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# Environmental energy security in the MENA region – an aggregated composite index

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**Abstract**
Energy security is a multi-dimensional concept that is gaining a growing interest worldwide for studying the sustainability of a given energy sector. The level of energy security has been always quantified and evaluated by focusing on economic and technical dimensions, and modest importance was attributed to social and environmental aspects. Moreover, countries of the Middle East and North Africa (MENA) region were always underreported in the literature pertaining to energy security issues. This study strives to evaluate energy security in this region through the establishment of an original Environmental Energy Security Index (EESI) in order to cover different dimensions of security of energy supply within these counties. A total of nine sub-indicators were selected based on the current policies and orientations in the region. These indicators were normalized, weighted, and aggregated for each country of the MENA region between 2008 and 2017. According to the assessment objectives, results showed that on average Yemen holds the highest EESI score of 5.319 followed by Morocco 4.304 and Algeria 4.087. On the other hands, Bahrain is ranked last 1.610 preceded by UAE 2.249 and Qatar 2.461. Some key proposals were suggested including investment in local resources, diversification of the energy mix, reduction of energy imports, and use of energy-efficient technologies.

**Keywords** Energy security · Renewable energy · MENA countries · Composite Index · Environmental sustainability

## 1 Introduction

Energy is a vital commodity for ensuring economic prosperity and betterment of living standards in any nation (Acheampong, 2018). Since various sectors are directly linked with this critical asset (Nawab et al., 2019), many countries are continuously struggling to keep up with their growing energy demand without putting extra burden on their financial budget, their ecosystems, and their technical limitations (Chentouf & Allouch, 2017).

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In order to promote a sustainable energy sector, decision makers need to address various dimensions of energy security and find an optimal trade-off between possible scenarios (Röpke, 2013). In fact, energy security is traditionally defined as the continuous access to affordable, reliable, and clean energy services (IEA, 2019). It implies the availability in space and time of inexpensive energy services that are not finite and which are eco-friendly. This dynamic concept was always present at the core of heated debates regarding economic, technical, political, social, and environmental aspects of energy issues (Jakstas, 2020), and hundreds of studies were trying to tackle its growing complexity and diverse implications. A report on the quest for energy security (APERC, 2007) highlighted the difficulty to limit a single definition to energy security due to the frequent emergence of new factors and dimensions that are associated with energy security. The authors pointed out that political unrests, natural calamities, and environmental impacts are on the forefront of the list. Within this context, (Gracceva & Zeniewski, 2014) identified key features of energy security and they found that a secure energy system needs to be stable (able to resist unexpected damages or threats), flexible (able to balance fluctuations in real time between demand and supply), resilient (able to use other methods of production or consumption to cope up with sudden changes), adequate (able to answer energy demand continuously under different conditions), and robust (able to adjust the evolution of the energy system to economic and political barriers.

Due to this dynamic and complex nature of energy security, the indicator-based approach was developed to address different dimensions and provide an in-depth analysis regarding the level of security of energy supply either locally or globally (Couder, 2015). These indicators can be used for shaping energy policies, market decisions, and strategies in short, mid, and long terms (Pahwa & Chopra, 2013). Either simple or aggregated indicators can be developed and quantified in order to address one or several dimensions of energy security. (Sovacool & Mukherjee, 2011), pointed out that using isolated indicators might lead to misleading conclusions and incomplete evaluation. Hence, their extensive literature review resulted in grouping 20 distinct dimensions of energy security that are covering 320 simple and 52 complex indicators, which can be used for studying energy security issues, evaluating best practices, and understanding tradeoffs between different dimensions. This large number of indicators was criticized though for difficulty to obtain such data along with providing valid and comprehensible implications to decision makers from various backgrounds. (Kruyt et al., 2009) have classified four distinguished dimensions along with 24 simple and complex indicators. They emphasized the fact that the absence of ideal indicators can be only dealt with by combining various indicators in order to cover major attributes of energy security. (Vivoda, 2010) provides a list of 11 dimensions including demand management, policy, and human and military security along with 44 features for evaluating energy security. Finally, (Azzuni & Breyer, 2017) have conducted a literature review on energy security and provided 15 dimensions and 66 definitions. Various parameters were also allocated for each dimension ranging from diversity of resources and consumers, through energy conservation, population settlement, and distribution, to governance and connectivity.

Regarding the geographical coverage of energy security indices, (Gasser, 2020) found (upon reviewing 63 indices in the literature) that countries including the ones in the MENA region (especially African countries) suffer from under-reporting and only few energy indices were developed for these countries over the last few years. The author emphasized the urgent importance of developing energy security indices for such countries due to the expected demand growth and different constraints that might arise following consumption patterns. It must be noted that since the 1970s, energy security was always linked with the MENA region following the oil embargo in 1973 (Goel & Morey, 1993) that was proclaimed by many exporting countries in this region. This crisis was the direct reason behind policy and regulatory reforms dealing with diversification of energy resources, energy dependency, and energy efficiency among other strategies. According to the (World Bank, 2020a, b, c, d, e, f), the MENA region contains the following countries: Morocco, Algeria, Tunisia, Libya, Egypt (north African countries), Jordan, Israel & Palestinian territories, Lebanon, Syria (Levant countries), Saudi Arabia, Qatar, Bahrain, Oman, United Arab Emirates (UAE), Kuwait (Gulf Cooperation Council (GCC) countries), and other countries including Iran, Iraq, Yemen, Malta, and Djibouti. In our study, we do consider all of these countries except the last two countries since Djibouti is not located in northern Africa or Middle East, and Malta belongs to the European Union (See Fig. 1).

The MENA countries occupy a surface area of 11,347,100 $km^2$ (8.59% of the World's area) and had a population of 455,231,191 (8.93% of the World's population) in 2019 (World Bank, 2020a, b, c, d, e, f). The region is characterized by many discrepancies including first a non-uniform distribution of energy resources. For instance, Morocco and Lebanon are both known for being one of the major fossil importers not only in the region, but in the world as well with importing rates beyond 96% and 99%, respectively, in 2017 (IEA, 2020). On the other hands, the GCC countries along with Iran, Iraq, Algeria, and Libya are among the major exporters of fossil fuels in the world and the Organization of Petroleum Exporting Countries (OPEC) contains 7 member countries from the MENA region out of 13 in total (OPEC, 2020). Second, the region is frequently witnessing political unrests and boundary delimitation and demarcation issues (Al-Mulali & Ozturk, 2015). While the rich endowments of fossil sources are among the main reasons behind these raising tensions, the political instability in some countries is putting security of energy supply in great danger resulting in price fluctuations, potential damages to proven reserves and energy-related infrastructure, and reluctance of investors regarding future energy projects (Bellakhal et al., 2019). Another issue relates to the carbon footprint of these countries and their environmental vulnerability (Gorus & Aslan, 2019). In fact, while the MENA countries emitted about 7.47% of 2017 global $CO_2$ emissions in the world (World Bank, 2020a, b, c, d, e, f), three out of five countries ranked as the major emitters per capita in 2017 including Qatar (39.77 $tCO_2$/capita), Kuwait (24.07 $tCO_2$/capita), and UAE (21.09 $tCO_2$/capita) (World Bank, 2020a, b, c, d, e, f). Furthermore, the MENA region is considered as the most water-scarce region in the world (WRI, 2019) having 12 out of the 17 major water-stressed countries on earth and GDP losses from this alarming situation are


**Fig. 1** Countries of the MENA region

expected to range between 6 and 14% by 2050 (World Bank, 2017). In addition, forest area in the MENA region was estimated at 232,071.5 km$^2$ in 2016 (only 0.58% of the world's forest areas), and the region is known as having the smallest forest area in terms of land share (2.1% in 2016 compared for instance to 39.6% in the European Union and 36% in North America) (World Bank, 2020a, b, c, d, e, f). In fact, while countries like Lebanon and Morocco have acceptable shares (13.4 and 12.6%, respectively), other countries are having a negligible share around 0% including Oman and Egypt.

In light of previous statements, our research work aims to evaluate the level of environmental energy security in the MENA region by establishing and quantifying a composite index for different countries following their energy challenges and strategies. Our composite index will cover different dimensions of security of energy supply by combining various sub-indicators including economic, technical, environmental and social categories. A special focus will be given to the environmental aspect of energy security taking into account not only the growing environmental burden of current energy policies in the MENA region, but also the promising opportunities that can turn the region into a global leader in terms of environmental stewardship.

The layout of this paper is as follows: Sect. 2 provides a background information on energy situation in the MENA countries. The methodology for selecting sub-indicators, normalizing their values, assigning their weights, and aggregating them into the final composite index will be discussed in Sect. 3. In Sect. 4, the main results of this index for different MENA countries will be presented for the period of 2008–2017 along with a detailed interpretation of these findings. Based on these results, the major recommendations for enhancing energy security in the MENA region will be suggested in the last section along with the conclusion.

## 2 Energy in the MENA countries

The MENA region is considered as a potential energy hub for both conventional and non-conventional energy sources. In fact, this region is endowed with important fossil reserves and advantageous climate conditions for harnessing renewable energies.

Table 1 (Worldometers, 2020) illustrates oil, natural gas, and coal reserves in all of these countries. The total oil reserves in the MENA region accounted for almost 59% of the world's oil reserves in 2016. Yet, more than two-thirds of these reserves are located only in four countries, namely Saudi Arabia (2nd biggest oil reserves in the world), Iran (4th biggest oil reserves in the world), Iraq (5th biggest oil reserves in the world), and Kuwait (6th biggest oil reserves in the world). On the other hands, countries like Lebanon, Morocco, and Jordan have almost no significant proven oil reserves. Regarding natural gas, the MENA countries contain 45% of the world's proven reserves. More than two-thirds of this share are available in Iran and Qatar having, respectively, the second and third largest reserves in terms of natural gas just behind Russia. The share of coal reserves in the MENA region represents only about 0.1% of the world's proven reserves. Only four countries contain coal reserves in this region, and Iran has the lion share (93.11%) of these reserves.

While previous studies (APICORP, 2019) expected an increasing growth of expenditures on upstream oil and gas investments amounting to USD 961 bn up to 2023, recent estimates predict a sharp loss of USD 50 bn during the next 5 years due to the coronavirus pandemic (Arabnews, 2020). In fact, early in 2020, oil prices decreased noticeably due to the oil price war that occurred between Russia and Saudi Arabia. It was the direct answer

**Table 1** Oil, natural gas, and coal reserves in the MENA region in 2016

| Country | Oil reserves (barrels) | Natural gas (MMcf) | Coal (tons) |
|---|---|---|---|
| Morocco | 684,000 | 51,000 | 15,432,340 |
| Algeria | 12,2000,000,000 | 159,054,000 | 65,036,290 |
| Tunisia | 425,000,000 | 2,300,000 | 0 |
| Libya | 48,363,000,000 | 53,183,000 | 0 |
| Egypt | 4,400,000,000 | 77,200,000 | 17,636,960 |
| Jordan | 1,000,000 | 213,000 | 0 |
| Israel & Palestinian territories | 13,953,000 | 7,027,000 | 0 |
| Lebanon | 0 | 0 | 0 |
| Syria | 2,500,000,000 | 8,500,000 | 0 |
| Bahrain | 124,560,000 | 3,250,000 | 0 |
| Kuwait | 101,500,000,000 | 63,500,000 | 0 |
| Oman | 5,306,000,000 | 24,910,000 | 0 |
| Saudi Arabia | 266,578,000,000 | 294,205,000 | 0 |
| Qatar | 25,244,000,000 | 871,585,000 | 0 |
| UAE | 97,800,000,000 | 215,098,000 | 0 |
| Iraq | 143,069,000,000 | 111,522,000 | 0 |
| Yemen | 3,000,000,000 | 16,900,000 | 0 |
| Iran | 157,530,000,000 | 1,201,382,000 | 1,326,078,930 |

of the latter to the Russian withholding of limiting its production for keeping the optimal price of oil in the market.

Table 2 shows the total installed renewable capacities in the MENA region up to 2018 along with individual capacities regarding hydropower, wind, solar, and bioenergy (IRENA, 2019). The total installed renewable capacity in the MENA countries accounted only for 1.8% of the world's global capacity, and more than 71% of this capacity is provided by only three countries mainly Iran, Egypt, and Morocco. Back in 2009, Kuwait, Oman, Saudi Arabia, and Qatar had 0 MW of renewable capacity, and only eight countries in the MENA region were having a capacity over 50 MW. In fact, since many countries have the status of fossil exporters, few interest was attributed to renewable energy sources (RES) before the last decade. However, the increasing uncertainty regarding fossil fuels prices, the reluctance of new investments in upstream oil and gas, and the promising potentials of RES in the region have all contributed to substantial investments in the field of RES. Figure 2 (Solargis, 2019) highlights the solar Direct Normal Irradiation (DNI) for the MENA countries. It can be seen that the MENA region is among the top receiving regions of solar energy with previous estimates of almost 3500 h of sunshine per year and more than 5 kWh/m$^2$ (Almasoud & Gandayh, 2015).

Similarly, many countries in the region are blessed with a mean wind speed that is beyond 7.5 m/s at an altitude of 100 m as it is shown in Fig. 3 (Global Wind Atlas, 2019).

Regarding the energy supply, the latest available data in 2017 (see Fig. 4 (IEA, 2020)) showed that the region is still highly dependent on fossil fuels. In fact, the shares of fossil fuels in the total energy mix range from 89.5% in Tunisia to 100% in countries like Bahrain, Kuwait, Oman, Saudi Arabia, and Qatar. Moreover, Iran is the only country that used nuclear power in its TPES although to a limited share 0.7%. By analyzing each source

**Table 2** Renewable installed capacities in the MENA region in 2018

| Country | Hydropower | Wind | Solar | Bioenergy | Total |
|---|---|---|---|---|---|
| Morocco | 1306 | 1220 | 735 | 2 | 3263 |
| Algeria | 228 | 10 | 435 | 0 | 673 |
| Tunisia | 66 | 245 | 47 | 0 | 358 |
| Libya | 0 | 0 | 5 | 0 | 5 |
| Egypt | 2851 | 1125 | 770 | 67 | 4813 |
| Jordan | 12 | 285 | 771 | 4 | 1072 |
| Israel & Palestinian territories | 7 | 27 | 1112 | 28 | 1174 |
| Lebanon | 253 | 3 | 42 | 9 | 307 |
| Syria | 1494 | 1 | 1 | 7 | 1503 |
| Bahrain | 0 | 1 | 5 | 0 | 6 |
| Kuwait | 0 | 10 | 31 | 0 | 41 |
| Oman | 0 | 0 | 8 | 0 | 8 |
| Saudi Arabia | 0 | 3 | 139 | 0 | 142 |
| Qatar | 0 | 0 | 5 | 38 | 43 |
| UAE | 0 | 1 | 594 | 1 | 596 |
| Iraq | 2274 | 0 | 37 | 0 | 2311 |
| Yemen | 0 | 0 | 150 | 0 | 150 |
| Iran | 12,095 | 282 | 286 | 12 | 12,675 |

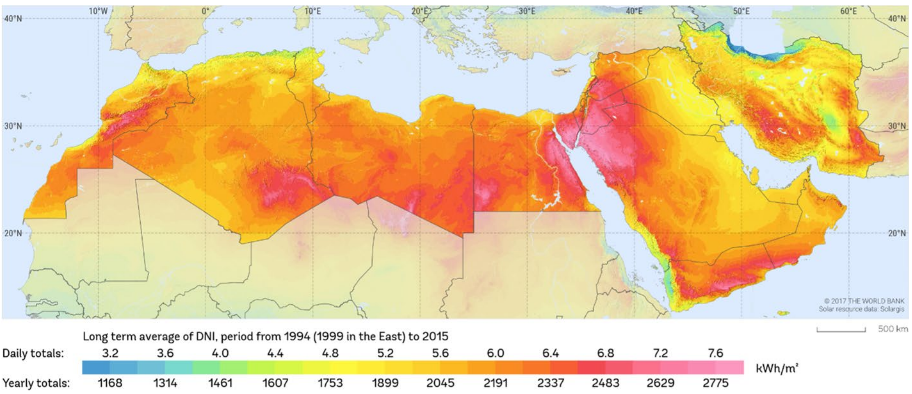


**Fig. 2** The direct normal irradiation in the MENA region

contribution to the TPES, oil amounts to 95.7% in Lebanon (the highest value in the MENA region) compared to only 5.7% in Qatar (the lowest value in the MENA region). Natural gas on the other hands ranged from 0% in Lebanon (the lowest value in the MENA region) to 94.3% in Qatar (the highest value in the MENA region). Due to its limited reserves in the MENA region, coal is absent in the TPES of nine countries including Tunisia, Libya, Syria, Bahrain, Kuwait, Oman, Saudi Arabia, Qatar, and Iraq. These conventional sources are majorly used in Morocco with a total share of 22.3% compared to a minimal used in both Algeria and Egypt with a share of 0.4%.

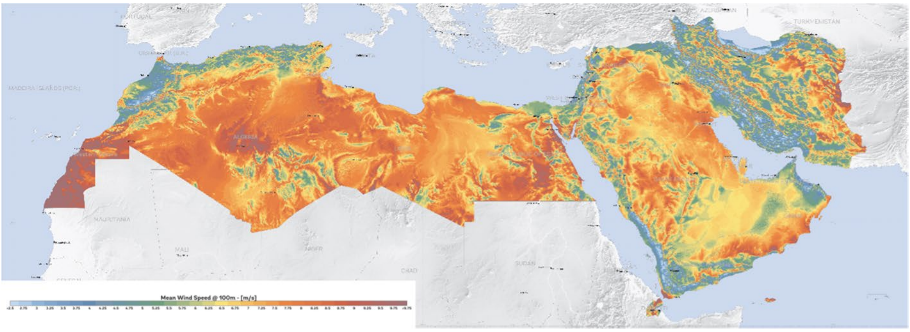

**Fig. 3** The mean wind speed in the MENA region

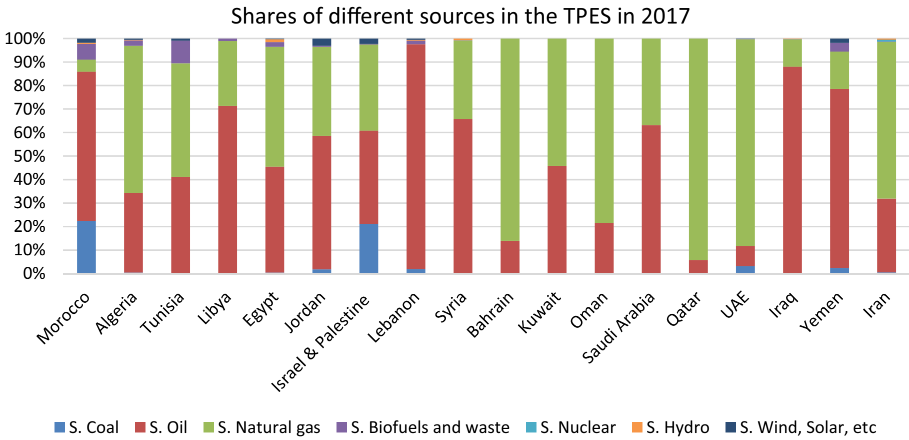


**Fig. 4** The shares of the different sources in the TPES of MENA countries in 2017

Tunisia is having the highest value regarding the use of biofuels (9.6%) compared to the lowest value (0.1%) in Syria, UAE, and Iraq. Hydropower has a modest share in Egypt (1.2%) being the highest among the MENA countries compared to UAE (0.2%) having the lowest one among countries relying on this renewable source. For both wind and solar, Jordan was leading the region by supplying 3.1% of its TPES from these sources compared to the Egyptian share of 0.3%, which is the lowest in countries where both solar and wind energies are used.

Concerning energy demand (see Fig. 5 (IEA, 2020)), it was found that both the industrial and transportation sectors are the main consumers of energy in the MENA region covering more than one half of energy demand in all of these countries and sometimes even more than three quarters in some fossil-rich countries. The residential sector comes third in terms of energy use followed by commercial and public services. The least consuming sector is the agriculture due to the limited agricultural activities in the MENA region. Regarding the industrial sector, UAE attributes 55% of its energy demand to this sector due to the high-energy-consuming fossil industries. This trend is also present in similar status countries like Oman (49.3%), Qatar (48.9%), and Kuwait (46%). Libya had the least energy consumption in terms of industrial activities (7.7%) due to the political tensions in

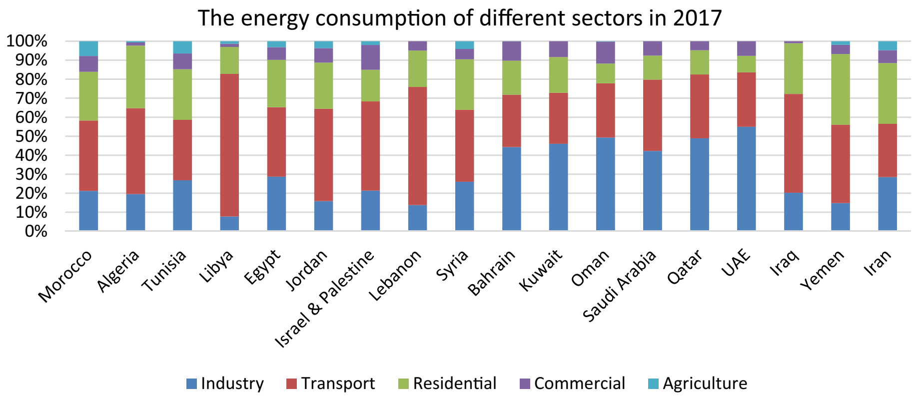


**Fig. 5** The energy consumption of different sectors in the MENA countries in 2017

this country during recent years that largely affected industrial mechanisms and new investments. The country in return allocates the highest share of its energy demand to the transportation sector (75%) due to the reliance on local fossil fuels for transportation means. Kuwait on the other hands had the lowest value among MENA countries (26.8%) due to its small surface area along with the size of its population. Yemen had the highest value of consumed energy from households (37.2%) although the total consumption in this country is fairly small compared to other MENA countries due to some difficulties for giving electricity access to all the population. In fact, many energy infrastructures were harmed during the ongoing Yemeni conflict and many households are living without electricity and they rely mainly on traditional means for providing lighting and heat. UAE has the lowest share within this regard (7.7%) due to many reasons including good energy efficiency measures in households along with modern architecture solutions for controlling energy bills and consumption behaviors. Israel and Palestine have the highest consumption in terms of commercial and public services (13.1%) due to the high reliance on trading activities and also touristic attractions in the national GDP. Iraq on the other side consumed only 1.1% in 2017 following the modest commercial and public institutions in the country generated from the Iraqi political conflict. Finally, Morocco consumed the highest share of energy provided for agricultural activities (7.8%) in the MENA region. In fact, agricultural revenues bring more than 12% of the total GDP in this country (Statista, 2020), which is blessed with major agricultural potentials being among the best ones in the MENA region. On the opposite, the agricultural sector in Bahrain consumes only 0.1% of energy due to the limited agricultural activities in this gulf country. It must be noted that six countries in the MENA region are not having any noticeable energy demand from this sector including Lebanon, Kuwait, Saudi Arabia, Qatar, UAE, and Iraq.

Concerning the global energy policy in the MENA region, many reviews and studies were conducted by either academic researchers or energy-related institutions in order to evaluate these policies and suggest key recommendations for achieving a sustainable energy sector in the region. First, (Griffiths, 2017) has highlighted the noticeable transition toward renewable and alternative energies in the MENA countries that is currently under development. He pointed out that such transition will generate long-term impacts on economic revenues from exporting fossil fuels along with carbon footprint from energy production activities. The author recommended the regional cooperation between countries along with robust management of energy demand in order to overcome different barriers that might hinder such transition.

Griffiths emphasized the role of support tools for enhancing the continuous deployment of renewable energies in the MENA region including regulatory instruments, fiscal incentives, and public financing (See Fig. 6 (Griffiths, 2017)). He demonstrated that Israel is considered as a regional leader in terms of diversifying its renewable energy policies. Jordan, UAE, and Morocco were also exhibiting good models to follow by other MENA countries. He suggested that know-how transfer along with progressive support schemes can further facilitate the transition to renewable energies in this region by following best practices in countries with similar conditions and orientations. Another report (RECREE, 2019) focused on evaluating these policies for Arab countries (not including Israel and Palestinian territories and Iran, but including Mauritania and Djibouti) by developing the Arab Future Energy Index (AFEX) for renewable energy. According to the results in 2019 (see Fig. 7 (RECREE, 2019)), Morocco, Jordan, and Egypt were all ranked 1st in the region. This index was calculated based on many categories including market structure, policy framework, institutional capacity, and finance and investment. Each category was evaluated by quantifying specific sub-indicators. The list of these indicators includes feed-in tariffs, net metering, land access, RE fund, fiscal incentives, and the share of private investment among others.

The previous findings are also aligned with the outcomes of the Renewable Energy Country Attractiveness Index (RECAI) (EY, 2020) in which countries are ranked based on their attractiveness to invest in renewable energies. The index provides the list of top 40 countries worldwide, and Morocco comes first in the Arab region (23rd worldwide) with a global score of 49.6 followed by Egypt (29th) having a score of 47.7 and finally Jordan (30th worldwide) reaching a score of 47.5. In general, Israel was ranked as the best country in the MENA region (14th worldwide) having a score of 51.3.

Finally, it is obvious that the MENA region is shifting its energy mix toward deploying more renewables within in the upcoming few years. In fact, (APICORP, 2019) estimated a total investment amount of USD 348 bn to be spent on planned and committed energy projects in the field of power industry (excluding oil, gas, and chemicals) in the MENA

| | Regulatory | | | | | | | Fiscal Incentives and Public Financing | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | Feed-in tariff / premium payment | Electric utility quota / obligation / RPS | Net metering / Net billing | Transport obligation / mandate | Heat obligation/ mandate | Tradable REC | Tendering | Capital subsidy, grant, or rebate | Investment or production tax credits | Reductions in sales, energy, VAT or other taxes | Energy production payment | Public investment, loans, or grants |
| Bahrain | | | | | | | | | | | | ○ |
| Kuwait | | | | | | | ○ | | | | | |
| Oman | | | | | | | | | | | | |
| Qatar | | | | | | | | | | | | |
| Saudi Arabia | | | | | | | | | | | | |
| UAE | | • | ▪* | | • | | ▪* | | | | • | • |
| Israel | ○ | ○ | ○ | | ○ | | ○ | ○ | ○ | ○ | | ○ |
| Jordan | ○ | | ○ | ○ | ○ | | ▪ | | | R | | ○ |
| Lebanon | | | ○ | | | | | | | ○ | | ○ |
| Palestine | | | | | | | | | | | | |
| Syria | ○ | | ○ | | | | ○ | | ○ | | | |
| Iran | ○ | | | | | | | | ○ | | ○ | ○ |
| Iraq | | | | | | | ▪ | | | | | |
| Yemen | | | | | | | | | | | | |
| Algeria | ○ | | | | | | ○ | ○ | | | ▪ | ○ |
| Egypt | R | | ○ | | | | ○ | ○ | | ○ | | |
| Libya | | | | | | | | | | ○ | | |
| Morocco | | | ○ | | | | ▪ | | | | | ○ |
| Tunisia | | | ○ | | | | | ○ | | ○ | | ○ |

○ EXISTING NATIONAL (could also include subnational), • EXISTING SUB-NATIONAL (but no national), ▪ NEW (one or more policies of this type), R REVISED (one or more policies of this type), ▪ * NEW SUB-NATIONAL

Fig. 6 The current renewables energy policies in the MENA countries

| | Final Score | Market Structure | Policy Framework | Institutional Capacity | Finance and Investment |
|---|---|---|---|---|---|
| Egypt | 75% | 84% | 53% | 73% | 89% |
| Jordan | 75% | 78% | 51% | 78% | 94% |
| Morocco | 75% | 79% | 51% | 78% | 90% |
| UAE | 73% | 83% | 44% | 69% | 94% |
| Tunisia | 70% | 78% | 44% | 73% | 84% |
| Algeria | 64% | 78% | 33% | 66% | 78% |
| Palestine | 59% | 47% | 50% | 58% | 80% |
| Lebanon | 58% | 56% | 44% | 59% | 75% |
| Saudi Arabia | 58% | 50% | 29% | 71% | 82% |
| Bahrain | 46% | 55% | 36% | 66% | 29% |
| Oman | 46% | 51% | 22% | 51% | 60% |
| Mauritania | 45% | 33% | 32% | 51% | 61% |
| Djibouti | 36% | 28% | 47% | 35% | 33% |
| Qatar | 35% | 38% | 14% | 57% | 33% |
| Iraq | 31% | 33% | 22% | 45% | 23% |
| Kuwait | 30% | 40% | 21% | 51% | 10% |
| Yemen | 30% | 15% | 22% | 29% | 55% |
| Sudan | 29% | 25% | 24% | 38% | 29% |
| Syria | 26% | 18% | 19% | 39% | 26% |
| Libya | 19% | 10% | 18% | 38% | 12% |

**Fig. 7** The AFEX for renewable energies of the Arab countries. (Color figure online)

region. During only one decade, all MENA countries were having an installed capacity of at least one renewable energy source compared to only five countries back in 2004 (RECREEE, 2019). Table 3 showed the renewable energy targets in the region (RECREEE, 2019). Most countries have set RE targets for the year 2030 and Morocco is considered to be the top country in terms of expected renewable share in total power (52%), while Saudi Arabia will lead the region in terms of expected RE capacity (58.7 GW) after the achievement of planned projects. This shift toward renewables is expected to generate potential job opportunities in this area along with revenues from regional energy exports, while fossil-based economies might witness a continuous decline of exporting assets that needs to be replaced with new economic pathways.

## 3 Construction of the MENA environmental energy security index

### 3.1 Selection of sub-indicators

#### 3.1.1 Diversification of Energy Supply Sources (DESS)

Diversification of energy supply sources refers to the use of various fuels into the energy mix of a given country. This strategy enables the creation of a balanced energy portfolio that can answer the growing needs of energy demand without relying on a single fuel. This indicator seems to be a high importance in the case of MENA countries due to disparities of energy mixes among countries following economic, social, and technical factors. Our DESS indicator is defined by Eq. 1 (Aslani et al., 2012). It considers the number of various

**Table 3** The RE targets in the MENA countries

| Country | RE target (capacity) | Share in total power | Year of achievement |
|---|---|---|---|
| Morocco | 10 GW | 52% | 2030 |
| Algeria | 22 GW | 32% | 2030 |
| Tunisia | 3.815 GW | 30% | 2030 |
| Libya | 4.6 GW | 22% | 2030 |
| Egypt | 54 GW | 42% | 2035 |
| Jordan | 3.22 GW | 15% | 2025 |
| Israel | 16 GW | 30% | 2030 |
| Palestine | 0.5 GW | 25% | 2030 |
| Lebanon | 0.75 GW | 30% | 2030 |
| Syria | 4.5 GW | 30% | 2030 |
| Bahrain | 0.71 GW | 10.3% | 2035 |
| Kuwait | 4.266 GW | 15% | 2030 |
| Oman | 3.05 GW | 16% | 2025 |
| Saudi Arabia | 58.7 GW | 30% | 2030 |
| Qatar | 1.8 GW | 20% | 2030 |
| UAE | 6.5 GW | 44% | 2050 |
| Iraq | 6.2 GW | 10% | 2028 |
| Yemen | 0.715 GW | 15% | 2025 |
| Iran | 20 GW | 18% | 2025 |

energy sources for the MENA countries along with their spread in the energy mix of each country.

$$\mathrm{DESS} = -\left(\frac{\sum_{i=1}^{n} \mathrm{ai} * \mathrm{Ln}(ai)}{\mathrm{Ln}(n)}\right) \tag{1}$$

ai stands for the share of each energy source in the total energy mix, while ***n*** refers to the number of these sources. Due to particular characteristics of the energy sector in MENA countries, we will include seven sources, namely coal, oil, natural gas, biofuels and waste, nuclear, hydropower, and other renewables (mainly wind and solar). The DESS has no unit.

### 3.1.2 Net Import Dependency (NID)

This indicator is used for reflecting the level of energy imports in a given country, and it seems highly interesting in the case of MENA countries due to different statuses of these countries that can be divided into either high conventional fuels' importers (countries like Morocco) or high conventional fuels exporters (countries like Qatar). While the NID includes a direct measurement of energy imports for each source in the energy mix as it is shown in Eq. 2 (Aslani et al., 2012), it englobes as well the share of each source in relation to the DESS in order to provide an insightful analysis about both energy diversification and independency in a given country.

$$\text{NID} = 1 - \frac{\left(\frac{\sum_{i=1}^{n}((1-\text{mi})*\text{ai}*\text{Ln(ai)})}{\text{Ln}(n)}\right)}{\text{DESS}} \tag{2}$$

mi is defined as the import share of each source in the total energy mix. The NID has not unit.

### 3.1.3 Energy Intensity (EI)

Measuring energy intensity for a given country enables to know the level of sustainability of the energy sector in that country by quantifying the cost of converting a unit of consumed energy sources into a unit of gross domestic product (GDP) as it is demonstrated in Eq. 3 (Shah et al, 2019). This indicator covers various topics of interest in the case of MENA countries including behaviors of energy consumption, energy efficiency, research, and development activities for enhancing advanced technologies in the field of energy, and economic and social preferences for each nation. The unit of EI is toe/2010 kUSD.

$$\text{EI} = \left(\frac{\text{Total Primary Energy Supply}}{\text{Gross Domestic Product}}\right) \tag{3}$$

### 3.1.4 Total Primary Energy Supply per capita (TPESpc)

Assessing the level of energy consumption per capita can be done through this indicator. The population size of a given country can be misleading in comparing energy consumption patterns between countries, especially among countries with different living standards, which is the case of the MENA countries (Golf countries compared to Maghreb Countries). Hence, this indicator provides the amount of energy consumption for each citizen in a given country with regard to the total primary energy supply that has been called for use in different vital economic sectors in that country. The TPES per capita is defined by Eq. 4 (OECD, 2010), and its unit is toe/capita.

$$\text{TPESpc}\left(\frac{\text{Total Primary Energy Supply}}{\text{Total Population}}\right) \tag{4}$$

### 3.1.5 Electricity Use per capita (EUpc)

While the amount of power consumption in a given country may not mainly be the result of its population size, electricity use is more related to population size and living standards of citizens in that country. The MENA countries exhibit various patterns to this regard due to different electricity consumption behaviors following environmental, economic, and social factors. This indicator is defined by Eq. 5 (OECD, 2010) and has the unit of MWh/capita.

$$\text{EUpc} = \left(\frac{\text{Electricity Consumption}}{\text{Total Population}}\right) \tag{5}$$

### 3.1.6 Gross Domestic Product per capita (GDPpc)

Although a high level of energy intensity in a given country can reflect the amount of reliance on energy fuels in its local economy (especially for fossil fuels), the nation wealth can only be assessed by measuring the local distribution of this country on its population. The GDPpc seems of huge interest in the case of the MENA countries in order to evaluate the level of prosperity for each country while taking into account (implicitly) the added value from the main economic sectors of every particular country. The indicator is defined by Eq. 6 (Shah et al, 2019), and its unit is current USD.

$$\mathrm{GDPpc}\left(\frac{\text{Gross Domestic Product}}{\text{Total Population}}\right) \tag{6}$$

### 3.1.7 Electrification Ratio (ER)

Although the EUpc in a given nation may reflect consumption behaviors and living standards in that very particular country, one needs to consider the ER in order to know whether the whole population is connected to the grid and which options are available in the electricity market including facilities and regulations to diversify stakeholders and market players, while taking into consideration the local potentials for providing electricity to remote human clusters. This indicator is extremely important for the MENA countries due to the previous reasons along with geopolitical tensions that are arising in some countries, which led to sabotaging different infrastructures including national grids. Equation 7 (Shah et al, 2019) provides the definition of the ER, which has the unit of a fraction of % to quantify the percentage of population that have an access to the national grid.

$$\mathrm{ER} = \left(\frac{\text{Population connected to the grid}}{\text{Total Population}}\right) \tag{7}$$

### 3.1.8 Carbon Intensity (CI)

The CI is a direct measurement of carbon dioxide emitted from different economic activities in a given nation. Since these emissions vary considerably among the MENA countries, this indicator is able to highlight the carbon footprint of economic preferences for each nation along with its environmental cost and contribution to endangering human health (i.e., air pollution) and natural ecosystems for that particular country. While the CI can be calculated indirectly via the multiplication of energy intensity by fuel mix, we do consider a direct approach to measure this indicator as it is shown in Eq. 8 (Shah et al, 2019). The CI has the unit of kg $CO_2$/2010 USD.

$$\mathrm{CI} = \left(\frac{\text{Carbon Dioxide Emissions}}{\text{Gross Domestic Product}}\right) \tag{8}$$

### 3.1.9 Carbon Emissions per capita (CEpc)

While the previous indicator can reflect to some extent the level of environmental impact of a particular economy, this indicator covers the individual contribution of these anthropogenic carbon emissions in order to avoid misleading conclusions that can be drawn solely from relying on the total amount of $CO_2$ emissions. Thus, the CEpc entails a growing importance for the MENA countries with some economies that are generating a high level of carbon emissions compared to their modest population size (e.g., Qatar). Equation 9 (OECD, 2010) provides a definition of the CEpc, which has the unit of $tCO_2$/capita.

$$\mathrm{CEpc}\left(\frac{\text{Carbon Dioxide Emissions}}{\text{Total Population}}\right) \tag{9}$$

## 3.2 Normalization

According to the guidelines of the handbook for constructing composite indexes (OECD, 2008), there are ten steps that can be performed in order to construct a composite index. First, after laying the ground for building the composite index (theoretical framework), one must select the sub-indicators and justify his choice by highlighting their relevance, availability, source, and type (data selection). If missing data or similarities are present, the builder needs to complement his dataset (imputation of missing data) and identify similar set of indicators (multivariate analysis). Our next step is to ensure the comparability of different values of the selected sub-indicators (due to their various units of measurement) in order to be able to aggregate them later. This can be through normalization. While various techniques can be used for normalization (Talukder et al., 2017) including ranking, min–max, categorical scales or z-scores, we have selected the proportionate normalization due to the following reasons:

- The different normalized values are obtained through by dividing each value by the sum of other values for studied entities (MENA countries).
- The resulted values are similar to the original, and these measurements can be understood by decision makers with no complexities.
- The differences among various indicators will be minimized and even countries with some sub-indicators that have low values will be accounted for rather than being compensated by higher values.

The general equation (OECD, 2008) of this technique is provided below:

$$N_{\mathrm{ias}} = \frac{\mathrm{Ii}}{\sum_i Ii} \tag{10}$$

where: $0 < \mathrm{Nias} < 1$.

*N*ias refers to the normalized value of a sub-indicator *i* for a country *as*, while *Ii* is the real value of this sub-indicator for that country.

## 3.3 Weighting and Aggregation

Both weighting and aggregation are considered as the following step after normalizing the values of all the selected sub-indicators. They allow the allocation of individual importance for each sub-indicator along with the accumulation of different sub-indicators' values for each country in order to construct its composite indicator.

### 3.3.1 Weighting

While the weighting process can involve either objective or subjective approaches due to the theoretical framework behind the construction of the composite index and the studied entities (Greco et al, 2018), we selected the equal weighting (EW) method, which is considered to be the most frequent weighting technique for building composite indexes (Gan et al., 2017). In fact, we suggest that all the selected sub-indicators share the same importance for the MENA countries in order to give equal chances for each country to satisfy different criteria for ensuring its environmental energy security while avoiding the subjective assumptions of experts from these countries (a single criterion in one country can exhibit a high output that will affect its overall result compared to other countries). Later, during the step of sensitivity analysis, we will check the effect of each sub-indicator of the overall result by changing the weighting matrix. In order to get the individual weight for each sub-indicator, we have used the simple equation of dividing 1 (100%) by the total number of sub-indicators (9 in our case).

### 3.3.2 Aggregation

Different techniques can be used for aggregating the sub-indicators ranging from simple addition, geometric aggregation, and multi-criteria analysis (Talukder et al., 2017).

In our study, we selected the geometric aggregation (multiplication) by calculating the product of normalized values for sub-indicators and using their respective weights as exponents (Mauricio-Iglesias, 2020). This technique allows minimizing the effect of compensability among sub-indicators for a given country. Moreover, it enables the direct highlighting of a low value of any sub-indicator by reflecting this low score in the overall value of the composite index. It must be noted that this technique cannot be used in the case of having a 0 value for a given sub-indicator.

The final equation (OECD, 2008) for calculating our composite index is below:

$$CI_{as} = \prod_{Nias} Wias \tag{11}$$

CI is the composite index for a country as, while Wias is the weight of a sub-indicator ***i*** for the same country.

## 3.4 Time scope and data source

In our study, we decided first to calculate sub-indicators, where they are missing, for the MENA countries from 2008 until 2017 (year of the most recent available data). Based on our calculations, we then constructed the yearly composite indexes for these countries to enable a fair comparison between them and highlight the key recommendation for each country.

Our data are mainly retrieved from (IEA, 2020), the (World Bank, 2020a, b, c, d, e, f) and (Statista, 2020).

# 4 Assessment of environmental energy security in the MENA countries

## 4.1 Evaluating the selected sub-indicators for the MENA countries

### 4.1.1 DESS in the MENA countries

Based on the TPES for different MENA countries, we have calculated the annual DESS indicator to highlight both the optimal spread and the use of different sources in the total energy mix. This was done also with the aim of quantifying the direct results of energy strategies that were implemented in many MENA countries recently.

Table 4 provides the DESS values for these countries between 2008 and 2017. It was found that on average the mean DESS in the MENA countries has increased from 0.334 in 2008 to 0.346 in 2017. In fact, although this increase was fluctuating during this period, it showed the growing tendency in many countries to diversify their energy supply in order to ensure a sustainable energy mix. It must be noted that a high value of DESS in a given country means that this country is using different sources to meet its local demand with an optimal spread. The results showed that only eight countries out of 18 had a higher score than the average when it comes to DESS. Many discrepancies were noticed between various nations following their available resources, their geopolitical status, their economic

**Table 4** The annual DESS values for the MENA countries between 2008 and 2017

| Country | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|
| Morocco | 0,497 | 0,477 | 0,503 | 0,486 | 0,502 | 0,514 | 0,539 | 0,478 | 0,553 | 0,542 |
| Algeria | 0,384 | 0,380 | 0,376 | 0,370 | 0,365 | 0,362 | 0,349 | 0,346 | 0,340 | 0,400 |
| Tunisia | 0,512 | 0,519 | 0,500 | 0,509 | 0,506 | 0,505 | 0,509 | 0,510 | 0,510 | 0,507 |
| Libya | 0,350 | 0,330 | 0,330 | 0,321 | 0,330 | 0,370 | 0,309 | 0,310 | 0,346 | 0,331 |
| Egypt | 0,467 | 0,461 | 0,461 | 0,456 | 0,454 | 0,456 | 0,455 | 0,457 | 0,452 | 0,448 |
| Jordan | 0,386 | 0,392 | 0,372 | 0,248 | 0,266 | 0,302 | 0,226 | 0,375 | 0,462 | 0,459 |
| Israel & Palestinian territories | 0,582 | 0,599 | 0,613 | 0,608 | 0,507 | 0,592 | 0,604 | 0,604 | 0,600 | 0,596 |
| Lebanon | 0,149 | 0,150 | 0,225 | 0,164 | 0,155 | 0,154 | 0,127 | 0,125 | 0,121 | 0,118 |
| Syria | 0,296 | 0,327 | 0,364 | 0,359 | 0,362 | 0,384 | 0,378 | 0,346 | 0,352 | 0,351 |
| Bahrain | 0,260 | 0,234 | 0,228 | 0,228 | 0,212 | 0,210 | 0,204 | 0,210 | 0,223 | 0,208 |
| Kuwait | 0,336 | 0,322 | 0,338 | 0,353 | 0,351 | 0,353 | 0,355 | 0,356 | 0,356 | 0,354 |
| Oman | 0,304 | 0,264 | 0,258 | 0,273 | 0,279 | 0,244 | 0,251 | 0,226 | 0,206 | 0,267 |
| Saudi Arabia | 0,332 | 0,319 | 0,323 | 0,331 | 0,326 | 0,332 | 0,324 | 0,322 | 0,333 | 0,338 |
| Qatar | 0,258 | 0,252 | 0,234 | 0,157 | 0,116 | 0,033 | 0,054 | 0,027 | 0,022 | 0,112 |
| UAE | 0,263 | 0,299 | 0,274 | 0,238 | 0,261 | 0,290 | 0,353 | 0,318 | 0,320 | 0,231 |
| Iraq | 0,200 | 0,218 | 0,219 | 0,243 | 0,221 | 0,214 | 0,202 | 0,212 | 0,202 | 0,196 |
| Yemen | 0,045 | 0,138 | 0,243 | 0,233 | 0,269 | 0,246 | 0,261 | 0,408 | 0,377 | 0,405 |
| Iran | 0,391 | 0,386 | 0,386 | 0,381 | 0,383 | 0,386 | 0,375 | 0,364 | 0,355 | 0,359 |

assets, and their connection to some regional energy grids. Israel and Palestinian territories are ranked first with an average value of 0.591 during the studied decade. This high performance is justified by an optimal use of various sources including coal, oil, natural gas, wind, solar, and biofuels. Hydropower was used to a limited extent until 2015 and although nuclear research facilities are used widely, power plants from this source are still planned for cutting carbon dioxide emissions (Mahlooji et al., 2020).

Both Morocco and Tunisia are ranked second with an average value of 0.509. Morocco is relying on coal, oil, natural gas, biofuels, wind, solar, and hydropower to meet his domestic demand. Both natural gas and renewables have received a growing interest during the last decade and plans to opt for nuclear energy are under study. Tunisia is relying on oil, natural gas, biofuels, wind, solar, and hydropower to a limited share. The country was using coal up to 2012 for meeting its local demand and some cooperation agreements and memorandum of understanding were signed with France and Russia (World Nuclear News, 2015) to launch a nuclear power plant project for meeting 20% of the country's energy demand.

Qatar has the lowest DESS on average with a value of 0.126. The fossil-rich country is relying mainly on oil and natural gas to meet its energy demand. In order to limit its carbon footprint, the country signed in January 2020 a contract with both Total and Marubeni to construct a solar power plant with a capacity of 800MWe by 2022 (The Star, 2020). Lebanon is ranked just before Qatar with an average DESS value of 0.149. Although the country is relying on five sources, the lion share is dominated by oil (about 95% in the total energy mix). The country is showing an increasing interest in considering local renewable energies to meet its needs. Geothermal energy in particular is able to provide theoretically $10^9$ GWh, yet the current plans are exploring a tiny amount of this promising source. Iraq comes ahead of Lebanon in terms of its DESS having an average value of 0.213. This political struggling country is relying mainly on local fossil sources (oil and natural gas) to meet its demand. In addition, a minor share of hydropower and biofuels are also available in the total energy mix. The political conflicts resulting from the invasion of Iraq in 2003 are still hindering decision makers and investors to opt for alternative ways for meeting the national energy demand.

#### 4.1.2 NID in the MENA countries

While some MENA countries opt for an optimal diversified approach toward the elements of their energy mix, other countries are preferring to enhance local energy endowments for meeting their national energy demands and even exporting the surplus for economic benefits. Generally, a trade-off must be ensured between diversification and energy dependency in order to strengthen the energy supply of a given nature. Hence, we have calculated the yearly NID indicators for those countries to provide an insightful analysis about the changing patterns during the studied period.

According to Table 5, the mean NID for the MENA countries has increased from 0.327 in 2008 to 0.368 in 2017. On average, an average NID value of 0.358 has been recorded for these countries during this period. A low value of the NID in a given country means that this country is not relying too much on energy imports. It was found that 11 countries out of 18 were below the average, which shows that many countries in the region are considered as energy exporters, especially in the Arab Gulf region. Saudi Arabia has the lowest NID with an average value of 0.058. In fact, the country is endowed with natural gas and oil reserves, and it imports only a modest share of oil products from abroad. Yemen

**Table 5** The annual NID values for the MENA countries between 2008 and 2017

| Country | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|
| Morocco | 0,701 | 0,683 | 0,676 | 0,668 | 0,727 | 0,702 | 0,728 | 0,812 | 0,720 | 0,724 |
| Algeria | 0,087 | 0,091 | 0,094 | 0,120 | 0,188 | 0,183 | 0,123 | 0,143 | 0,125 | 0,117 |
| Tunisia | 0,553 | 0,514 | 0,517 | 0,512 | 0,542 | 0,536 | 0,548 | 0,545 | 0,568 | 0,586 |
| Libya | 0,104 | 0,109 | 0,107 | 0,120 | 0,164 | 0,287 | 0,205 | 0,218 | 0,261 | 0,234 |
| Egypt | 0,138 | 0,159 | 0,175 | 0,177 | 0,175 | 0,204 | 0,220 | 0,225 | 0,246 | 0,238 |
| Jordan | 0,871 | 0,875 | 0,856 | 0,739 | 0,768 | 0,802 | 0,719 | 0,856 | 0,868 | 0,959 |
| Israel & Palestinian territories | 0,651 | 0,710 | 0,711 | 0,649 | 0,709 | 0,659 | 0,623 | 0,624 | 0,605 | 0,618 |
| Lebanon | 0,526 | 0,578 | 0,685 | 0,528 | 0,516 | 0,468 | 0,572 | 0,525 | 0,539 | 0,539 |
| Syria | 0,168 | 0,201 | 0,191 | 0,182 | 0,134 | 0,316 | 0,377 | 0,400 | 0,385 | 0,386 |
| Bahrain | 0,640 | 0,660 | 0,665 | 0,665 | 0,676 | 0,677 | 0,682 | 0,677 | 0,668 | 0,679 |
| Kuwait | 0,001 | 0,041 | 0,107 | 0,106 | 0,077 | 0,061 | 0,092 | 0,095 | 0,111 | 0,117 |
| Oman | 0,123 | 0,154 | 0,171 | 0,127 | 0,118 | 0,184 | 0,081 | 0,077 | 0,094 | 0,094 |
| Saudi Arabia | 0,001 | 0,040 | 0,032 | 0,039 | 0,054 | 0,086 | 0,071 | 0,084 | 0,092 | 0,084 |
| Qatar | 0,084 | 0,098 | 0,076 | 0,022 | 0,001 | 0,215 | 0,010 | 0,824 | 0,830 | 0,035 |
| UAE | 0,764 | 0,746 | 0,771 | 0,783 | 0,795 | 0,786 | 0,752 | 0,761 | 0,758 | 0,788 |
| Iraq | 0,037 | 0,075 | 0,074 | 0,083 | 0,086 | 0,085 | 0,096 | 0,101 | 0,101 | 0,093 |
| Yemen | 0,310 | 0,234 | 0,243 | 0,293 | 0,330 | 0,295 | 0,322 | 0,391 | 0,296 | 0,277 |
| Iran | 0,119 | 0,117 | 0,109 | 0,081 | 0,046 | 0,051 | 0,051 | 0,061 | 0,055 | 0,050 |

comes right after Saudi Arabia with a NID value of 0.074. The country is importing all of its used coal from abroad, but this represents a tiny share in its TPES (less than 5%) and the amount of oil products that are imported from abroad is decreasing due to the recent political conflict. Kuwait is ranked behind Yemen and has the NID value of 0.081. This country is relying mostly on its available oil and natural gas to meet the local demand. Yet, a local tendency to import natural gas from abroad has been growing in order to ensure enough fuel for petrochemical industries and power plants. The country has recently signed an agreement with Qatar to import Liquefied Natural Gas (LNG) for 15 years starting from 2022 (NS Energy, 2020).

Jordan has the highest NID value, which implies a high importing rate. In fact, this kingdom is importing almost all of its three main fuels (coil, oil, and natural gas) from abroad. Moreover, the contribution of local energy sources is representing only 1% in the national energy mix. This high reliance on imported energies was the main driver that pushed the country to develop future plans for developing both nuclear and renewable energy plants in the mid-term (with a total cost of USD 15 bn) with an ambitious project for constructing two 1000 MW nuclear power plants by 2022, which wad reduced recently to small modular reactors to avoid financial burdens according to Jordanian officials (Albawaba, 2018).

UAE comes right after Jordan with a NID value of 0.770. In fact, while the country is rich in natural gas and oil, all of its coal and biofuels are imported from abroad. Moreover, an increasing amount of natural gas and oil products is being imported to ensure the growing demands of petrochemical industries and the accelerated industrialization process in the country. Adding to that the fact that UAE only started developing renewable energy plans during the last decade, and their output came into the grid in 2013. It is expected that the future development of nuclear and renewable energy power plans will shift the status of the country from relying on conventional to alternative and renewable fuels for meeting its growing domestic demand. The under-development Barakah nuclear power plant will have an estimated installed capacity of 5600 MW once its four reactors will be finished (Power Technology, 2020). This will provide 25% of electricity energy in the country. Finally, Morocco has the NID value of 0.714 behind UAE. This can be attributed mainly to its category as a major importer of fossil fuels from abroad. However, the increasing contribution of renewables (mainly biofuels, wind, hydro, and solar) is growing steadily during the last decade ranging from 10 to 14%. The government is considering both renewable and nuclear power plants to play a major role into alleviating this dependency in the coming few years.

#### 4.1.3 Energy Intensity (EI)

The results regarding the EI in the MENA countries are shown in Table 6. They have been retrieved from IEA statistics, and they were checked by recalculating the ratio of TPES for each country on its GDP. The same results were found and validated. Countries like Israel and Palestinian territories (0.1 toe/2010 kUSD), Morocco (0.2 toe/2010 kUSD), Tunisia (0.2 toe/2010 kUSD), Lebanon (0.2 toe/2010 kUSD) and UAE (0.2 toe/2010 kUSD) are considered to have an average EI below or equal to the world average (0.2 toe/2010 kUSD), while countries like Bahrain (0.49 toe/2010 kUSD), Syria (0.48 toe/2010 kUSD) and Iran (0.47 toe/2010 kUSD) are considered as the major energy-intensive countries among the MENA countries. The average energy intensity of the MENA region has been continuously increasing from 0.27 toe/2010 kUSD in 2008 up to almost 0.3 toe/2010 kUSD in 2017.

**Table 6** The annual NID values for the MENA countries between 2008 and 2017

| Country | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|
| Morocco | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 |
| Algeria | 0,2 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 |
| Tunisia | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 |
| Libya | 0,2 | 0,2 | 0,3 | 0,6 | 0,3 | 0,3 | 0,5 | 0,4 | 0,4 | 0,3 |
| Egypt | 0,4 | 0,4 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 |
| Jordan | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 |
| Israel & Palestinian territories | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 |
| Lebanon | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 |
| Syria | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,5 | 0,6 | 0,6 | 0,7 |
| Bahrain | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,4 |
| Kuwait | 0,2 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,2 | 0,3 | 0,3 | 0,3 |
| Oman | 0,3 | 0,3 | 0,3 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,3 | 0,4 |
| Saudi Arabia | 0,3 | 0,3 | 0,4 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 |
| Qatar | 0,2 | 0,2 | 0,2 | 0,2 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 |
| UAE | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 |
| Iraq | 0,2 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 |
| Yemen | 0,3 | 0,3 | 0,3 | 0,3 | 0,2 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 |
| Iran | 0,5 | 0,4 | 0,4 | 0,4 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 |

Some regions like Europe or North America have already managed to decrease their energy intensity up to 0.1 toe/2010 kUSD during the last decade. This was achieved through the implementation of energy efficiency measures, the use of new technologies, the support for R&D activities, the raise of awareness for changing the consumption behaviors along with the diversification of economic sectors.

#### 4.1.4 Total Primary Energy Supply per capita (TPESpc)

The TPESpc in the MENA region is illustrated in Fig. 8. They have been obtained through IEA dataset, and they were checked and validated by recalculating the ratio of TPES for each country on its population size. The average TPESpc in the region has been declining from 4.2 toe/capita in 2008 to 3.87 in 2017, which seems at first as a good tendency. However, by analyzing the changing pathways for each country, we have noticed that this decline was due to political tensions that damaged the supply infrastructure in countries like Libya (from 2.8 toe/capita in 2008 to 2.1 toe/capita in 2017), Syria (from 1.1 toe/capita in 2008 to 0.5 toe/capita in 2017), Yemen (from 0.3 toe/capita in 2008 to 0.1 toe/capita in 2017) rather than betterment of energy efficiency like in Israel and Palestinian territories (from 3.1 toe/capita in 2008 to 2.6 toe/capita in 2017), Bahrain (from 11.3 toe/capita in 2008 to 9.4 toe/capita in 2017), or UAE (from 8.6 toe/capita in 2008 to 7.2 toe/capita in 2017). Namely 10 countries out of 18 have a TPESpc that is higher than the world average in 2017 (1.9 toe/capita). Apart from countries with political tensions, both Morocco and Tunisia have the lowest average TPESpc values of 0.57 toe/capita and 0.96 toe/capita. This is explained mainly by the absence of intensive industries in such countries compared to Golf countries and Iran, which are all above the average and they rely heavily on energy-consuming industries like petrochemicals. It is interesting to notice that Qatar has the highest TPESpc in the world (16.4 toe/capita) in 2017, compared to Yemen who had the lowest value in the world (0.1 toe/capita) at the same year.

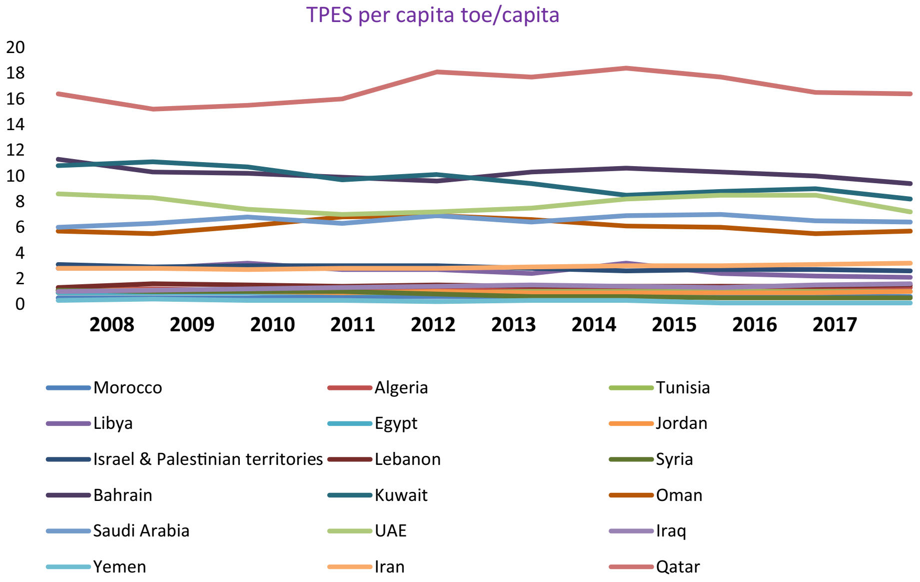


**Fig. 8** Growth of TPES per capita in the MENA countries between 2008 and 2017

#### 4.1.5 Electricity Use per capita (EUpc)

The EUpc in the MENA region is shown in Fig. 9. They have been obtained through IEA statistics and they were checked and validated by recalculating the ratio of electricity consumption for each country on its population size. It was found that in 2017, the average EUpc in the region (6 MWh/capita) is higher than the world's average (3.2 MWh/capita), and this value has increased continuously from 2008 (5.45 MWh/capita) compared to the world's average (2.8 MWh/capita). Countries like Bahrain (18.66 MWh/capita on average), Kuwait (15.79 MWh/capita on average), and Qatar (15.1 MWh/capita on average) are consuming a considerable amount of electricity compared to their population size due to their status as fossil importers relying on electricity-intensive industries. These countries are also having a high electrification ratio as we will see later. On the opposite, countries like Yemen (0.21 MWh/capita on average), Morocco (0.84 MWh/capita on average), and Iraq (1.15 MWh/capita on average) are having the lowest EUpc in the region. These countries have either some political conflicts that affected the electrification ratio and thus the access to the national grid (Yemen and Iraq), or they are not relying too much on electricity-intensive activities (Morocco). Energy efficiency measures are also leading to a moderate electricity consumption in many countries including addition of one hour in their local time or using efficient light bulbs among other schemes (Chentouf & Allouch, 2018).

#### 4.1.6 Gross Domestic Product per capita (GDPpc)

The GDPpc in the MENA region is shown in Table 7. The results have been obtained through World Bank dataset, and they were checked and validated by recalculating the ratio of GDP for each country on its population size. It was found that in 2017, the average GDPpc in the MENA countries has decreased from 18,178.11 USD/capita in 2008 to 15,081.44 USD/capita in 2017. However, the region is still considered to have a higher score than the world's average of 10,780.81 in the same year. It was that for 2017, many countries, especially in the Arab gulf region, are considered to be among the wealthiest nations in the world due to their fossil revenues including Qatar (72,459

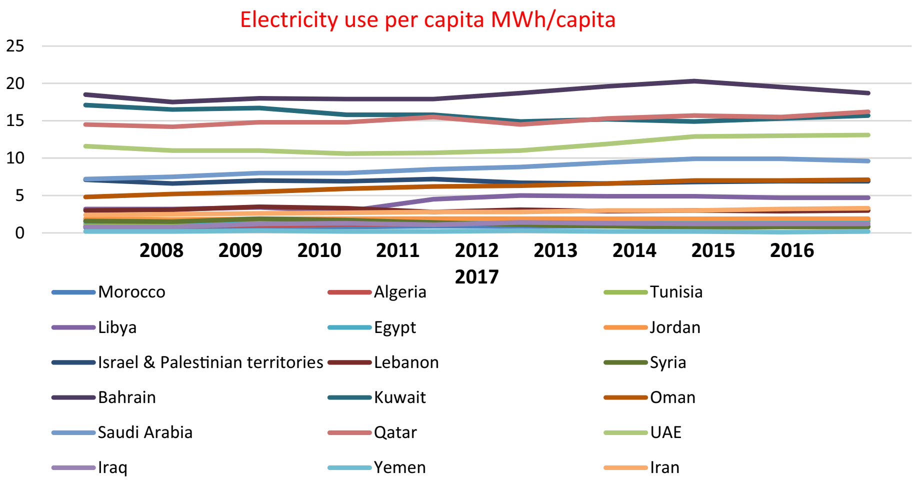


**Fig. 9** Evolution of electricity use per capita in the MENA countries between 2008 and 2017

**Table 7** Evolution of GDP per capita in the MENA countries between 2008 and 2017

| Country | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|
| Morocco | 2890 | 2866 | 2839 | 3046 | 2912 | 3121 | 3171 | 2875 | 2897 | 3036 |
| Algeria | 4923 | 3883 | 4480 | 5455 | 5592 | 5499 | 5493 | 4171 | 3946 | 4044 |
| Tunisia | 4307 | 4128 | 4141 | 4264 | 4152 | 4222 | 4305 | 3861 | 3698 | 3482 |
| Libya | 14,382 | 10,275 | 12,064 | 5554 | 13,025 | 10,363 | 6466 | 4337 | 4036 | 5756 |
| Egypt | 2044 | 2329 | 2644 | 2791 | 3232 | 3264 | 3378 | 3598 | 3525 | 2440 |
| Jordan | 3398 | 3504 | 3690 | 3816 | 3877 | 3998 | 4072 | 4105 | 4103 | 4162 |
| Israel & Palestinian territories | 29,567 | 27,715 | 30,693 | 33,669 | 32,511 | 36,309 | 37,678 | 35,776 | 37,321 | 40,541 |
| Lebanon | 6134 | 7371 | 7756 | 7703 | 7985 | 7923 | 7712 | 7649 | 7634 | 7838 |
| Syria | 2557 | 2557 | 2807 | 3192 | 3604 | 1379 | 1235 | 1061 | 709 | 890 |
| Bahrain | 23,066 | 19,355 | 20,722 | 22,514 | 23,654 | 24,744 | 24,989 | 22,688 | 22,619 | 23,715 |
| Kuwait | 55,494 | 37,561 | 38,577 | 48,618 | 51,978 | 49,388 | 44,062 | 29,869 | 27,653 | 26,759 |
| Oman | 22,139 | 16,823 | 19,281 | 20,896 | 21,923 | 20,926 | 20,131 | 16,150 | 14,721 | 15,130 |
| Saudi Arabia | 20,078 | 16,113 | 19,262 | 23,745 | 25,243 | 24,844 | 24,463 | 20,627 | 19,879 | 20,803 |
| Qatar | 80,234 | 59,094 | 67,403 | 82,409 | 85,076 | 85,050 | 83,858 | 63,039 | 57,163 | 61,264 |
| UAE | 44,498 | 32,024 | 33,893 | 39,194 | 40,976 | 42,412 | 43,751 | 38,663 | 38,141 | 39,811 |
| Iraq | 4636 | 3853 | 4657 | 6045 | 6836 | 7076 | 6818 | 4989 | 4776 | 5205 |
| Yemen | 1229 | 1116 | 1334 | 1374 | 1446 | 1607 | 1674 | 1608 | 1139 | 963 |
| Iran | 5630 | 5677 | 6603 | 7818 | 7927 | 6111 | 5608 | 4916 | 5265 | 5627 |

USD/capita), Kuwait (40,995.9 USD/capita), and UAE (39,336.3 USD/capita). On the other hands, some countries who were devastated by war are facing economic hurdles including both Yemen (1349 USD/capita) and Syria (1999.1 USD/capita).

### 4.1.7 Electrification Ratio (ER)

The ER in the MENA region is shown in Fig. 10. The results have been obtained through World Bank dataset. It was found that the average ER has been fluctuating between 2008 (95.4%) and 2017 (96.6%) due to many reasons. In fact, while electrification plans have led to increase the ER of some countries during this period (Morocco moved from 86.39% in 2008 to 100% in 2017), other countries have witnessed a great damage to their electrical grid due to political conflicts, which led to migration and postponed plans (Libya moved from 84.07% in 2008 to only 70.14% in 2017). As of 2017, only three countries were having an ER below 100% ranging from Libya (70.14%) to Yemen (79.2%) and then Syria (89.63%). It is expected that by fulfilling the ongoing plans for electrifying the population of these countries, MENA region will continue to be one of the highest electrified regions in the world since it is already ranked above the world's average. Moreover, the geographic position of this region presents favorable conditions for enhancing the existed regional electricity grids, which might increase furthermore security of supply and cooperation opportunities among the countries of this region.

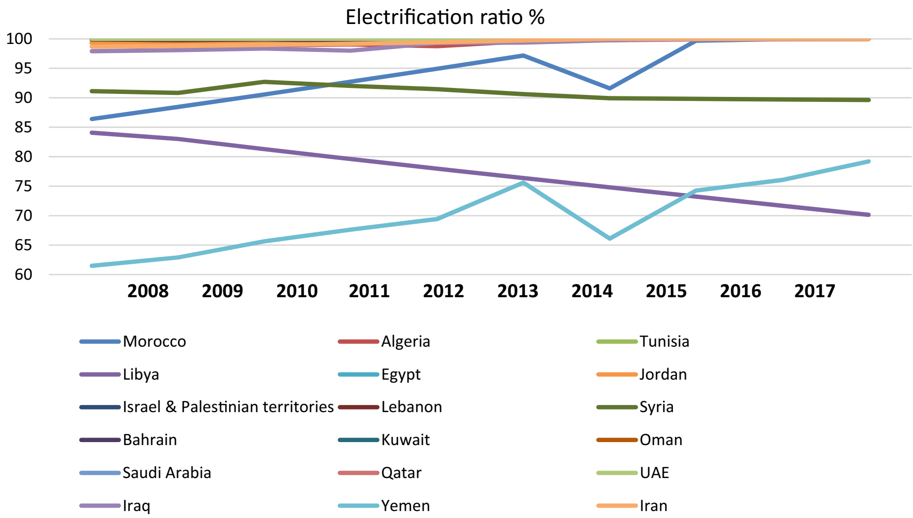


**Fig. 10** Evolution of electrification ratio in the MENA countries between 2008 and 2017

### 4.1.8 Carbon Intensity (CI)

The CI results in the MENA region are illustrated in Fig. 11. The results have been obtained through IEA dataset, and they were checked and validated by recalculating the ratio of carbon emissions on units of GDP. The general trend in the MENA countries shows a steady increase in the CI from 2008 (0.683 kg $CO_2$/2010 USD) up to 2017 (0.728 kg $CO_2$/2010 USD). Israel and Palestinian territories ranked as the least carbon-based economy with an average CI value of 0.26 kg $CO_2$/2010 USD due to the local commitments to cut $CO_2$ emissions from power plants, industrial activities, and transportation services. On the other

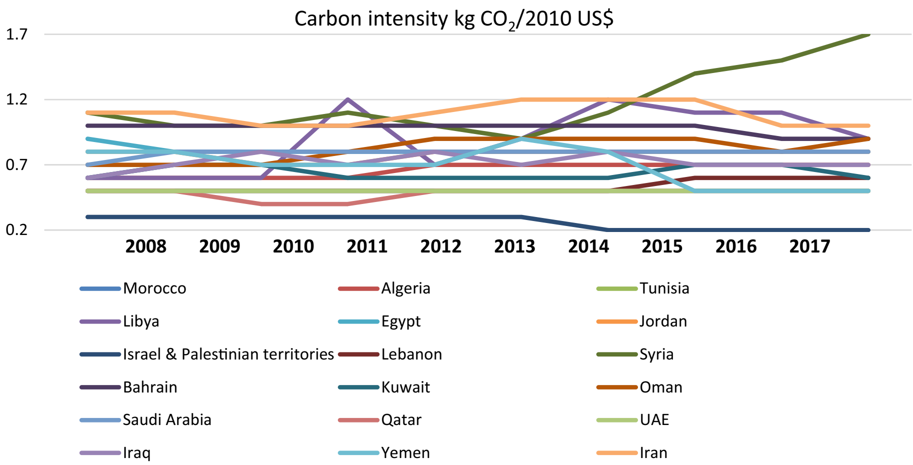


**Fig. 11** Evolution of carbon intensity in the MENA countries between 2008 and 2017

hands, Syria ranked as the most carbon-intensive nation in the region with an average CI value of 1.18 kg $CO_2$/2010 USD following its high reliance on fossil fuels for feeding its economy and its power plants taking into consideration its modest GDP.

#### 4.1.9 Carbon Emissions per capita (CE per capita)

The Cpc of the MENA countries is provided in Fig. 12. The results have been obtained through IEA dataset, and they were checked and validated by recalculating the ratio of carbon emissions on population size. The governmental commitments of many nations in this region have led to decrease the average carbon footprint of individuals from 9.728 $tCO_2$/capita in 2008 to 9.194 $tCO_2$/capita in 2017. However, 10 countries out of 18 have emitted more Cpc than the world's average (4.4 $tCO_2$/capita) in 2017. Furthermore, three small countries (but high fossil consumers and exporters) in the MENA region are ranked in top 5 per capita carbon emitters in the world including Qatar (an average Cpc of 31.67 $tCO_2$/capita), Bahrain (an average Cpc of 24.13 $tCO_2$/capita), and Kuwait (an average Cpc of 20.99 $tCO_2$/capita). On the other hands, Yemen ranked among the lowest per capita carbon emitters in the world with an average Cpc of 0.74 $tCO_2$/capita.

### 4.2 The environmental energy security index for the MENA countries

Table 8 illustrated the EESI for the MENA countries from 2008 to 2017. The resulted were obtained after normalizing, weighting, and aggregating the sub-indicators for each country and on an annual basis.

We have suggested a categorical scaling of the studied countries based on their overall average performance as it is shown in Table 9. The first category includes only Bahrain, which has the lowest EESI score (1.610) due to many reasons comprising its relatively high NID value (0.669), its major EI (0.49 toe/2010 kUSD), its high TPESpc (10.19 toe/capita), its major EUpc (18.66 MWh/capita), its important Cpc (0.98 kg $CO_2$/2010 USD), and its key CI (20.99 $tCO_2$/capita) all of which are considered as cost criteria (the higher they are, the worse the composite index score will be).

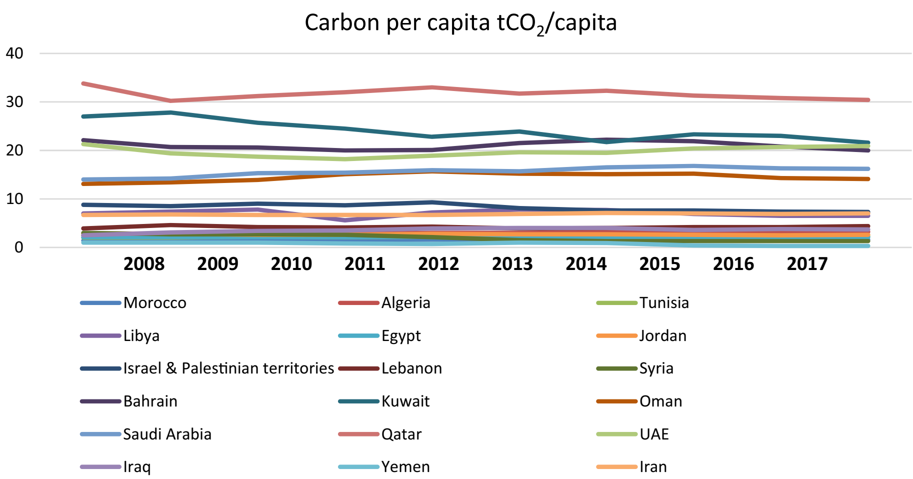


**Fig. 12** Evolution of carbon per capita in the MENA countries between 2008 and 2017

**Table 8** The ECI in the MENA countries between 2008 and 2017

| Country | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Morocco | 4,291 | 4,410 | 4,355 | 4,224 | 4,128 | 4,271 | 4,281 | 4,330 | 4,418 | 4,328 | 4,304 |
| Algeria | 4,637 | 4,328 | 4,340 | 4,204 | 3,850 | 3,860 | 3,974 | 3,889 | 3,903 | 3,883 | 4,087 |
| Tunisia | 3,980 | 4,074 | 3,910 | 3,992 | 3,921 | 3,928 | 3,932 | 4,040 | 3,980 | 3,829 | 3,959 |
| Libya | 3,474 | 3,374 | 3,174 | 2,610 | 2,961 | 2,673 | 2,321 | 2,473 | 2,454 | 2,661 | 2,817 |
| Egypt | 3,562 | 3,697 | 3,780 | 3,730 | 3,794 | 3,821 | 3,826 | 3,996 | 3,901 | 3,627 | 3,773 |
| Jordan | 2,889 | 3,013 | 3,086 | 3,013 | 2,941 | 3,059 | 3,044 | 3,298 | 3,349 | 3,188 | 3,088 |
| Israel & Palestinian territories | 3,408 | 3,523 | 3,491 | 3,541 | 3,400 | 3,679 | 4,016 | 4,117 | 4,109 | 4,064 | 3,735 |
| Lebanon | 2,923 | 2,902 | 2,989 | 2,986 | 3,020 | 3,102 | 3,013 | 3,061 | 3,019 | 2,903 | 2,992 |
| Syria | 3,068 | 3,252 | 3,245 | 3,286 | 3,757 | 3,473 | 3,369 | 3,339 | 3,154 | 3,063 | 3,301 |
| Bahrain | 1,562 | 1,588 | 1,582 | 1,591 | 1,597 | 1,587 | 1,584 | 1,636 | 1,674 | 1,696 | 1,610 |
| Kuwait | 5,888 | 2,565 | 2,338 | 2,483 | 2,614 | 2,722 | 2,777 | 2,563 | 2,462 | 2,458 | 2,887 |
| Oman | 2,780 | 2,641 | 2,571 | 2,474 | 2,466 | 2,340 | 2,605 | 2,611 | 2,633 | 2,530 | 2,565 |
| Saudi Arabia | 4,734 | 2,887 | 2,841 | 2,936 | 2,804 | 2,707 | 1,972 | 2,705 | 2,679 | 2,679 | 2,894 |
| Qatar | 2,526 | 2,518 | 2,628 | 2,901 | 4,160 | 1,786 | 2,649 | 1,520 | 1,469 | 2,458 | 2,461 |
| UAE | 2,151 | 2,211 | 2,219 | 2,222 | 2,246 | 2,281 | 2,339 | 2,324 | 2,293 | 2,199 | 2,249 |
| Iraq | 4,816 | 4,110 | 3,860 | 3,901 | 3,861 | 3,820 | 3,784 | 3,966 | 3,801 | 3,757 | 3,968 |
| Yemen | 3,609 | 4,164 | 4,505 | 4,691 | 5,298 | 4,475 | 4,796 | 7,043 | 7,667 | 6,947 | 5,319 |
| Iran | 2,784 | 2,920 | 3,010 | 3,107 | 3,206 | 3,062 | 3,020 | 3,026 | 3,077 | 3,040 | 3,025 |

**Table 9** The categories of MENA countries based on their average EESI

| Range | Category |
|---|---|
| $1 \leq x < 2$ | Poor |
| $2 \leq x < 3$ | Fair |
| $3 \leq x < 4$ | Good |
| $4 \leq x < 5$ | Very Good |
| $5 \leq x < 6$ | Excellent |

UAE (2.249), Qatar (2.461), Oman (2.565), Libya (2.817), Kuwait (2.887), Saudi Arabia (2.894) and Lebanon (2.992) are belonging to the second category. Qatar has the lowest average DESS (0.126), the highest average TPESpc (16.79 toe/capita), the thirdhighest average EUpc (15.1 MWh/capita), and the highest average Cpc (31.67 $tCO_2$/capita) among the MENA countries. UAE has the second-highest average NID (0.770) in the MENA countries, and its performance on different sub-indicators is quite moderate except for its GDPpc and its EI. Libya has the lowest 2017 ER (70.14%), and it is exhibiting similar patterns with other fossil exporters including Kuwait who had the third-lowest average NID (0.081) and the second-highest EUpc (15.79 MWh/capita) and Cpc (24.13 $tCO_2$/capita), Saudi Arabia who had the lowest average NID (0.058) and Oman. Lebanon has been always ranked around the average for both beneficial and cost criteria.

The third category comprises Iran (3.025), Jordan (3.088), Syria (3.301), Israel and Palestinian territories (3.735), Egypt (3.773), Tunisia (3.959), and Iraq (3.968). Each country is having some good scores at least in 3 to 4 out of total sub-indicators. For instance, Israel and Palestinian territories have both the best EI score (an average value of 0.1 toe/2010 kUSD) and the best CI value (an average value of 0.26 kg $CO_2$/2010 USD) among MENA countries.

Both Algeria (4.087) and Morocco (4.304) ranked in the fourth category, while Yemen (5.319) is the only country that belongs to the fifth category. Morocco has the second best EI score (an average value of 0.2 toe/2010 kUSD), CI performance (an average value of 0.5 kg $CO_2$/2010 USD), and Cpc value (an average value of 1.52 $tCO_2$/capita). Yemen has the best Cpc performance (an average value of 0.74 $CO_2$/capita), the lowest EUpc (an average value of 0.21 MWh/capita), and the lowest value of TPESpc (an average value of 0.24 toe/capita).

## 4.3 Robustness of the environmental energy security index for the MENA countries

In order to investigate the robustness of our composite index, we have decided to conduct uncertainty analysis by changing the allocated weight values for each sub-indicator in a given year (2008) and recalculate the index, while check the ranking on the MENA countries again. Instead of giving an equal weight for each sub-indicator, we have given a double weight each time for a single indicator while giving the others half of its weight. The results of our uncertainty analysis are shown in Table 10. We can notice that the average ranking did not change quite a lot although different sub-indicators are being amplified each time. This was in line with our initial assumption about the equal importance of each sub-indicator to assess the EESI in light of our theoretical framework.

The Pearson correlation coefficient was also calculated for different composite indexes in order to investigate the mutual relationship between each two sub-indicators along with ensuring the conducting of sensitivity analysis as another step to complement our uncertainty analysis. It is known that a high correlation coefficient value reflects a strong relationship between the two sub-indicators (variables). The results of our calculation are shown in Table 11, and they were calculated for the same year (2008) in order to be in consistence with the uncertainty analysis checking choice.

**Table 10** The effect of each sub-indicator on the ranking of the MENA countries. (Color figure online)

| Country | CI Eq | CI DESS | CI NID | CI EI | CI TPES | CI EPC | CI GDP | CI ELE | CI CI | CI CPC |
|---|---|---|---|---|---|---|---|---|---|---|
| Morocco | 5 | 5 | 6 | 5 | 2 | 3 | 6 | 5 | 5 | 3 |
| Algeria | 4 | 3 | 4 | 3 | 3 | 2 | 4 | 4 | 4 | 2 |
| Tunisia | 6 | 6 | 8 | 6 | 6 | 6 | 7 | 6 | 6 | 5 |
| Libya | 9 | 9 | 5 | 8 | 9 | 9 | 8 | 9 | 9 | 9 |
| Egypt | 8 | 7 | 7 | 10 | 8 | 8 | 11 | 7 | 10 | 8 |
| Jordan | 13 | 11 | 16 | 13 | 12 | 12 | 15 | 13 | 13 | 12 |
| Israel & Palestinian territories | 10 | 8 | 11 | 7 | 11 | 11 | 5 | 9 | 7 | 11 |
| Lebanon | 12 | 15 | 15 | 11 | 13 | 13 | 13 | 12 | 11 | 13 |
| Syria | 11 | 10 | 10 | 12 | 10 | 10 | 14 | 11 | 12 | 10 |
| Bahrain | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| Kuwait | 1 | 1 | 1 | 1 | 4 | 5 | 1 | 1 | 1 | 4 |
| Oman | 15 | 14 | 13 | 14 | 15 | 15 | 10 | 14 | 14 | 15 |
| Saudi Arabia | 3 | 2 | 2 | 4 | 7 | 7 | 2 | 3 | 3 | 7 |
| Qatar | 16 | 16 | 14 | 15 | 16 | 16 | 9 | 16 | 16 | 16 |
| UAE | 17 | 17 | 17 | 17 | 17 | 17 | 16 | 17 | 17 | 17 |
| Iraq | 2 | 4 | 3 | 2 | 1 | 1 | 3 | 2 | 2 | 1 |
| Yemen | 7 | 12 | 9 | 9 | 5 | 4 | 12 | 8 | 8 | 6 |
| Iran | 14 | 13 | 12 | 16 | 14 | 14 | 17 | 14 | 15 | 14 |

**Table 11** The Pearson correlation coefficients between different CIs

| | Eq | DESS | NID | EI | TPESpc | EUpc | GDPpc | ER | CI | Cpc |
|---|---|---|---|---|---|---|---|---|---|---|
| Eq | 1 | 0,804 | 0,631 | 0,723 | 0,784 | 0,824 | 0,642 | 0,777 | 0,723 | 0,768 |
| DESS | 0,804 | 1 | 0,624 | 0,507 | 0,704 | 0,759 | 0,683 | 0,772 | 0,506 | 0,648 |
| NID | 0,631 | 0,624 | 1 | 0,702 | 0,613 | 0,705 | 0,581 | 0,474 | 0,694 | 0,588 |
| EI | 0,723 | 0,507 | 0,702 | 1 | 0,658 | 0,680 | 0,526 | 0,518 | 0,992 | 0,649 |
| TPESpc | 0,784 | 0,704 | 0,613 | 0,658 | 1 | 0,874 | 0,572 | 0,661 | 0,677 | 0,991 |
| EUpc | 0,824 | 0,759 | 0,705 | 0,680 | 0,874 | 1 | 0,652 | 0,649 | 0,673 | 0,842 |
| GDPpc | 0,642 | 0,683 | 0,581 | 0,526 | 0,572 | 0,991 | 1 | 0,620 | 0,526 | 0,514 |
| ER | 0,777 | 0,772 | 0,474 | 0,518 | 0,661 | 0,652 | 0,620 | 1 | 0,517 | 0,646 |
| CI | 0,723 | 0,506 | 0,694 | 0,992 | 0,677 | 0,673 | 0,526 | 0,517 | 1 | 0,674 |
| Cpc | 0,768 | 0,648 | 0,588 | 0,649 | 0,991 | 0,842 | 0,514 | 0,646 | 0,674 | 1 |

## 5 Conclusion and Key Recommendations

This research work evaluated the level of energy security in the MENA countries based on an indicator approach. After reviewing the current situation of the energy sector in these countries, we have developed an aggregated index for assessing security of energy supply in terms of different attributes including diversification, dependency, accessibility, consumption behaviors, and environmental stewardship among others. The roles of renewable energies and energy efficiency were also given an implicit emphasis by depicting their contribution to enhancing energy security through the quantification of related sub-indicators. The paper has contributed to the literature by showing the effect of each attribute to the whole energy security in the region on an annual scale between 2008 and 2017. It was found that under equal weights for each sub-indicator, Yemen ranked first on average (5.319), followed by Morocco (4.304) and Algeria (4.087). Benefit-type criteria such as diversification, GDP per capita, and electrification ratio seem to have an important share in ranking most countries, while cost-type criteria on the opposite, such as energy dependency, energy intensity, and carbon intensity are decreasing the global score of the composite index. All of the fossil-rich countries are having poor performances regarding energy security including the last ranked countries, namely Bahrain (1.610), UAE (2.249) and Qatar (2.461). According to the criteria behind the global scoring, the main reasons for this ranking are due to (1) high reliance on local fossil fuels for answering the growing energy demand in fossil-rich economies, (2) intensive energy industries and consumption patterns due to available infrastructures and affordable costs, and (3) carbon-based economies and greenhouse gas emissions from the power industry and related activities.

The outcomes of our study suggest that in order to enhance energy security in the MENA region, these countries need to implement different strategies including (1) enhancing energy efficiency measures via technological innovation and awareness raise regarding consumption behaviors to achieve energy savings and avoid further dependency on energy imports, which generated budget deficits and geopolitical upheavals in many countries, (2) providing support schemes for renewable energies in order to facilitate their deployment within the total energy mix and thus achieve both a diversified energy portfolio along with a smooth transition toward a carbon-free energy sector, since renewables are considered so far to be the optimal solution for the military fragile situation (instead of nuclear power plants) and the vulnerable climate conditions in many countries, (3) promoting bilateral and regional cooperation through the reinforcement of electricity interconnection and know-how transfer while supporting R&D activities in the field of energy storage and technical exploitation of renewable potential in the region in order to cope with the intermittent nature of renewables while renewing depreciated plants, (4) creating new job opportunities in the energy sector while supporting academic programs for training and preparing local skilled personnel in this growing field, along with reducing poverty levels and energy precariousness by extending national grids and supporting independent power producers (IPPs), and (5) reforming legal and regulatory texts while creating institutional bodies that promote an integrated management of different projects while facilitating data collection and access along with exchange of experiences among different stakeholders from various backgrounds.

It should be noted that in our current globalized world, energy security issues must be addressed cooperatively more than any time before in order to create a sustainable system that can provide the growing energy needs without harming the environment. In fact, potential breakthroughs in battery storage technology, electric vehicles, and hydrogen energy (to name a few) are paving the way toward more partnerships between the MENA countries and the rest of the world since the major benefits of such policies and schemes can only be retrieved through collaborations that go beyond borders. A thorough analysis of the current global energy markets can provide us with some major trends that are reshaping the landscape of these markets worldwide. Hence, both the understanding and the adoption of effective strategies that are going to meet these trends are becoming more crucial for any country or region to face the complex future developments of energy markets while enhancing their resilience faced to potential threats.

Needless to say that despite the dominant historical role of the MENA countries into providing conventional fuels to many regions in the world and thus preserving the global energy security, the recent risks and sudden events (geopolitical concerns, techno-economic shifts, and the COVID-19 pandemic) put this role under test and thus invite the concerned countries to review their energy strategies and consider their recovery choices in the short and mid-terms. Options such as decentralization and digitalization of electricity, energy decarbonization, energy flexibility can provide major opportunities even for the MENA countries and also other countries in the world with a firm commitment to take part in this energy shift.

It must be noted that this research work can be extended by adding new sub-indicators to include other attributes of interest such as electricity price, geopolitical risks including supply perturbation and infrastructure damages, and finally market liquidity.

Our methodology can be used in other regions with similar conditions to the MENA countries in order to evaluate the level of energy security based on national trends and policies regarding the role of various attributes that we studied and analyzed above.

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