allow for three clearly defined objectives to be simultaneously achieved:

1. To cover current energy needs.
2. To guarantee the energy supply for the future generations considering energy dependence.
3. To minimize the environmental impact of the chosen energy scenario.

We can therefore evaluate the degree of energy sustainability of a certain region by considering the degree of compliance with each of the three above-mentioned factors:

1. To cover current energy needs

The level of available energy per capita could be used as an indication of the degree of compliance with the requirement to cover existing energy needs. The corresponding compliance factor

($I_{const}(t)$) could be given by:

$$I_{cons}(t) = \left(\frac{\min(TPC(t), TPC_0)}{TPC_0}\right) \tag{1}$$

where TPC (t) represents the available annual energy per capita consumption and TPC_0 is the adequate value considered for this parameter in order to get an acceptable human development index.

2. To guarantee the energy supply for the future generations considering energy dependence

The energy supply for future generations could be guaranteed at any time if it is based on own energy resources, that implies a null value for the external dependence of that supply. The external dependence of the area under consideration (dep(t)) will be given by:

$$dep(t) = \frac{FD(t) - FG(t)}{TPES(t)} \tag{2}$$

$$dep(t) = max(dep(t), 0) \tag{3}$$

where FD(t) and FG(t) are the fossil demand and generation, respectively, and TPES(t) accounts for the total primary energy demand.

The sustainable degree of the external dependence ($I_{dep}(t)$) could be defined as:

$$I_{dep}(t) = 1 - dep(t) \tag{4}$$

3. To minimize the environmental impact of the chosen energy scenario.

The rate of variation of CO_2 equivalent emissions could be used to analyse the environmental impact of the energy system. A fair criterion would be to force the annual emissions per capita level ($I_{CO2}(t)$) at the same value for all countries in accordance with the value required for the political approaches to fight against the climate change.

$$I_{CO_2}(t) = \left(\frac{C_{emp}}{CO_{2p}(t)}\right) \tag{5}$$

Being C_{emp} the value of emissions per capita considered sustainable and $CO_{2p}(t)$ the emissions per capita for the year under consideration.

Assigning weights for each of these indicators, the sustainability index of the energy scenario (sost (t)) will be given by:

$$sost(t) = \left(w_{cons} \cdot I_{cons}(t) + w_{dep} \cdot I_{dep}(t) + w_{CO_2} \cdot I_{CO_2}(t)\right)$$

$$w_{cons} + w_{dep} + w_{CO2} = 1 \tag{6}$$

3.2. Algorithm for sustainability degree determination

Fig. 1 shows the flowchart for the algorithm developed for the evolution of the sustainability index and its extrapolation.

Input data includes the time span for the simulation and the energy demand from the different sectors in the period under consideration: *De(i, j, t)*, where: $i = \{1$ (transport), 2 (industry), 3 (residential), 4 (services), 5 (agriculture and fishing), 6 (electricity generation)$\}$ and $j = \{1$ (coal), 2 (oil), 3 (natural gas), 4 (renewable), 5 (nuclear), 6 (electricity)$\}$.

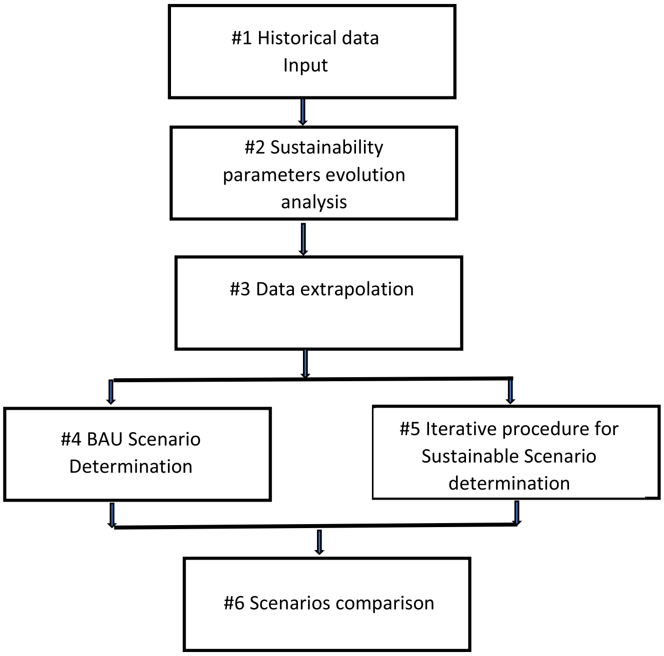

Fig. 1. Flowchart for the algorithm for sustainability degree determination.

These historic data could be obtained from the International Energy Agency (IEA) database [37]. Additionally, CO_2 emissivity for the specific fuel used in each sector, Em (i,j), are included in the data block [38]. Population data, P(t), for the entire period are also included [39], together with the different fossil sources (coal, oil and natural gas) generation F (j,t) [37].

Using all these data, sustainability parameters are calculated:

$$S(1,t) = \frac{TPES(t)}{P(t)} \tag{7}$$

$$S(2,t) = \frac{FD(t) - FG(t)}{TPES(t)} \tag{8}$$

$$S(3,t) = \frac{(CO_2(t) + CO_2S(t))}{P(t)} \tag{9}$$

where total primary energy demand, fossil demand and generation are given, respectively, by:

$$TPES(t) = \sum_{j=1}^{5} \sum_{i=1}^{6} De(i,j,t) \tag{10}$$

$$FD(t) = \sum_{j=1}^{3} \sum_{i=1}^{6} De(i,j,t) \tag{11}$$

$$FG(t) = \sum_{j=1}^{3} F(j,t) \tag{12}$$

CO_2 emissions from the different sectors are given by:

$$CO_2(t) = \sum_{i=1}^{6}\sum_{j=1}^{3} De(i,j,t)\cdot Em(i,j) \tag{13}$$

And the emissions from electricity generation will be:

$$CO_2S(t) = \frac{\sum_{j=1}^{3} De(6,j)\cdot Em(6,j)}{\sum_{i=1}^{5} De(i,6)} \tag{14}$$

Contribution to the sustainability index evolution from each of the considered parameters can be obtained from eq. (15).

$$CS(k,t) = Min\left(1;\frac{S(k,t)}{SO(k)}\right) \tag{15}$$

Being SO (k) the values taken as a sustainability reference for each parameter.

Sustainability index evolution can be deduced from these three contribution with the corresponding assigned weights w(k).

$$INS(t) = \sum_{k=1}^{3} w(k)\cdot CS(k,t) \tag{16}$$

Deficits or surpluses for each parameter are given by:

$$BS(k,t) = \frac{(S(k,t) - SO(k))}{SO(k)} \tag{17}$$

BAU scenario is deduced by lineal extrapolation of the available data while iterative process for the sustainable scenario uses as independent variables the primary energy sources contributions to fulfil the demand.

4. Evolution of the energy sustainability of the Mediterranean Countries

An analysis based on this approach has been developed and applied to countries in the Mediterranean area looking for the evolution during the period 1990–2018 of their energy sustainability and the extrapolation to the year 2040, both in a BAU approach and a sustainable energy scenario definition. Mediterranean area includes two well-defined zones in relation to their energy sustainability: the North side has an adequate level of energy consumption, but with excessive CO_2 emissions and a high level of external dependence on energy supply; and, by the contrary, the MENA zone, including the Middle East and North African countries, has a deficit in energy supply without problems in CO_2 emissions and external energy supply [40,41]. Analysis for each Mediterranean country, both separately and by grouping them in the two areas considered, and, finally, a global scenario that includes all of them in one single unit, will allow to define the requirements of a sustainable scenario in each case and the advantages of these global approaches.

Using the IEA database [37], we can analyse the evolution during the period 1990–2018 (the last year available in this database so far) of the energy sustainability for the different countries in the Mediterranean Area outlined in Table 1.

Table 1
Countries in the two zones considered in the study.

North Zone	MENA Zone
Albany	Algeria
Croatia	Egypt
France	Israel
Greece	Lebanon
Italy	Libya
Malta	Morocco
Montenegro	Syria
Slovenia	Tunisia
Spain	
Turkey	

To address the calculation of the sustainable index, we have assumed a level of CO_2 emissions per capita in the order of 2,5 t/capita·year. This value represents a 40% reduction on the averaged global value of 4 t/capita·year deduced from the evolution of these emissions that, as shown at Fig. 2, presents an almost constant evolution for the period 1990–2018 [37]. This reduction percentage is in accordance with the recommendations of the Intergovernmental Panel on Climate Change (IPPC) panel [42] and the EU directives [43].

We developed a thorough analysis of the appropriate values for TPC_0, which have been widely studied in the scientific literature. Specifically, we present Fig. 3, extracted from the previous study [44]. This plot determines total primary energy demand per capita (80 GJ/year-capita, which corresponds to 2 toe/capita·year) for an adequate human development index (quantified in 0.8) based on an extensive database. Hence, the selection for the appropriate value of TPC_0 is supported by a wide scientific review.

Finally, the external dependence is deduced from the generation and demand of fossil fuels detailed in the IEA database [37].

Hence, the sustainable values for each parameter (SO(k)) correspond to: 2.5 tCO_2/cap, 2 toe/capita·year and 0% external dependence.

Using these constraints in the formula (1) to (17), the evolution of the sustainability index is deduced for each considered country. The acceptable level matches a sustainability index of 100%. Moreover, we have considered homogeneous weighting factors for the evolution of the sustainability index. As an example of the output of these analyses, Fig. 4 displays this evolution for the case of Spain, as representative for the North zone, and for Algeria, in the case of the south one. Solid line represents the sustainability index evolution and, to understand this evolution, the surplus or deficits in each of the three considered factors in the sustainability analysis have been calculated and plotted as columns in the figures.

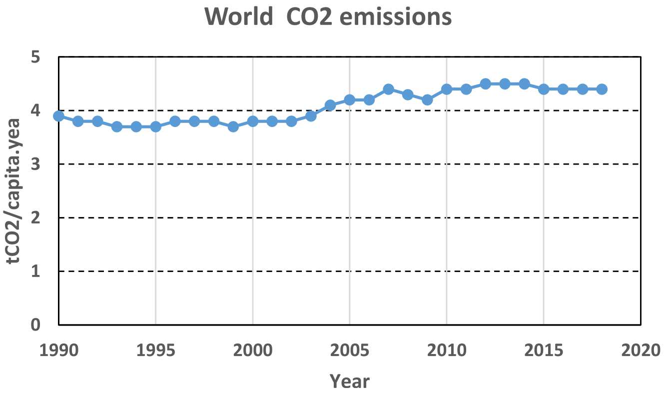

Fig. 2. Evolution of world CO_2 emissions per capita.

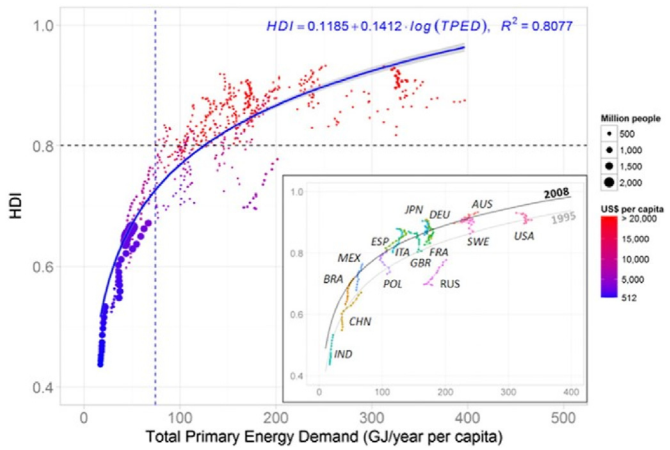

Fig. 3. Dependence of the HDI with available energy. From Ref. [31].

In both cases, there is not a substantial improvement for the sustainability index along the considered period. Values are 25% below the acceptable level for the case of Algeria and around 35% for Spain. In the case of Spain, there is a continuous deficit, between 50% and 70%, for the CO_2 emissions, and another deficit up to 75% in the external dependence, while the availability of energy is above the minimum required value, but with a tendency to reach the required sustainable level. By the contrary, in the case of Algeria there is big deficit in the energy per capita, while there are surplus in the CO_2 emissions and the external dependence. The first surplus is justified by the low level of energy consumption; even it is almost based on fossil fuels, while the external dependence values are sustainable given the abundance of these fossil fuels in the country.

Fig. 5 and Fig. 6 detail the sustainability analysis for all the considered countries in both Mediterranean zones, respectively. Similarly to the above mentioned analyses for Spain and Algeria, it can be deduced for all countries that the sustainability index has remained between 25% and 50% below the acceptable level and there are no significant variations throughout the considered period and a tendency to improve sustainability does not appear. Nevertheless, the reasons for this lack of sustainability are different. While in the countries of the northern zone there is a significant deficit in external dependence and CO_2 emissions, in those of the southern zone the deficit is motivated by an insufficient level of energy per capita.

Given the absence of substantial changes along the entire period, it is possible to reduce the comparison for the last available year and analyse the sustainability index for each country in 2018. All of them (Fig. 7) are in the range 50%–75% below the acceptable level.

To find the reasons for this lack of sustainability, Fig. 8 details the values of the different sustainable parameters of each countries. All European countries, except Albania, exceed the CO_2 emissions per capita sustainable level. Meanwhile, in the case of the MENA countries, only Israel, Lebanon and Libya are above that level. With respect to the energy availability, all European countries, except Albania, are close or above the required value and the MENA countries, except Israel and Libya, have a significant deficit. Finally, all the European countries present external dependence, very high in many of them, while for the MENA ones, half of the countries (Algeria, Egypt, Libya and Morocco) are self-sufficient and the others (Israel, Lebanon, Syria and Tunisia) have a significant external dependence.

The structure of the primary energy supply in each country, as detailed in Table 2 and in the corresponding Fig. 9, is dominated in the MENA countries by the use of fossil fuels, with almost no contribution from renewable sources, except Morocco and Tunisia, where this renewable contribution is around 10%. The European countries use renewables in higher percentage, in an average of 15%, but they still heavily depend on fossil fuels. Therefore, in order to increase the energy per capita in the MENA countries without deteriorating the environmental impact, and to reduce the CO_2 emissions and the external dependence in the European countries, actions should be addressed in both cases to increase the participation of renewable sources in the primary energy consumption.

Three European countries: France, Slovenia and Spain, include nuclear energy in their scenario and increasing this participation would be a way to reduce CO_2 emissions and external dependence. However current political plans are in the opposite way and a non-nuclear scenario should be considered in the medium term [45]. If fusion based nuclear power plants could be available as electricity generation units, these policies could change, but, in any case, these fusion reactors will not be a reality before the 2040 [46] and in the medium term the energy scenario should not considered them.

5. Determination of sustainable scenarios

Given the existing lack of sustainability for all the Mediterranean countries, it is necessary to determine the qualitative changes in their energy consumption scenario in order to get in a particular year, 2040 for this study, full sustainability for each of those countries. Once the sustainability index evolution is determined, its behaviour in the future up to a particular year can be deduced by a linear extrapolation of the data input (generation and

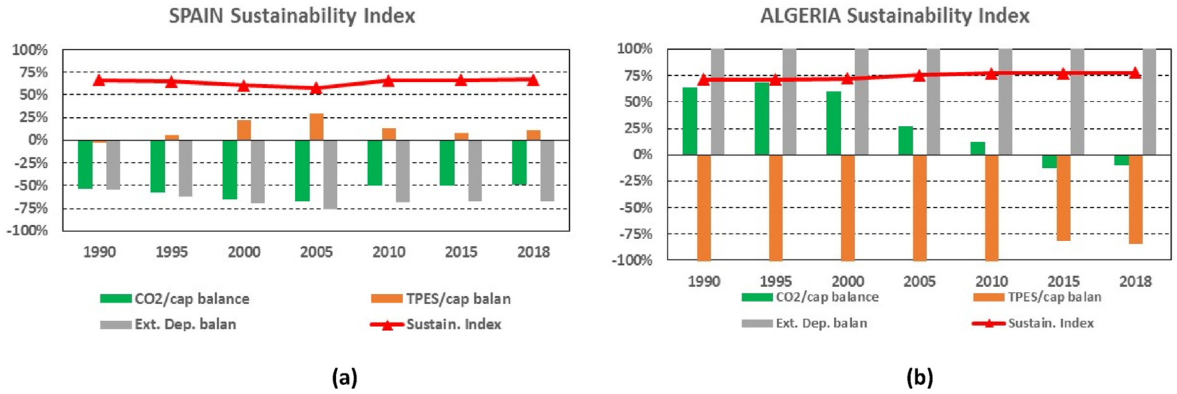

Fig. 4. Sustainability index evolution. (a) Spain. (b) Algeria.

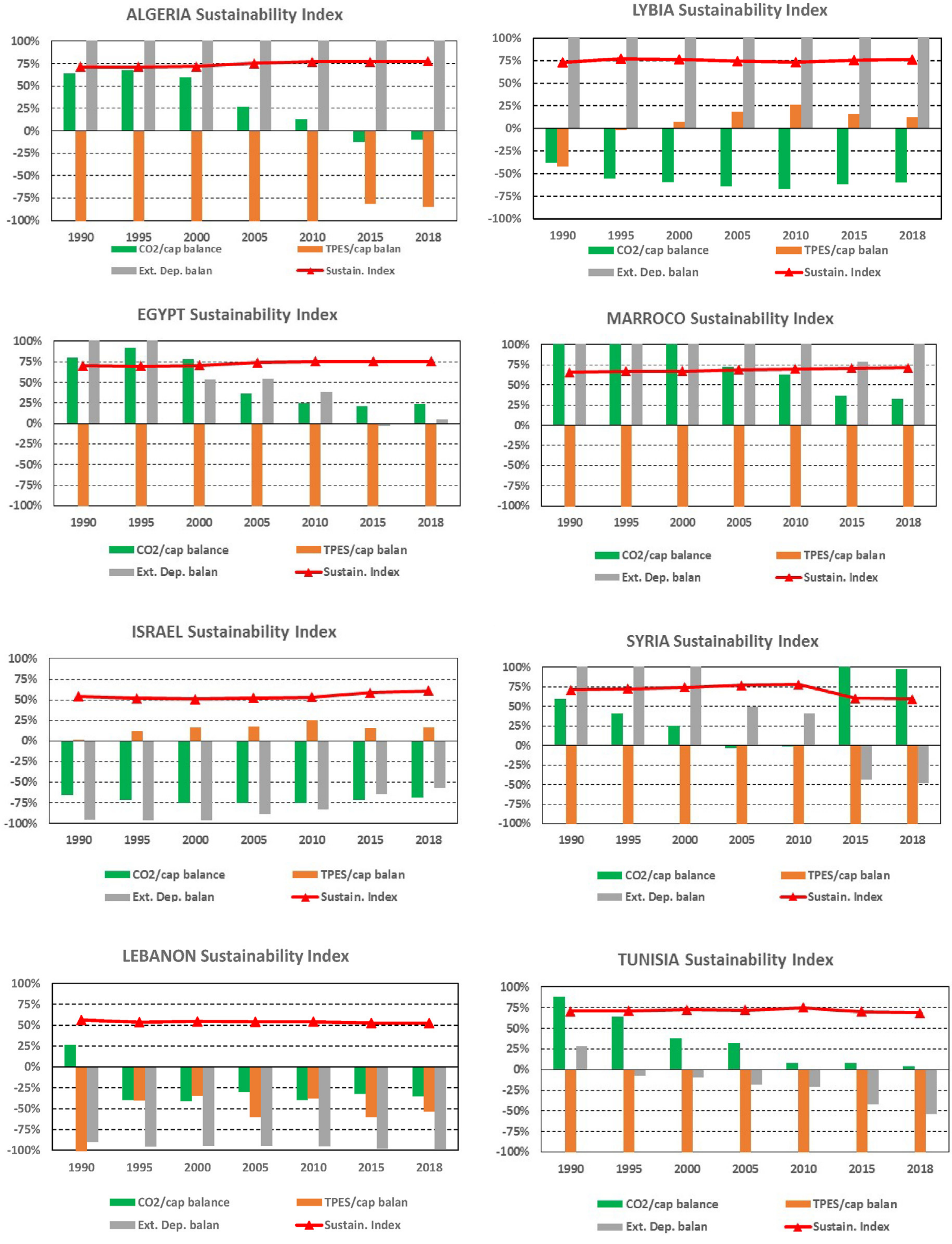

Fig. 5. Sustainability index evolution for countries in MENA region.

consumption) deducing a BAU scenario where no qualitative changes are introduced in the energy system structure.

Linear extrapolation methodology was selected by the authors for future BAU scenario determination according to its suitability: since BAU scenario embraces no qualitative changes in their consumption and generation structure, a linear extrapolation of these input data (consumption and generation) turns out to the be most adequate method to stablished future BAU scenarios [47,48].

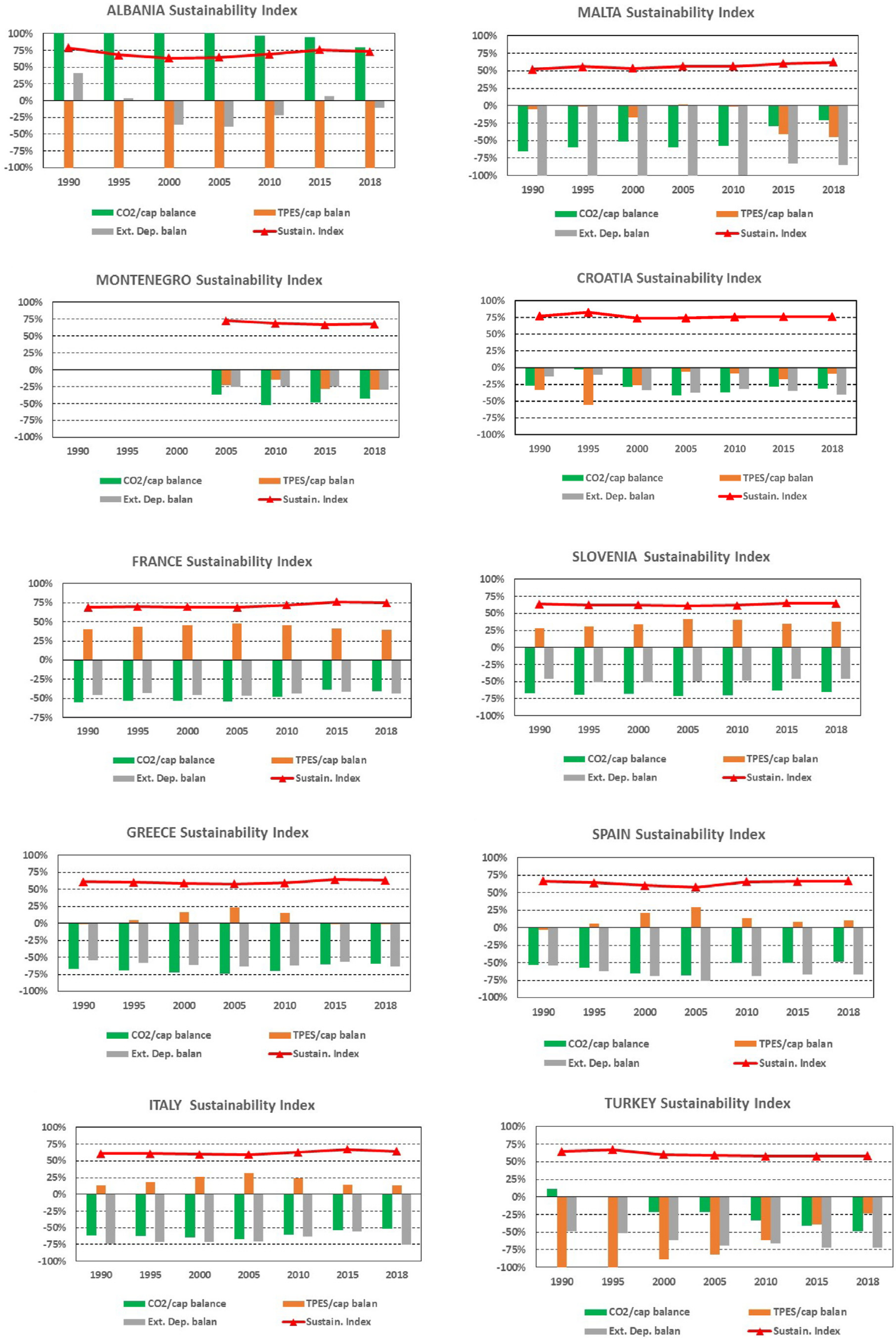

Fig. 6. Sustainability index evolution for countries in the North Mediterranean Area.

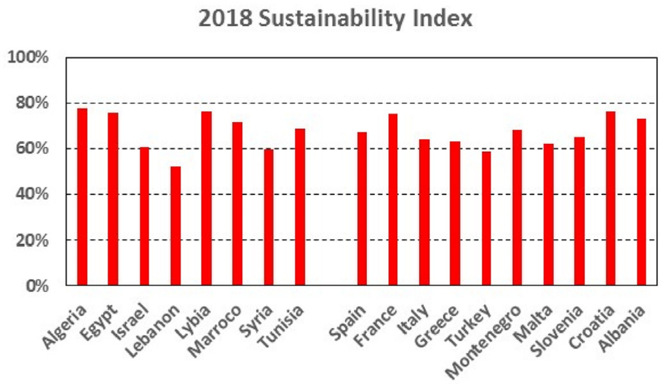

Fig. 7. Sustainability index for the year 2018 in the Mediterranean countries.

To reach a sustainable energy scenario an iterative process, by adjusting the contributions of the different primary energy sources, is addressed until all the considered parameters reach values equal or below the required sustainable values. Comparison with the BAU results provides the qualitative changes to introduce in the energy scenario in order to get sustainability.

Table 3 summarises the obtained results for each country of the values for the sustainability parameters, the total primary energy demand and the contribution of renewable sources, for the case of a sustainable energy scenario in 2040. These values are compared in the table with the published data corresponding to the year 2018.

Results from the study for the case of Spain are shown at Fig. 10 with indication of the evolution of the sustainability index. In addition the evolution of the CO_2 emissions per capita, the energy

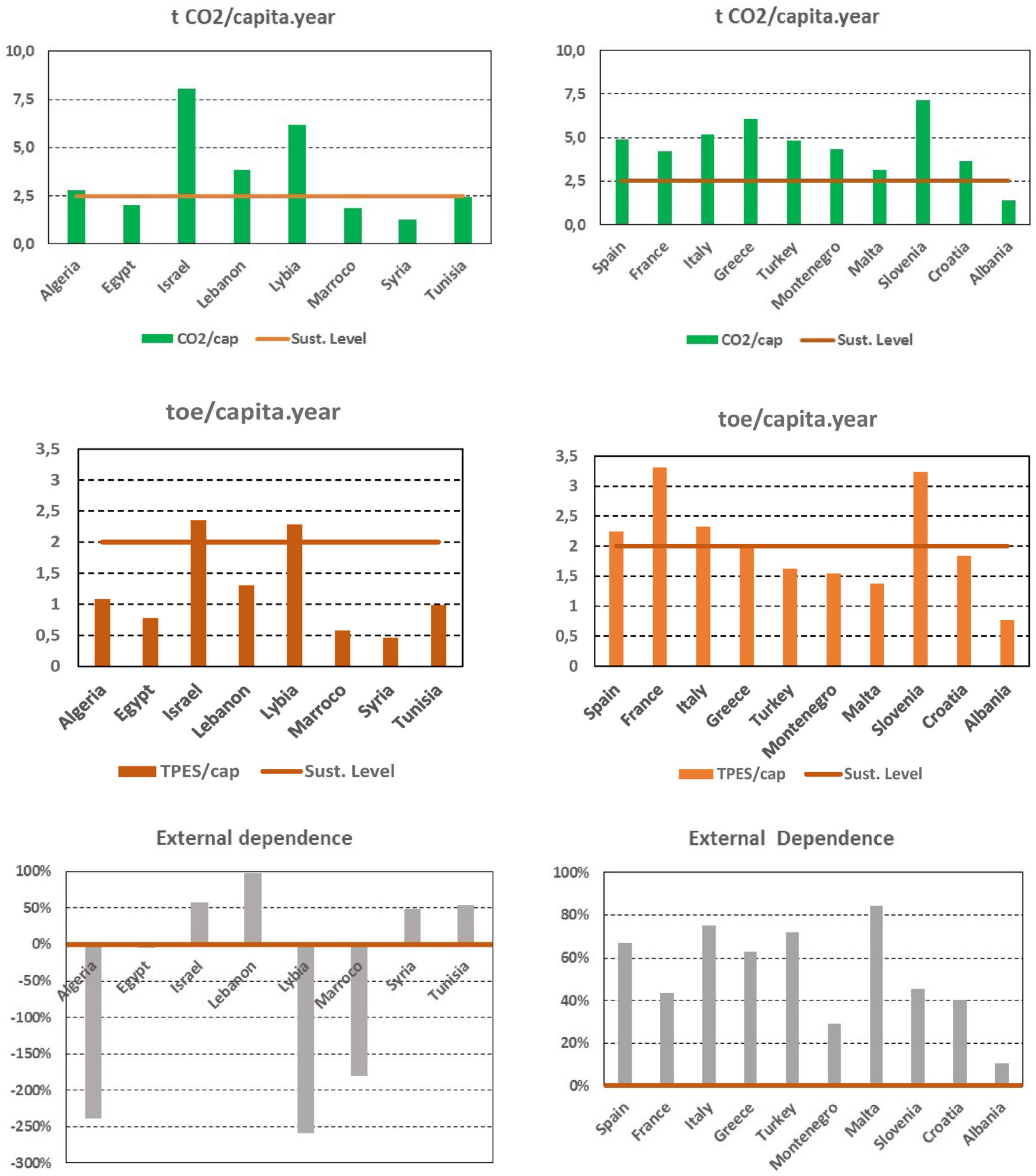

Fig. 8. Sustainability parameters in 2018 for Mediterranean Countries.

Table 2
Primary Energy Supply structure in 2018.

Country	Renewable	Coal	Oil	Natural gas	Nuclear
Algeria	*0,1%*	*0,1%*	*37,4%*	*62,4%*	–
Egypt	*3,1%*	*0,3%*	*49,4%*	*47,2%*	–
Israel	*2,8%*	*23,9%*	*33,5%*	*39,8%*	–
Lebanon	*1,9%*	*1,9%*	*96,2%*	*0,0%*	–
Libya	*1,0%*	*0,0%*	*61,3%*	*37,7%*	–
Morocco	*9,1%*	*22,8%*	*62,9%*	*5,2%*	–
Syria	*0,8%*	*0,0%*	*65,7%*	*33,5%*	–
Tunisia	*8,6%*	*0,0%*	*51,0%*	*40,4%*	–
Albania	*33,2%*	*6,0%*	*60,2%*	*0,6%*	–
Croatia	*27,3%*	*5,7%*	*41,6%*	*25,4%*	–
France	*10,9%*	*2,7%*	*24,9%*	*15,6%*	*45,9%*
Greece	*12,7%*	*23,0%*	*45,9%*	*18,4%*	–
Italy	*19,8%*	*6,3%*	*30,9%*	*43,0%*	–
Malta	*4,8%*	*0,0%*	*55,3%*	*39,9%*	–
Montenegro	*30,0%*	*35,2%*	*34,8%*	*0,0%*	–
Slovenia	*16,6%*	*16,7%*	*32,0%*	*10,4%*	*24,3%*
Spain	*17,3%*	*9,5%*	*40,1%*	*19,0%*	*14,1%*
Turkey	*13,6%*	*27,1%*	*27,2%*	*32,1%*	–

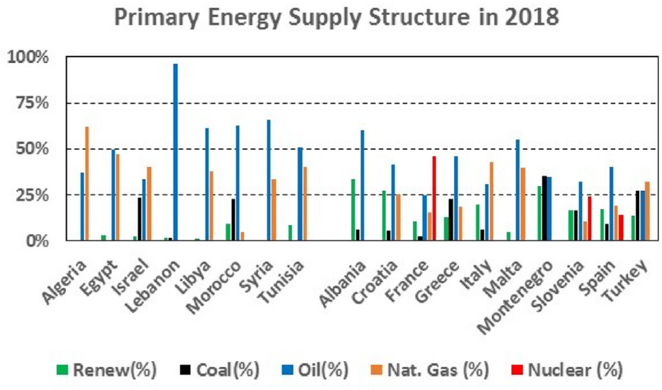

Fig. 9. Primary Energy Supply structure in Mediterranean countries.

demand per capita and the external dependence are also shown, together with the contributions from the different energy sources to the total primary energy demand structure. BAU scenario is calculated assuming that nuclear contribution reduces by steps until be null in 2040, substituting its contribution with renewable sources. This BAU scenario results for the year 2040 indicate a 33% contribution from renewable sources and maintains a 25% deficit in sustainability, due to the high external dependence and CO_2 emissions per capita, while energy per capita is 25% above the required value. Results for a sustainable scenario provide a steadily increasing renewable sources contribution until reach a 100% in 2040, without any fossil contribution, explained by the lack of generation of these type of fuels in Spain [49], and, obviously, with neither CO_2 emissions nor external dependence. Additionally, the reduction in energy per capita to 2,0 toe/capita·year generates a stabilisation of the total energy demand that would require additional energy saving and efficiency improvements.

Similar results are obtained from the majority of countries in the European side, where there is a clear relationship between renewable penetration and environmental awareness [50] and energy independence [51]. In contrast, the southern zone needs a substantial increase in the availability of energy per capita to reach a level of sustainability [52]. To avoid excessive CO_2 emissions part of the energy required by these countries should come from renewable sources [53,54], even they could use their own fossil resources [55,56].

Fig. 11 summarises the variation in energy consumption in 2040 in relation to the required in 2018 and the participation of renewable sources in the total energy consumption for both scenarios in 2040.

In the Annex, figures with the BAU and SUSTAINABLE results for the sustainability index and the TPES evolutions are presented for all the considered countries.

6. Synergies from global scenarios

In order to know if the two zones separately could achieve energy sustainability, we can group the data on demand, population and fossil generation from all the countries considered in each of the two zones and deduce the requirements to achieve a sustainable scenario. Fig. 12 shows the evolution for the period 1990–2040 of the sustainability index and the corresponding evolution of the primary energy demand for that period with the goal to reach sustainability in the year 2040.

In the case of the northern zone, efforts should focus on reducing external dependence until neutralizing it in 2040 and also on reducing energy demand to the limit of 2 toe/capita in that year. With these actions, it is possible to significantly reduce emissions to

Table 3
Sustainable scenario results comparison.

Country	CO_2 emissions (t/capita·year) 2018/2040	Energy demand (toe/capita·year) 2018/2040	External dependence (%) 2018/2040	TPES (Mtoe) 2018/2040	Renewable contribution (%) 2018/2040
Algeria	2,8/2,5	1,1/2.0	−238/-136	45,2/109,6	0,1/51,3
Egypt	2,0/2,0	0,8/2,0	−4,7/0	73,9/254,3	3,1/62,2
Israel	8,1/2,5	2,1/2,0	57,2/−13,9	20,9/23,8	2,7/57,4
Lebanon	3,9/0,2	1,3/2,0	98,0/0	8,8/19,4	1,9/100
Libya	6,2/2,5	2,3/2,0	−259/−202	15,0/17,0	1,0/54,3
Morocco	1,9/2,5	0,6/2,0	−180/−9,3	20,0/87,2	8,9/61,0
Syria	1,3/0,5	0,5/2,0	48,1/0	7,8/47,7	0,8/91,2
Tunisia	2,4/1,0	1,0/2,0	53,7/0	11,3/28,2	8,6/80,6
Albania	1,4/1,5	0,8/2,0	10,4/0	2,2/5,0	29,4/77,8
Croatia	3,6/1,3	1.8/2,0	40,4/0	7,5/7,2	25,1/79,2
France	4,2/0,1	3,3/2,0	43,7/0	221/151	11,0/99,0
Greece	6,1/1,1	2,0/2,0	62,8/0	21,1/22,7	12,4/82,8
Italy	5,2/0,5	2,3/2,0	75,2/0	140/128	19,4/90,2
Malta	3,2/0,1	1,4/2,0	84,5/0	0,65/1,1	4,3/100
Montenegro	4,4/2,1	1,5/2,0	29,3/0	0,96/2,7	27,0/70,8
Slovenia	7,1/1,0	3,2/2,0	45,4/0	6,7/4,3	16,7/85,1
Spain	4,9/0,0	2,2/2,0	67,1/0	103/109	17,3/100
Turkey	4,9/0,8	1,6/2,0	72,2/0	131/199	13,6/89,8

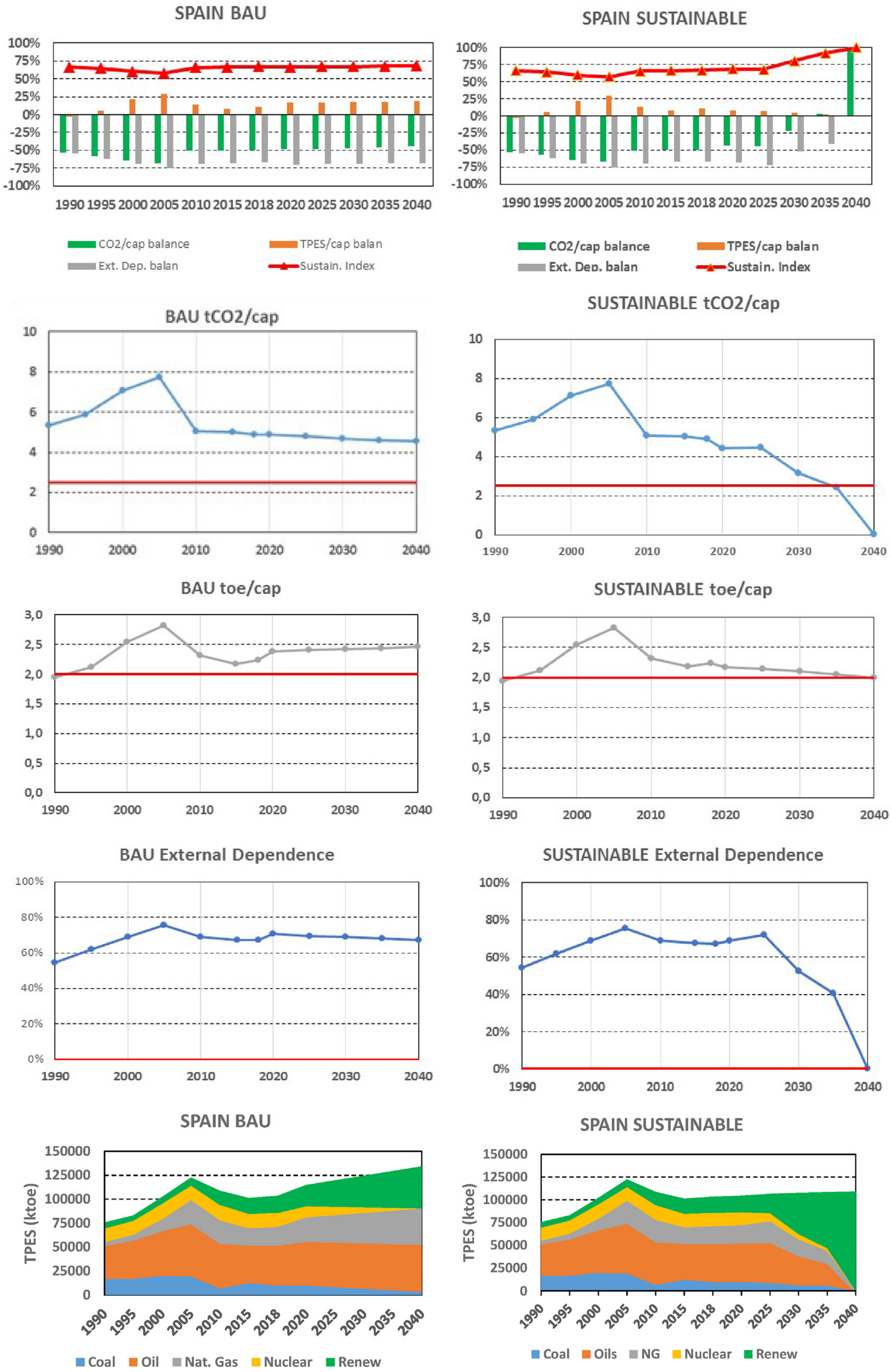

Fig. 10. BAU and SUSTAINABLE scenarios for Spain.

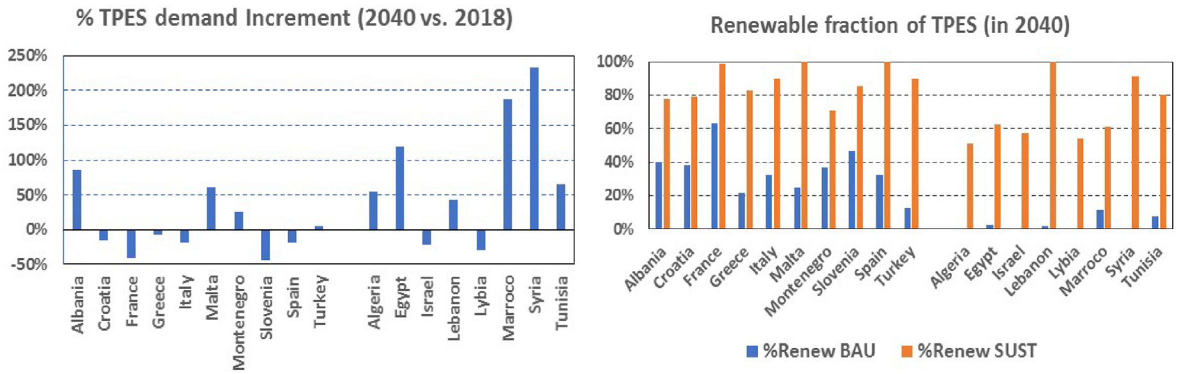

Fig. 11. Energy requirements for sustainability in 2040 and renewable contribution.

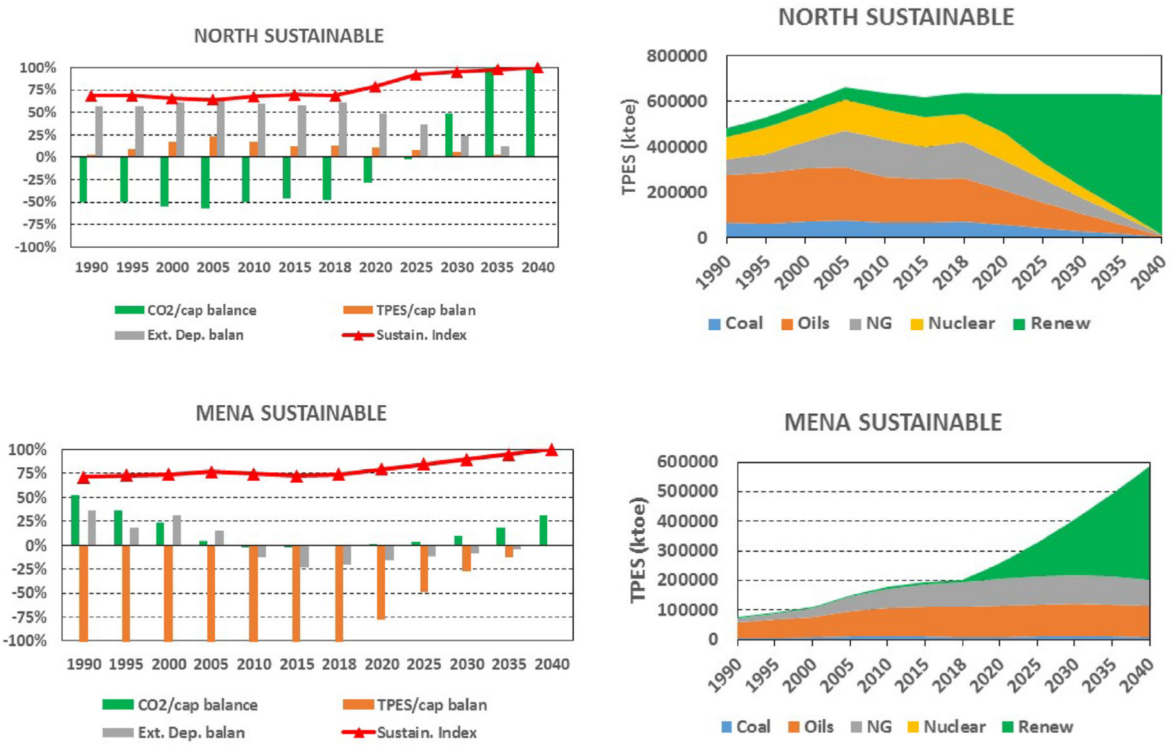

Fig. 12. Sustainability index and TPES demand evolution for MENA and European areas.

the point of cancelling them, since energy demand is covered almost entirely by renewables. Energy demand stabilizes as population growth is offset by the per capita demand reduction effect.

For the southern zone, it is possible to achieve adequate levels of energy per capita in 2040 through an increase in energy generation. This increase should be partly based on the introduction of renewable energies at the level required to reach CO_2 emissions below the level for sustainability, complementing with the contribution of natural gas and oil in energy consumption given the availability of fossil fuels on the region.

First two rows in Table 4 summarize the energy requirements of both areas in the sustainable scenario for the year 2040. The northern area reduces energy demand by 20% compared to the BAU scenario, but covers this demand by a 98% with renewable sources. Meanwhile, the southern zone increases its demand by 86% with a renewable contribution of 65%.

The total dependence on renewable sources in the case of the North zone, with the difficulties that a 100% renewable scenario could introduce [56,57], suggest the convenience to join both zones in a global area to take advantage of the fossil fuels availability in the MENA countries. Besides, these countries should partly avoid the use of fossil fuels and substitute them by renewable sources to reach the CO_2 emission criteria. Important synergies can be obtained from the global scenario that implies the transfer of renewable technologies from the North countries to the MENA ones and the supply of fossil fuels from these countries to the north ones to avoid their 100% dependence on renewable sources. Last row in Table 4 quantifies the needs in this global scenario. Total renewable contribution reaches a 70% of the total energy demand while demand increase goes only up to 10% in respect to the BAU requirements. Fig. 13 presents the results for this global scenario.

Table 4
Global TPES and Renewable demand for both zones in 2040.

Area	Renew BAU (ktoe)	TPES BAU (ktoe)	Renew SUST (ktoe)	TPES SUST (ktoe)	Renew Cont. BAU (%)	Renew Cont. SUST (%)	Inc. TPES (%)
NORTH	292.756	783.278	615.929	628.296	37,4%	98,0%	−19,8%
MENA	8.163	314.261	382.835	586.220	2,6%	65,3%	86,5%
NORT + MENA	300.919	1.097.539	851.873	1.214.516	27,4%	70,1%	10,7%

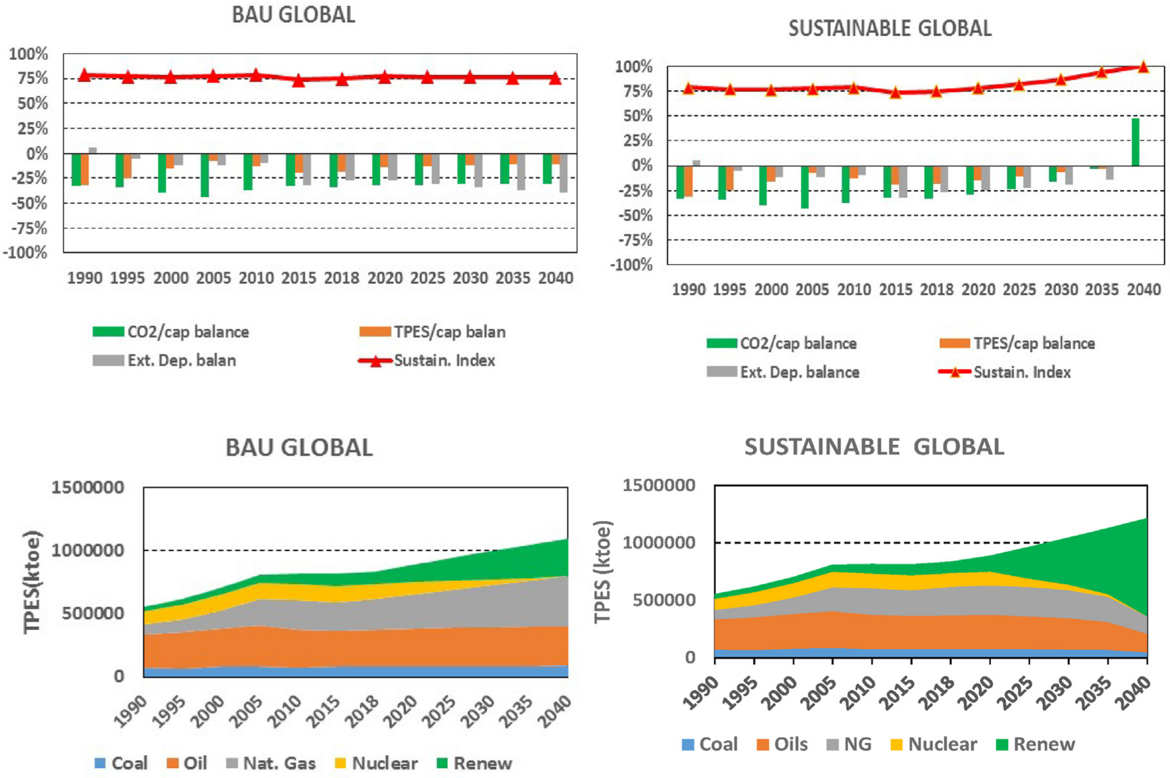

Fig. 13. BAU and SUSTAINABLE scenarios results for a global Mediterranean approach.

7. Conclusions

Energy supply is a central element in the search for social, environmental and economic development of any society together with the need for a sustainability in its energy scenario. Meanwhile the environmental impact of the energy sector receives predominant attention in its sustainability analysis, it should be necessary a similar coverage and adequate quantification for the external dependence for energy supply or the availability of enough energy for people, given these factors also compromise the sustainability of the assumed scenario and the policies to reach it.

A sustainability index taking into account these three factors has been defined and applied to countries in the Mediterranean area. No improvement in their sustainability evolution during the period 1990–2018 is deduced for any of the countries with deficits in the range of 25%–50%. Results also indicate that the Mediterranean area includes two well-defined zones in relation to their energy sustainability: the North side has an adequate level of energy consumption, but with excessive CO_2 emissions and a high level of external dependence on energy supply; by the contrary, the MENA zone, including the Middle East and North African countries, has a deficit in energy supply without problems in CO_2 emissions and external energy contribution.

Our detailed extrapolation studies looking for sustainability in the year 2040, show a requirement of a 100% renewable scenario for the countries in the North area, while those in the MENA region will need to increase drastically their energy demand, up to more than double in many of them, and with a significant contribution from renewable sources.

Assuming a global scenario for the entire area, energy sustainability can be reached with less demanding requirements. Renewable contribution will reduce to 70% of the total consumption and energy availability will reach 2 toe/capita·year in the entire area, while CO_2 emissions will decay up to 1,7 t CO_2/capita·year with no external dependence at all.

Policies to facilitate the transfer of renewable technologies from the North countries to the MENA countries and share the fossil resources by all the countries in the area will be needed to facilitate this global sustainable energy scenario.

Credit author statement

Paula Bastida-Molina: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing Original Draft, Writing-Review&Editing, Visualization, Supervision. Elías Hurtado-Pérez: Conceptualization, Validation,

Resources, Data curation, Visualization, Supervision, Project administration, Funding acquisition. María Cristina Moros Gómez: Resources, Data curation. Javier Cárcel-Carrasco: Resources, Data curation. Ángel Pérez-Navarro: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing Original Draft, Writing-Review&Editing, Visualization.

Declaration of competing interest

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

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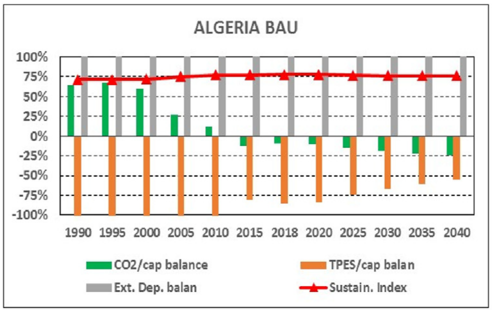
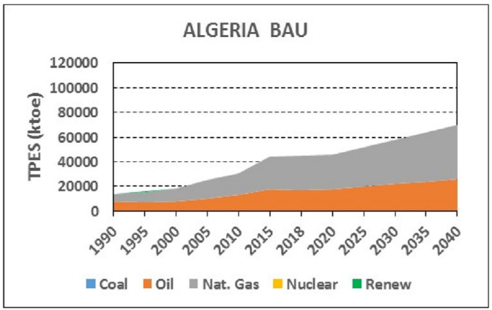
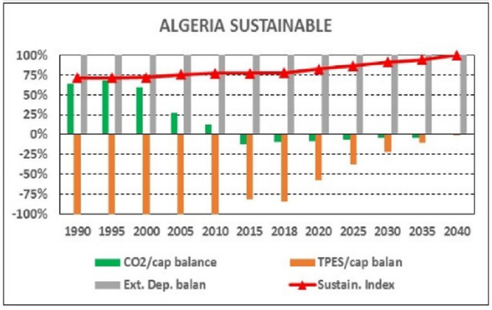
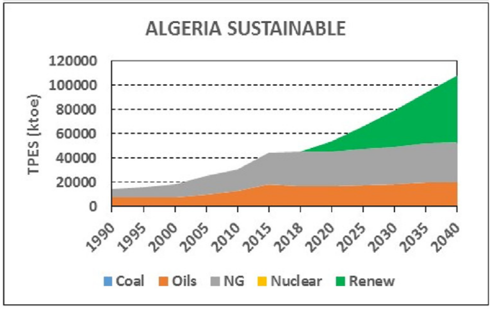
ANNEX

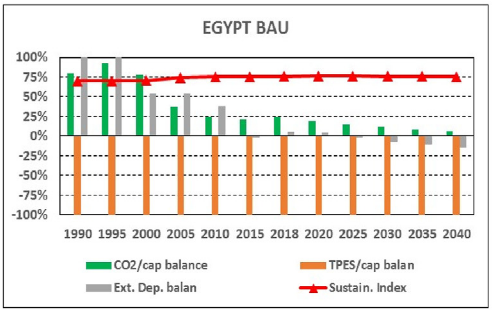
BAU and Sustainable scenarios for Mediterranean countries.

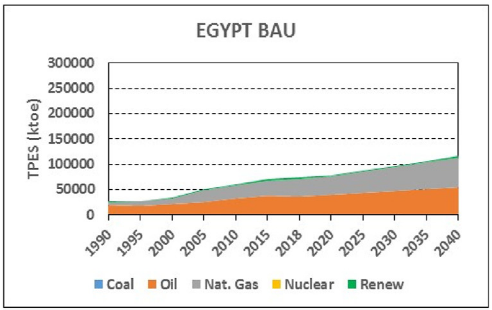


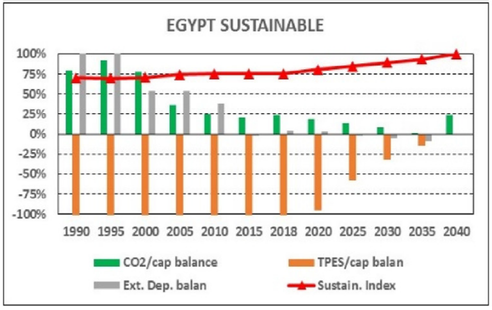


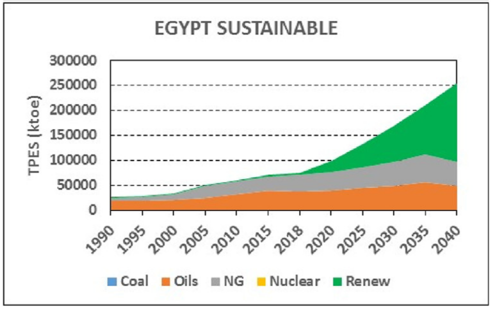


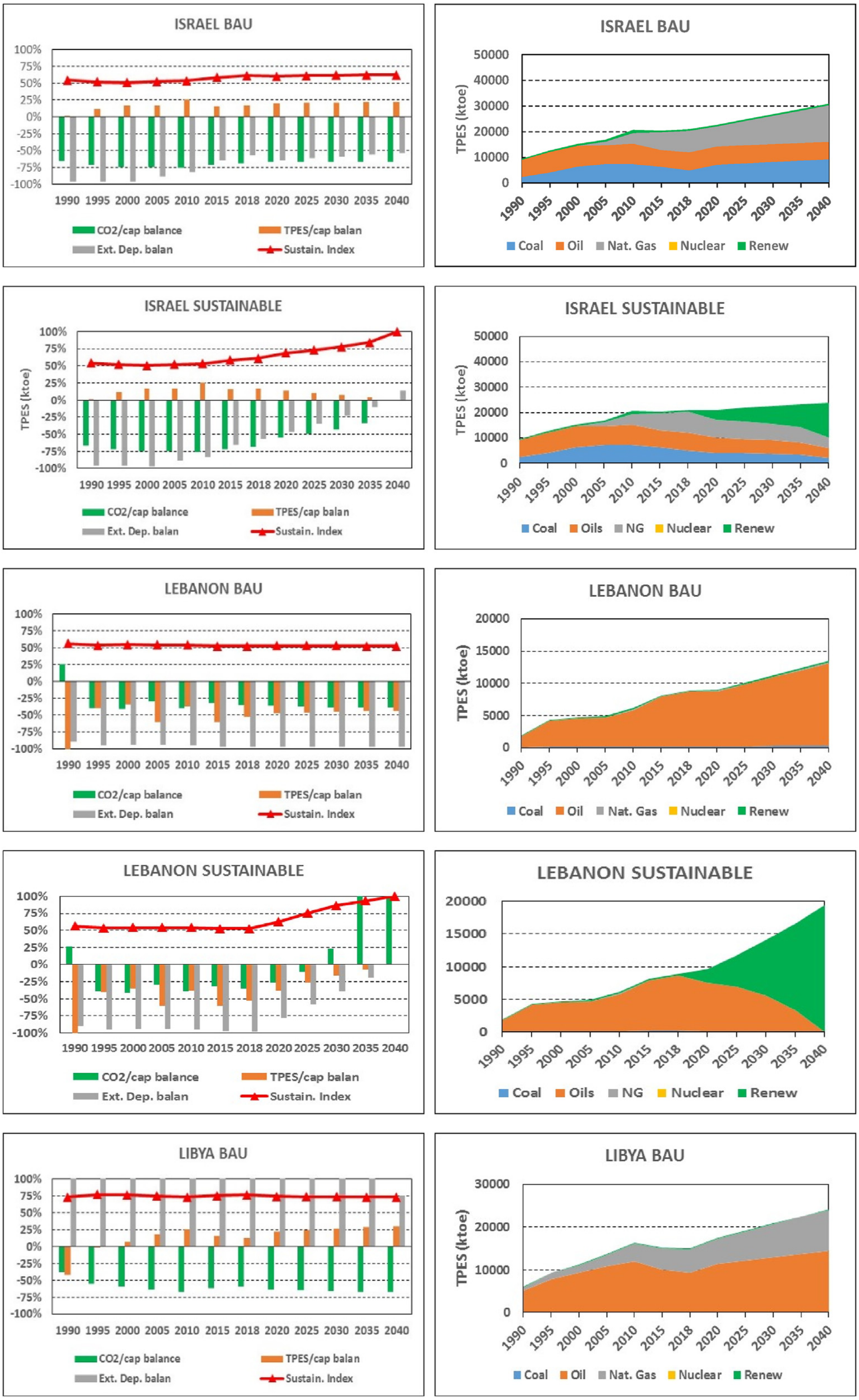








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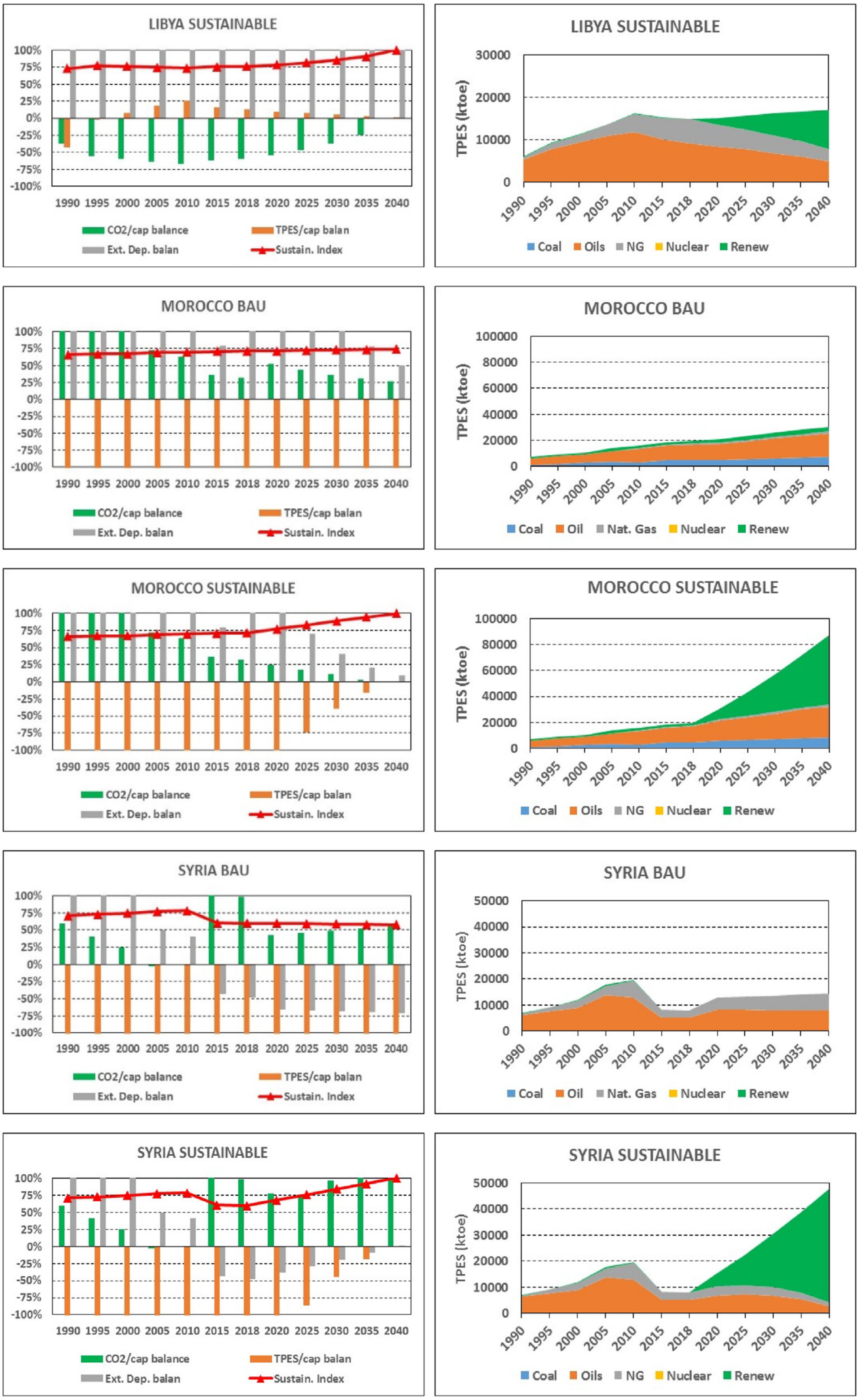
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MOROCCO SUSTAINABLE
CO2/cap balance
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Sustain. Index
MOROCCO SUSTAINABLE
TPES (ktoe)
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SYRIA BAU
CO2/cap balance
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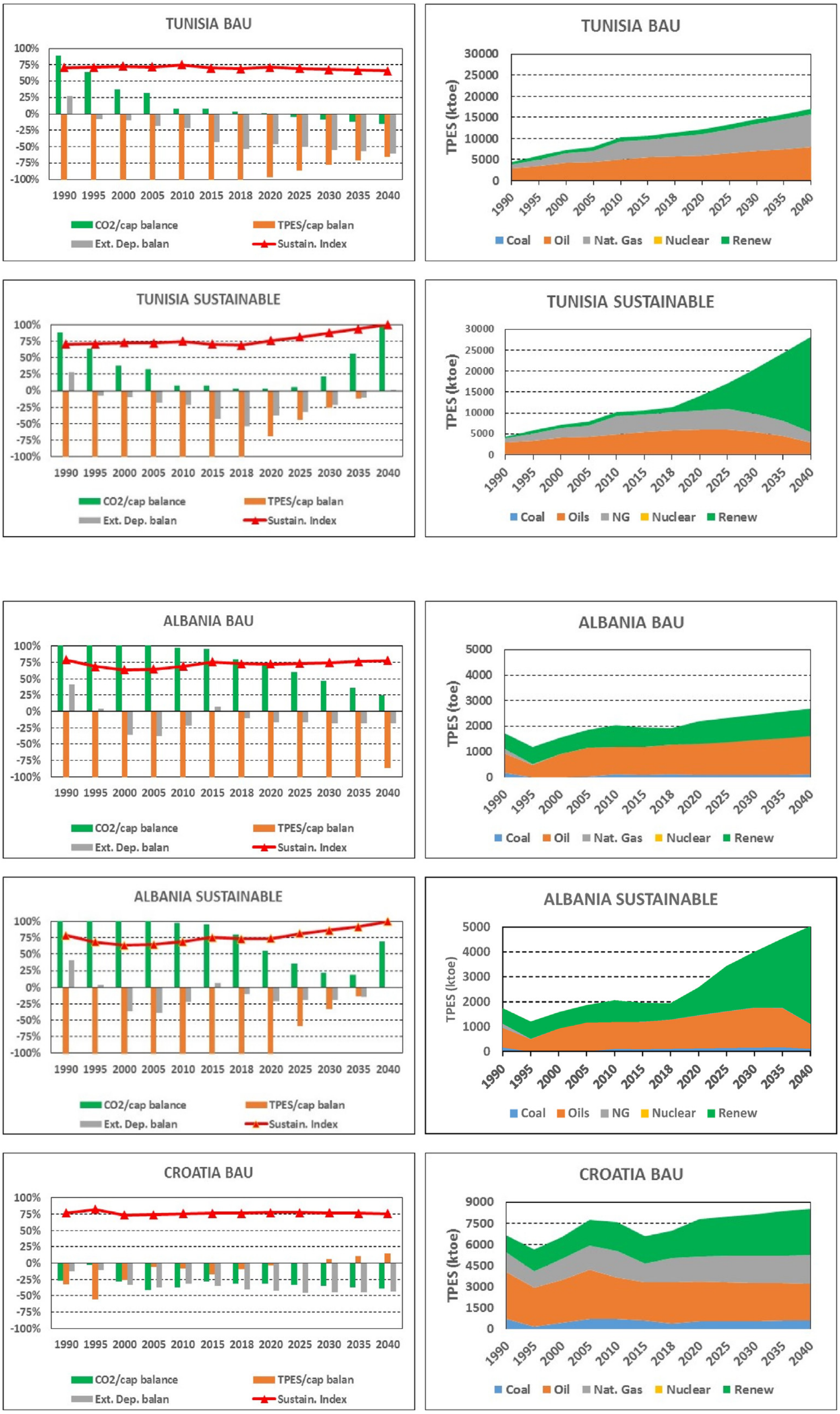
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TPES/cap balan
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Coal
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ALBANIA SUSTAINABLE
CO2/cap balance
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TPES (ktoe)
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CO2/cap balance
TPES/cap balan
Ext. Dep. balan
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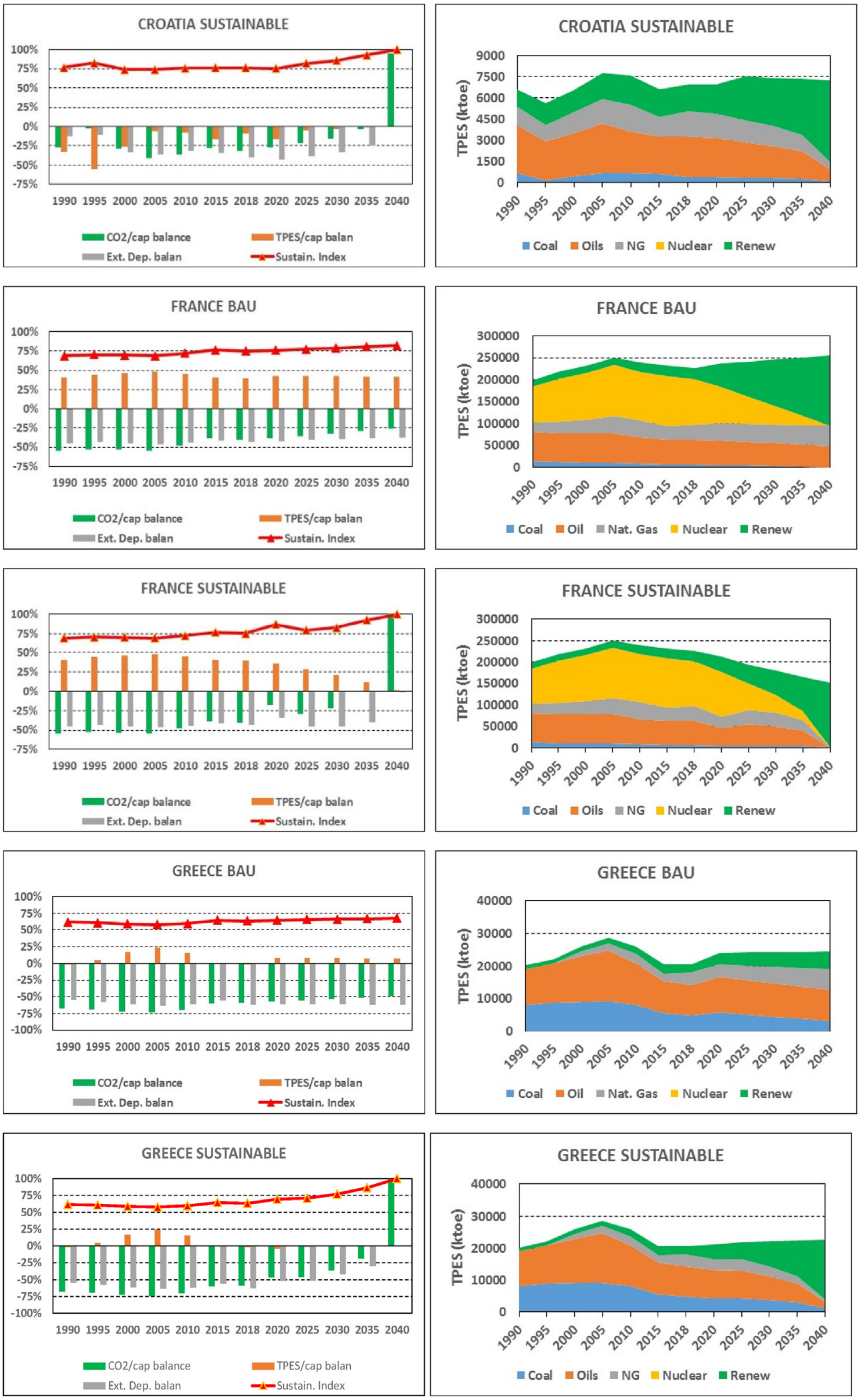
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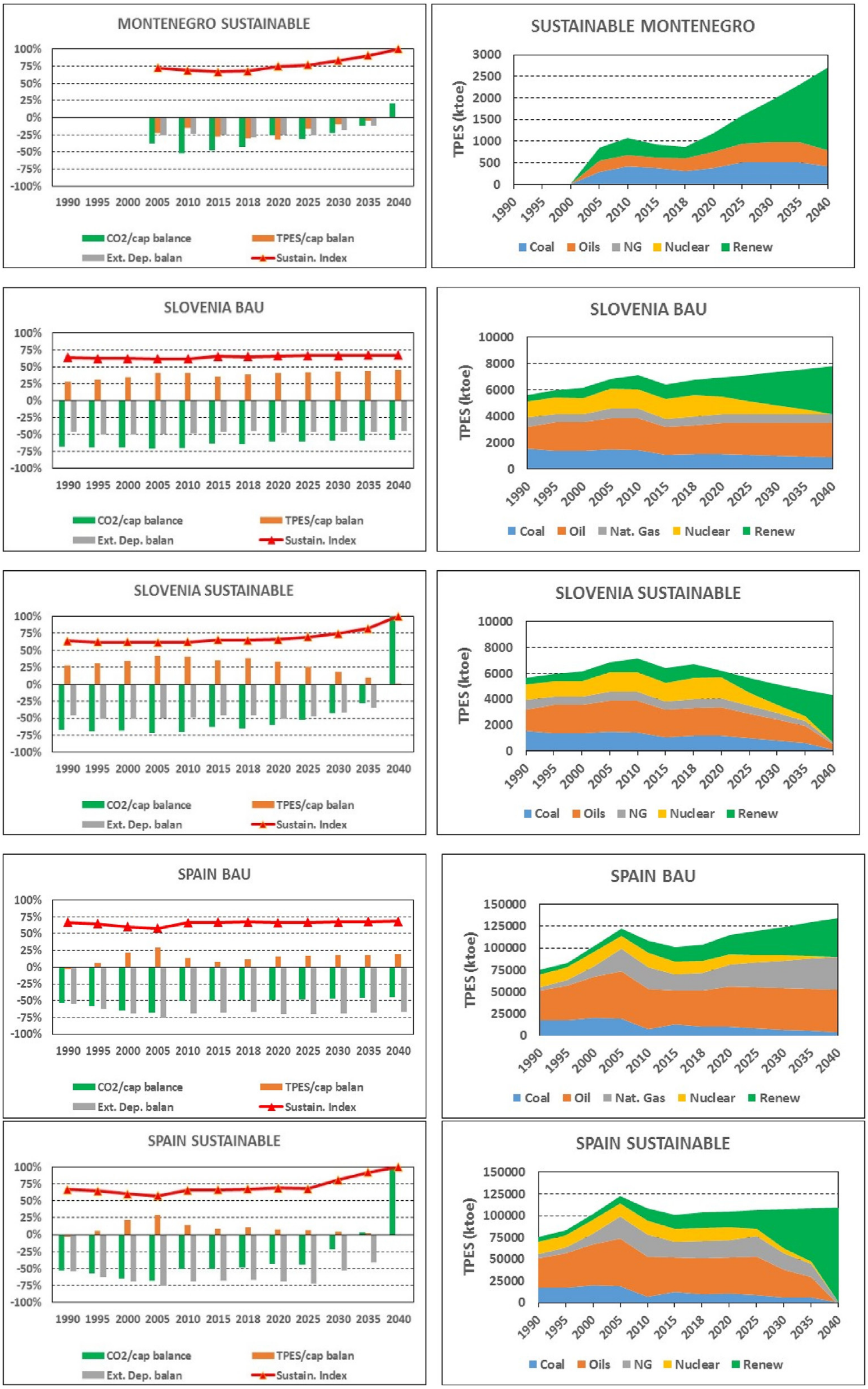
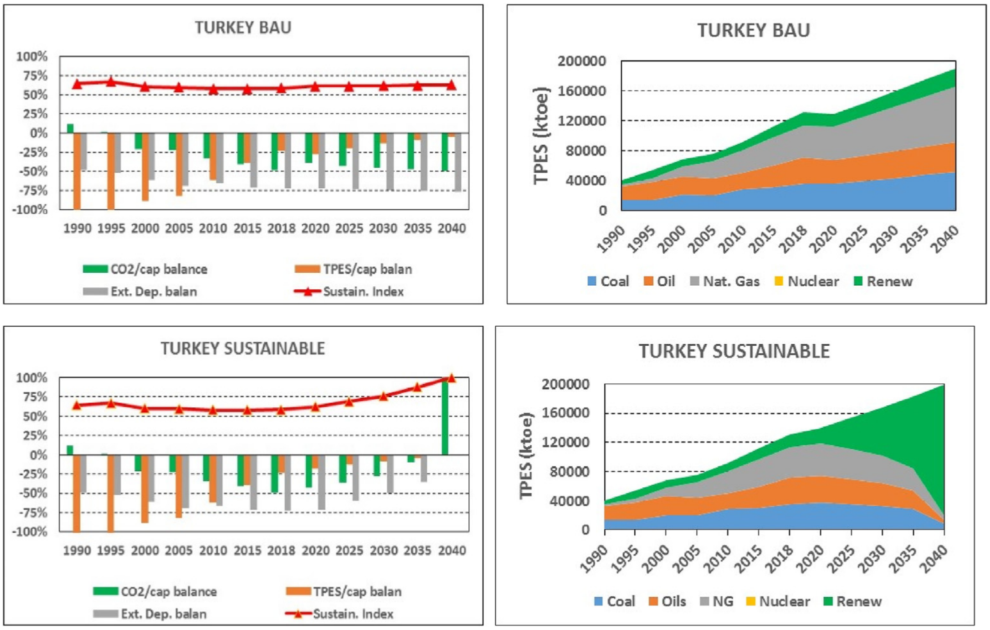
(**continued**).


MONTENEGRO SUSTAINABLE
SUSTAINABLE MONTENEGRO
SLOVENIA BAU
SLOVENIA SUSTAINABLE
SPAIN BAU
SPAIN SUSTAINABLE
100%
75%
50%
25%
0%
-25%
-50%
-75%
-100%
1990 1995 2000 2005 2010 2015 2018 2020 2025 2030 2035 2040
CO2/cap balance
TPES/cap balan
Ext. Dep. balan
Sustain. Index
TPES (ktoe)
3000 2500 2000 1500 1000 500 0
10000 8000 6000 4000 2000 0
150000 125000 100000 75000 50000 25000 0
Coal
Oils
Oil
NG
Nat. Gas
Nuclear
Renew

(***continued***).



(***continued***).

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