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The importance of considering resource availability restrictions in energy planning: What is the footprint of electricity generation in the Middle East and North Africa (MENA)?

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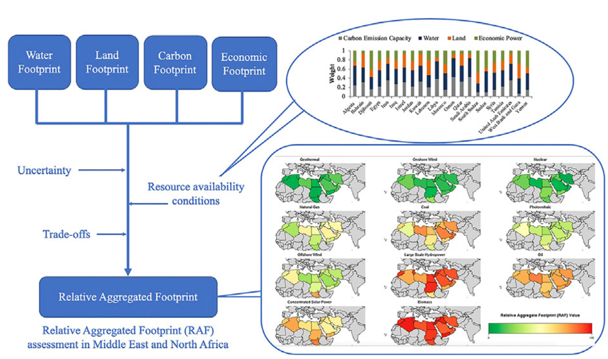
HIGHLIGHTS

- Regional resource availability affects the desirability of an energy technology.
- Some low-carbon technologies can lead to unsustainable outcomes.
- Unintended impacts on other valuable resources reduces desirability.
- Nuclear, geothermal and onshore wind are amongst the most desirable technologies across MENA.
- Hydropower and biomass are not desirable across the region.

GRAPHICAL ABSTRACT



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ABSTRACT

Global warming urges governments to decarbonise their energy portfolios. Many governments have indistinctly transited away from fossil fuels towards renewable energies. However, a sustainable turnaround calls for limiting the overall impact of this transition on environmental resources and the economy. This study identifies the most desirable energy alternatives for the Middle Eastern and North African (MENA) countries based on their environmental and economic footprints using the Relative Aggregate Footprint (RAF) indicator. The RAFs of eleven widespread electricity generation technologies are computed for each country by considering the availability of four resources – energy, water, land, and the economy – which were weighted according to the national resource availability conditions. The results indicate that the MENA region must adapt their electricity mix to mitigate the impacts of climate change with respect to resource availability conditions, especially their scarce water resources. Due to the specificities of this region, deploying biomass and large-scale hydropower may lower greenhouse gases but significantly alter the impact on other valuable natural resources. Therefore, wind, geothermal,

Abbreviations: AWEA, American Wind Energy Association; BAU, Business as Usual; CO_2, Carbon dioxide; COP, Conference of the Parties; CSP, Concentrated Solar Power; DNI, Direct Normal Irradiance; EIA, U.S. Energy Information Administration; EU, European Union; gCO2eq/kWh, Grams of carbon dioxide equivalent per kilowatt-hour; GDP, Gross Domestic Product; GHG, Green House Gas; GHI, Global Horizontal Irradiance; GJ, Gigajoule; GW, Gigawatt; GWh, Gigawatt hours; IEA, International Energy Agency; INDC, Intended Nationally Determined Contributions; IPCCI, Intergovernmental Panel on Climate Change; IRENA, International Renewable Energy Agency; kWh, kilowatt hour; MC-MCDM, Monte-Carlo Multi-Criteria Decision-Making; MCDM, Multi-Criteria Decision-Making; MENA, Middle East and North Africa; MW, Megawatt; MWh, Megawatt hour; NTI, Nuclear Threat Initiative; OECD, Organisation for Economic Co-operation and Development; PPP, Purchasing Power Parity; PV, Photovoltaic; RAF, Relative Aggregate Footprint; RCREEE, Regional Center for Renewable Energy and Energy Efficiency; TOPSIS, The Technique for Order of Preference by Similarity to Ideal Solution; TWh, Terawatt Hour; UAE, United Arab Emirates; UNFCCC, United Nations Framework Convention on Climate Change; USD, United States Dollar.

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and nuclear power plants seem more desirable for a transition away from carbon-intensive technologies while their secondary effects on other resources (e.g. nuclear energy's possible water and environmental impacts) must be carefully considered.

1. Introduction

The energy sector is responsible for a significant share of total carbon dioxide (CO_2) emissions, as it relies heavily on oil, natural gas and coal. The situation is set to worsen with the growing energy demand (EIA, 2016; Mirchi et al., 2012; Sorrell, 2015). The industry is expected to continue its significant contribution to environmental pollution and climate change (EIA, 2015; IPCC, 2011). These alarming risks and irreparable impacts (Camacho, 2009; Montgomery and Smith, 2000) push for transition to low-carbon energy portfolios (Bauen, 2006; Hadian, 2013; Helm, 2008; Schellnhuber et al., 2016). Decarbonizing the society with renewables is perceived as the immediate solution to such problems. However, policies focusing solely on carbon reductions can result in secondary environmental impacts and jeopardize sustainability goals (Hadian and Madani, 2015; Ristic et al., 2019).

Past energy deployments focused on implementing the cheapest energy sources. Affordability remains critical, but sustainable energy plans need to start accounting for other aspects (EIA, 2011). The trade-off between the cost of energy and its impacts on natural resources (Tang et al., 2015) have become crucial. For instance, failure to consider the water-energy nexus can result in competition over water (Gerbens-Leenes et al., 2008; Hadian and Madani, 2013; King et al., 2008; Madani and Khatami, 2015; Sanders, 2015; Stillwell et al., 2017), boost food prices, and decrease food security (Gerbens-Leenes and Hoekstra, 2011; Sanders and Masri, 2016; FAO, 2014). Similarly, land depletion can affect biodiversity, ecosystem productivity and water quality (Burkhard et al., 2012). Since the energy infrastructure induces long-term path-dependency, current decisions must consider such impacts. Neglecting the energy-water-land nexus and the economic dimension of managing energy can lead to poor policy-making and fabrication of contradictory strategies (Hadian et al., 2012; Howells et al., 2013; Madani et al., 2011).

The Middle East and North Africa (MENA) region deserves special attention as one of the world's most vulnerable regions to climate change (Jamali et al., 2013; Waha et al., 2017; World Bank, 2008), water, land and food scarcity (Shetty, 2006; Tropp et al., 2006; Zyadin, 2013). The local economy relies on oil and gas production as well as climate-sensitive agricultural activities. The regional economic hubs in MENA are also situated in coastal regions, vulnerable to sea level rise (World Bank, 2013). The region is likely to face serious social, economic and ecological impacts from global warming (World Bank, 2015), which can contribute significantly to energy uncertainty. Such issues are expected to aggregate in the near future (Alhanaee et al., 2017; Göll, 2017; World Bank, 2014a).

Appendix 1 Provides a brief overview of MENA countries' energy plans/actions and the global ranking of these counties in terms of their total CO_2 emission per year and per capita. Despite MENA's small share of global greenhouse gas (GHG) emissions, its contribution is significant relative to its size. The countries of this region lead the ranking of CO_2 emission per capita: With Qatar (1st), Kuwait (4th), the United Arab emirate (5th), Bahrain (7th), and Saudi Arabia (9th) being amongst the top 10 in the world. Iran (7th) and Saudi Arabia (8th) are among the top ten emitters of the world when their total annual CO_2 emissions are considered. While the oil and gas producing countries in the MENA region are generally ranked high with respect to their current CO_2 emission levels, they are not considered as historically responsible countries for global warming given their cumulative emissions since the industrial revolution. Nevertheless, their cutback on CO_2 and generally GHG emissions can contribute to climate change mitigation once combined with the efforts by other countries in the world.

MENA is amongst the regions with the lowest investment in renewable technologies. Renewables only generate around 4% of the total power in the region and hydropower accounts for 81% of that share (IEA, 2018). The abundance of low-cost fossil fuels in the region has impeded the penetration of renewable energies (IRENA, 2014; OECD, 2016). This has led to the lack of adequate renewable energy laws/initiatives, credible targets, and valid road-maps for sustainable energy policies. Nonetheless, MENA has enormous potential for renewable energies. Climatic and geographical conditions hold benefits for solar, wind (Davies et al., 2016), and geothermal energy generation (IRENA, 2014, 2012). Most of the region is positioned in the sunbelt, with global horizontal irradiance (GHI) of up to 2,600 $kWh/m^2/y$, and direct normal irradiance (DNI) of up to 2,800 $kWh/m^2/y$, creating a region with one of the most ideal conditions for solar energy in the world (Menichetti et al., 2018). Innovation could even boost their deployment by reducing costs and improving efficiency (Bryden et al., 2013; IRENA, 2014). The MENA countries have announced ambitious targets for the deployment of renewables, (see Appendix 1). Global political pressure, benefits of renewable energies, and awareness of the climate change challenges (Bryden et al., 2013) have triggered a change in the desirability of renewables, despite the fact that some governments may underrate the full potential of this type of energy in the region (Leal-Arcas et al., 2017).

In 2013, Saudi Arabia announced a target of 100% renewables in the coming decades (Creed and Kordvani, 2013), a target which was recently modified (Borgmann, 2016). The country is now aiming to source 4% of its energy demand from renewable resources by 2020, aiming for 9.5 GW of installed renewable capacity by 2023 (Borgmann, 2016; Griffiths, 2017). Saudi Arabia has also set a long-term goal of sourcing 54 GW of its installed capacity from renewables by 2040. More specifically, it aims to implement 41 GW of solar energy, 9 GW of wind, 3 GW of waste energy and 1 GW of geothermal (Erroukhi et al., 2016).

United Arab Emirates (UAE) has set a national government goal of 24% clean energy target by 2021 and to source 44% of its power generation capacity from renewables by 2050 (Griffiths, 2017). The information on the country's national targets for electricity generation from renewable resources is unclear. But, this country has determined targets for Abu Dhabi (7% by 2020) and Dubai (7% by 2020, 25% by 2030 (5 GW of which will come from solar (Erroukhi et al., 2016)) and 75% by 2050 (Griffiths, 2017)).

Iran has set a target to install 5 GW of renewable capacity by 2020, and an additional capacity of 2.5 GW by 2030. In 2016, Iranian Power Generation, Transmission, Distribution and Management Company (the 'TAVANIR'), projected that the country's renewable energy capacity will be able to attain 10% of the energy demand from renewables by 2021 (CMS, 2016).

Jordan has one of the highest dependencies on imported energy sources, with 97% of its energy need being delivered by foreign sources. The main focus of the country is producing 10% of its energy mix from renewables. The country has not specified its focus in terms of renewable resources (Abu Dyak et al., 2017); however, it has existing projects focusing on wind and solar for year 2020 (RCREEE, 2013).

Djibouti can reach its set target of 100% renewables by 2020, if it exploits its enormous renewable resources, mainly focusing on geothermal, wind and solar. But, around 55% of the country's population has no electricity access whilst approximately 65% of the nation's electricity demand is delivered by the Ethiopian grid (IRENA, 2015a,b).

Algeria is aiming to obtain 27% of its electricity from renewables, using photovoltaic (PV), wind, thermal solar energy and a combination of biomass, geothermal and cogeneration by 2030 (Ross and Damassa, 2015). Bahrain is aiming for 5% renewable electricity generation by 2020 (Erroukhi et al., 2016; Griffiths, 2017). Kuwait is aiming for 5% renewable energy by 2020 and 15% by 2030, expecting to generate 5.7 GW, 4.6 GW, and 0.7 GW of its energy from concentrated solar power (CSP), solar PV, and wind energies, respectively (Erroukhi et al., 2016). Egypt has the potential of sourcing 53% of its electricity mix from renewables by 2030 and is aiming to reach its full potential mainly by focusing on solar and wind while also exploring the potential of biomass energy (IRENA, 2018). Although Iraq has submitted its Intended Nationally Determined Contributions (INDC) prior to the 2015 United Nations Climate Change Conference (COP21), which reflects the country's intention to reduce GHG emissions, no data was found on the country's renewable targets and specified resources. Israel has set targets to increase its renewable electricity generation by 13% and 17% by 2025 and 2030, respectively. The exact sources and shares of renewables are not clear for this country, but solar, wind and biomass energies are among the top candidates (Israeli Ministry of Energy, 2018). Morocco has increased its renewable target to 52% by 2030, with a combination of solar, wind and hydropower (Wiseman, 2016). Oman is aiming for 10% renewable electricity by 2025 through solar, wind and waste energies (Oman Power and Water Procurement, 2018). Though Palestine (West Bank and Gaza) imports 100% and 87% of its fossil fuel and electricity, it has set a target to obtain 10% of its electricity generation from renewables by 2020 (Juaidi et al., 2016). Qatar has set a target to secure 2% of its electricity generation from renewables by 2020 (Griffiths, 2017) and 20% (1.8 GW) by 2030 (Erroukhi et al., 2016; Griffiths, 2017). South Sudan as the newest country in the world is also one of the least electrified countries. Reliable information on the country's renewable targets was unavailable (Mozersky and Kammen, 2018). Tunisia is aiming to provide 30% of its electricity using renewables by 2030, focusing on wind and solar (Climate Policy Observer, 2015). Yemen is aiming for 15% of its electricity grid to be sourced by renewables by 2025 focusing on wind and geothermal (UNFCCC, 2015e). Libya and Syria are among the world's few countries that did not submit their INDCs before COP21. However, both countries had set renewable targets previously. In 2013, Libya set a target to secure 7% and 10% of its energy from renewables by 2020 and 2025, respectively, by focusing on solar and wind (IEA, 2013). Syria had also set a target to obtain 4.3% of its primary energy demand from renewables (RCREEE, 2019).

While these ambitious renewable energy targets reflect some level of commitment to climate change mitigation, if decision makers indiscriminately deploy renewable technologies, they might promote unsustainable development. The benefits of renewable energy must be traded-off with its impacts on other resources such as water, land, and economy with respect to the national resource availability conditions (Ristic et al., 2019). Following Hadian and Madani (2015) and Ristic et al. (2019), the general objective of this paper was to highlight the possible unintended consequences of energy development plans that disregard: (1) the impacts of carbon reduction on other sectors; and (2) the variability in suitability of energy production options in different regions based on their resource availability conditions. In particular, this paper evaluated the relative footprint/desirability of various energy sources in the MENA, considering the climate-water-land-economy nexus and the varying resource availability conditions across this region of the world.

A previous study conducted by Hadian and Madani (2015) assessed the desirability of renewable energies by developing a method that considered the trade-offs of energy generation with life-cycle water and land use, GHG emissions, and economic cost. Ristic et al. (2019) extended their assessment method by incorporating resource availability conditions into the calculations to determine the regional desirability of energies for countries in the European Union (EU) with respect to resource availability constraints. Here, the Ristic et al.'s (2019) approach was used to identify desirable energy generation solutions across the MENA region with minimal undesirable secondary impacts with respect to the limitations of resource availability in different countries of the region.

This rest of the paper is structured as follows. The next section explains the method used in this study as well as the data collection procedure. Section 3 resents the results and discusses the policy implications of the results with respect to future energy development strategies in the MENA region. The last section concludes the study.

2. Method

2.1. Relative Aggregate Footprint (RAF)

RAF (Hadian and Madani, 2015) is an aggregate footprint indicator that is determined using a Monte-Carlo Multi-Criteria Decision-Making (MC-MCDM) approach (Mokhtari, 2013; Mokhtari et al., 2012) that uses a range of MCDM methods. Here, the RAF values of eleven different energy generation sources/technologies were calculated considering four impact/footprint indicators, namely cost, land, water and carbon footprints as proposed by Hadian and Madani (2015). The values of these indicators were compiled through literature review on lifecycle analysis of electricity generation in a previous study by Ristic et al. (2019). Table 1 provides the range and the median values of the indicators considered in this investigation.

The ranges in values of each impact indicator reflect uncertainty. MC-MCDM (Mokhtari, 2013; Mokhtari et al., 2012) is appropriate for determining the ranks of alternatives with uncertain performance ranges. Based on the procedure described in Read et al. (2017), performance values of each alternative under each four indicators were selected from Table 1 in 100,000 rounds of Monte-Carlo selection. To ensure there is consistency between the studies and assumptions made, following Ristic et al. (2019), a lognormal distribution was used for Monte-Carlo sampling, unless the median was close to the mean or was unavailable when a truncated normal distribution was used. When the median diverges by more than 25% from the mean, a truncated lognormal distribution can help reduce biases on skewed distributions compared to a uniform distribution used by Hadian and Madani (2015). In each round of Monte-Carlo selection, five MCDM methods, namely Maximin (Wald, 1945), Lexicographic (Tversky, 1969), TOPSIS (Yoon and Hwang, 1995), Simple Additive Weighting (Churchman and Ackoff, 1954) and Dominance (Fishburn, 1964) were used to rank the electricity generation technologies according to their randomly selected performance values. Given the differences between basic rationales of multi-criteria analysis methods

Table 1
Performance of different energy sources under the four life-cycle indicators considered in this study (adapted from Ristic et al. (2019)).

Energy source type	Carbon footprint (gCO2eq/kWh)			Water footprint (m^3/GJ)			Land footprint (m^2/GWh)			Cost (USD_{2010}/MWh)		
	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
Biomass	130	230	420	20.0000	–	64.0000	1443	–	21,800	77	150	320
Concentrated Solar Power	9	27	63	0.1180	–	2.1800	340	–	680	150	200	310
Solar Photovoltaic	18	48	180	0.0064	–	0.3030	704	–	1760	84	160	210
Onshore Wind	7	11	56	0.0002	–	0.0012	2168	–	2640	51	84	160
Offshore Wind	8	12	35	0.0002	–	0.0012	2168	–	2640	110	170	250
Large-scale Hydropower	1	24	2200	0.3000	–	850.0000	538	–	3068	9	35	150
Coal	740	820	910	0.0790	–	2.1000	83	–	567	30	78	120
Oil	657	–	866	0.2140	–	1.1900	1490	–	-	85	–	224
Natural Gas	410	490	650	0.0760	–	1.2400	623	–	–	34	79	150
Nuclear	4	12	110	0.0180	–	1.4500	63	–	93	45	99	150
Geothermal	6	38	79	0.0073	–	0.7590	33	–	463	18	89	190

and the subjectivity of the optimality notion, each MCDM method might provide different rankings of alternatives, even with the same set of input values (Madani et al., 2014; Read et al., 2014). So, the RAF index was then used as a relative aggregation technique (Read et al., 2017) to establish the overall relative desirability of energy technologies with respect to each other under various impact indicators and performance uncertainties. This index has been defined as (Hadian and Madani, 2015):

$$RAF_i = 100\left[1 - \left(\frac{C.N - B_i}{N(C-1)}\right)\right]$$

where C is the number of technologies, N is the number of optimality notions and B_i is the sum of individual ranks given to technology i by each MCDM approach, i.e. Borda score of technology i. RAF is an impact aggregation index presented in a range of values between 0 and 100. The higher the RAF value, the higher the aggregated footprint and the lower the corresponding desirability of the energy alternative. RAF scores of 0 would portray the ultimate best alternative (i.e. ranked first by all MCDM methods), whilst an RAF of 100 would indicate the ultimate worse energy alternative (i.e. ranked last by all MCDM methods). For the more in-depth mathematical description of each MCDM methods and the Monte-Carlo MCDM process, readers are referred to Madani et al. (2014) and Read et al. (2017).

2.2. Setting criteria weights

Initially, equal importance (weight) were assumed for all criteria to compute the RAFs as previously proposed by Hadian and Madani (2015). Based on Ristic et al. (2019), weights were then assigned to each indicator with respect to resource availability/limit in each country and the country's corresponding positions in global rankings. The available land area per capita (World Bank, 2017a, 2017b), freshwater withdrawals as a share of renewable water resources (FAO, 2016), GDP with purchasing power parity (PPP) (World Bank, 2017c), and carbon emissions per capita (World Bank, 2014b) were used as proxies for resource availability or depleting conditions of each country. For each indicator, the worldwide national values were divided into 5 groups, one per each 20th percentile. Each group was assigned a score between 1 (large resource availability) to 5 (low resource availability). The higher the ratio of freshwater withdrawal or the carbon emissions per capita, the higher the score of the criteria and the greater the associated weight of that criteria. Whilst, conversely the higher the GDP per capita or available land per capita, the lower the score and the lower the weight of that criteria. Finally, the weight was normalized with the sum of the four national scores.

3. Results and discussion

3.1. Relative aggregate footprints (case of equally weighted criteria)

Fig. 1 shows the RAF of the considered technologies when the performance indicators were given equal priority. No technology performed as an absolute best or worse option. Fig. 1 compares the RAF values calculated by Hadian and Madani (2015) with those of Ristic et al. (2019). The difference in the values is due to the updates in the performance values of the energies based on the

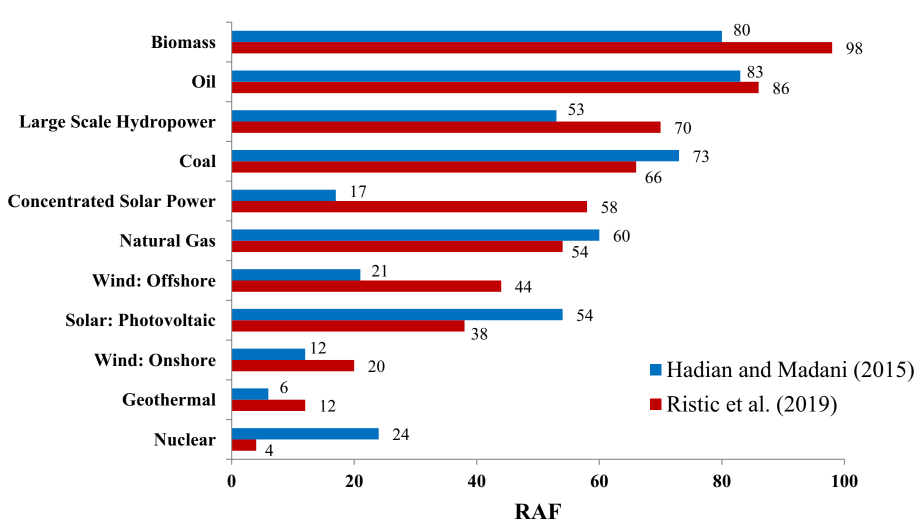

Fig. 1. The RAF of energy technologies under equal criteria weightings based on Hadian and Madani (2015) and Ristic et al. (2019).

most recent literature as well as the difference in the considered probability distributions.

Fig. 1 implies that renewable and non-renewable technologies can be both desirable or undesirable, no matter how large their carbon footprint is. This is because the MCDM approach used here considers the energy production impacts on several systems (not only climate). Therefore, damage on water, land or the economy can outweigh carbon reduction benefits. Generally, the results of Ristic et al. (2019) are in line with Hadian and Madani (2015) despite the changes in indicator values and probability distributions. However, some differences are seen across the RAF values of technologies. The positions of Solar Photovoltaic (PV) and Concentrated Solar Power (CSP) have switched. Solar PV is more desirable in the more recent study due to decrease of PV module prices, whilst CSP has lost its appeal due to significant increase in costs and water footprint in the updated indicator values. Large hydropower's significantly higher water footprint and carbon emission in the Ristic et al.'s (2019) study resulted in a significant increase in its RAF value.

Generally, biomass suffers from large water and land footprints despite a much lower carbon emission than coal, oil, and natural gas. While large hydropower is generally believed to be a clean energy, its desirability is outperformed by coal and natural gas when its secondary impacts on other resources (mainly water and land) are considered. Natural gas has a medium overall performance and the best performance amongst fossil fuels. It could represent a good alternative during the decarbonisation process and transition to higher share of renewables in energy supply portfolios rather than further investments in an energy like hydropower that is not an easy irreversible option given its long-lasting infrastructure. CSP is not yet mature, which may explain its updated RAF value. The high rate of innovation in this technology may improve its desirability in the future. It can be argued that investing in this alternative could boost research, and in turn its RAF score. Offshore wind (updated RAF = 44) is behind onshore (updated RAF = 20) in terms of its desirability. The main reason behind, their significant RAF difference is the higher cost of installation and maintenance of wind turbines in the sea. Finally, geothermal, and nuclear lead the updated ranking. Nuclear has the lowest RAF with a lower land footprint and carbon emissions, however it suffers from medium water footprint and relatively high cost. The more recent calculations of Ristic et al. (2019) identified nuclear energy as the most desirable technology in contrast to geothermal in Hadian and Madani's study (2015). Geothermal had a lower cost, however, more importantly the uniform distribution considered in the earlier study disadvantaged nuclear power. This was mainly because the median carbon footprint was too high. This change underlines the relevance of the advanced approach of Ristic et al. (2019) that was used here.

3.2. Resource availability impacts on indicator weighting

The availability of resources, affects the desirability of a technology. Thus, an optimal-impact energy option in one country might be sub-optimal in another with different resource availability conditions. Fig. 2 demonstrates the calculated criteria weights for the MENA countries. The variability of weights reflects the resource availability variability across the region and underlines the importance of considering local resource availability conditions in energy planning. For example, Djibouti's low rate of water use to water availability delegates a lower associated weight for water footprint. This means that the country is more open to a water intensive technology in its energy mix in comparison to a country like Sudan which is faced with severe water scarcity and assigns a higher weight to its water footprint.

Fig. 3 visualises the weight distribution of each indicator across the MENA region using a box plot. Water claims the highest median (0.36) amongst all indicators (land = 0.21, carbon = 0.23 and cost = 0.21), as well as the highest upper (0.37) and lower interquartile (0.33). Water footprint also has the largest number of highest associated weights in the region, i.e., 19 out of 22 countries have assigned their highest criteria weight to water footprint. This demonstrates the importance of water and the intensity of water scarcity the region is facing. Given this limitation, the region as a whole should deter to rely on water–intensive energy generation technologies. Carbon footprint demonstrates the second highest upper quartile (0.33) and median value (0.23), as the region is home to some of the highest per capita greenhouse emitting countries of the world. Thus, decarbonisation remains an important aspect in developing a low impact and sustainable electricity mix in the MENA region in addition to water use considerations. Next, land and economic power follow with equal importance since they have the same median (0.21). Land has a lower maximum (0.33) and a higher minimum (0.08) weight compared to cost (max = 0.47 and min = 0.06). Economic power presents the largest range among the four indicators in the region. This is due to the known variability of economic power across the MENA region.

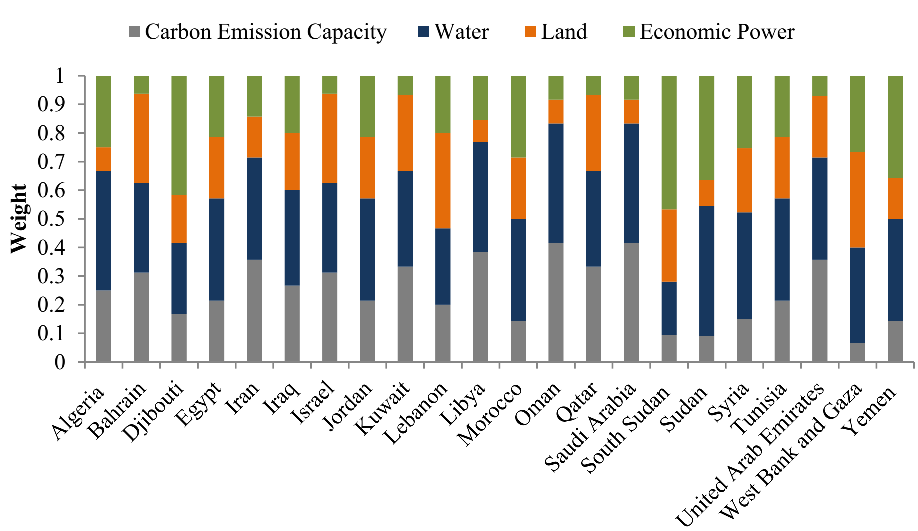

Fig. 2. The calculated weights of the four energy indicators for each MENA country.

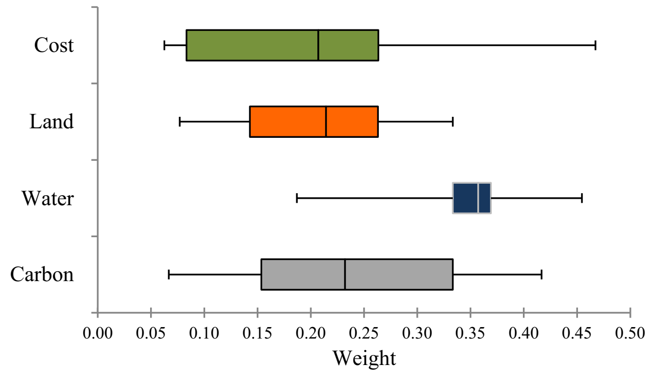

Fig. 3. Box-plots showing the distribution of weights across the MENA region.

3.3. Relative aggregate footprints (case of unequally weighted criteria)

Fig. 4 maps the RAF of each energy alternative for the MENA countries. The desirability of an energy technology, defined as the opposite of its RAF (Hadian and Madani, 2015), increases from red (highest RAF) to green (lowest RAF). Fig. 5 illustrates the RAFs of all energy alternatives across MENA. The differences in resource availability amongst the countries leads to variances in desirability and RAF of each energy technology across the region, reflecting the importance of taking regional resource availability conditions in the sustainability assessment of energy alternatives and local decision making.

Here, the RAF/desirability of different energy options across MENA has been calculated regardless of their technical feasibility. In the MENA region as a whole, onshore wind and geothermal become more desirable than nuclear because of their lower water footprints. In fact, nuclear is highly sensitive to cost and water criteria combinations, therefore its RAF fluctuates across the MENA countries. The wealthiest countries can afford to take on this higher associated cost to lower emissions and further impacts on their land. Despite of this, nuclear is still amongst the highly desirable energy technologies in the region.

Regardless of the high desirability of nuclear, this energy has a very low deployment across the region. Iran is the only country in MENA that has already developed nuclear energy production capacity. Middle East's first nuclear power plant came online in Iran in 2011, with 1 GW of capacity, responsible for producing 5.9 kWh of electricity on an annual basis. Iran is currently constructing an additional 1.8 GW of nuclear capacity (EIA, 2018a). United Arab Emirates (UAE) is due to complete the construction of a nuclear power plant with an anticipated capacity of 4.1 GW, by 2020. UAE has already constructed 1 unit of nuclear power plant in 2017 which was expected to begin its electricity production by mid-2018 (EIA, 2018a), however this has now been delayed (Langton, 2018). Saudi Arabia is expected to commence the construction of its first nuclear power plant (2 GW capacity) by 2021. Jordan has also put forward plans to install 2 GW of nuclear capacity, expecting to begin construction in 2019. Egypt has already submitted plans and it is in the phase of developing regulatory and legal infrastructure. Morocco, Algeria and Israel are currently forming nuclear energy development plans (EIA, 2018a). Though it is widely believed that Israel has already acquired nuclear weapons, there are no official records of such activities and Israel has maintained a policy of opacity (NTI, 2017). Countries such as Qatar, Syria, Tunisia and Sudan have demonstrated interest

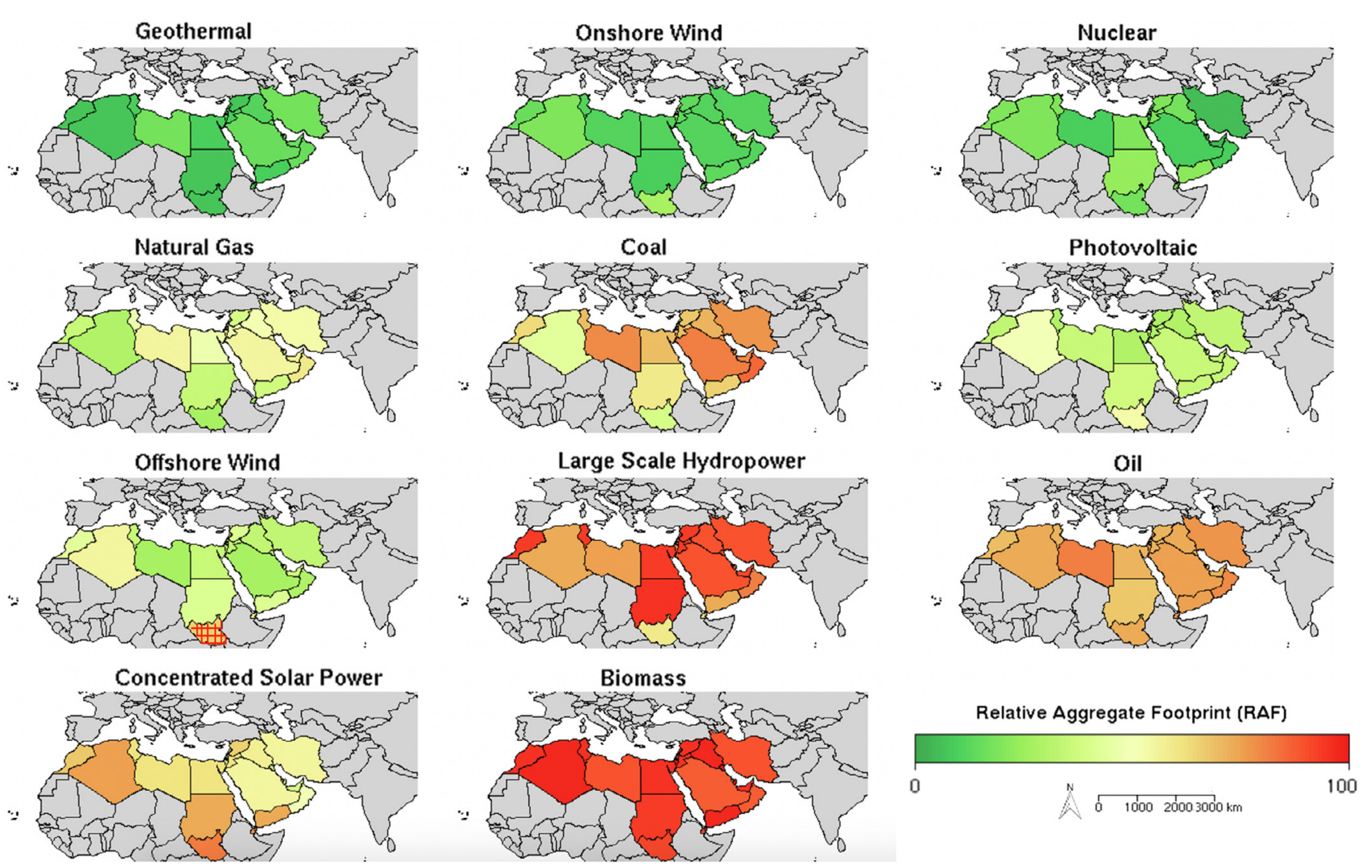

Fig. 4. RAF of energy options in MENA countries. Off-shore wind is considered infeasible for South Sudan (shaded in red) due to lack of access to the sea/ocean.

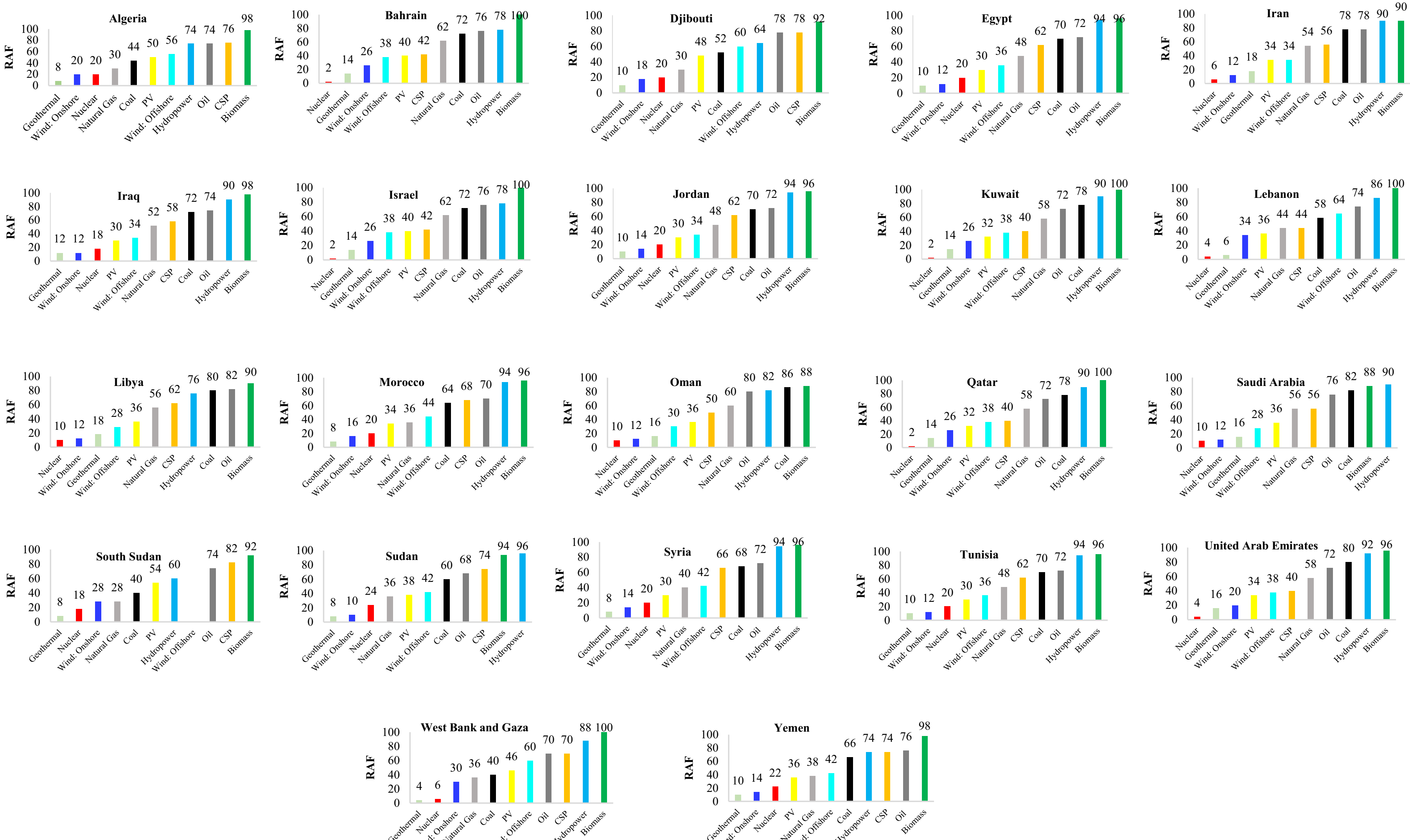

Fig. 5. RAF of energy options in MENA countries. Hydropower refers to large-scale hydropower, PV represents solar photovoltaic, and CSP denotes concentrated solar power. Off-shore wind is considered infeasible for South Sudan due to lack of access to the sea/ocean.

and are discussing policy options (World Nuclear Association, 2018a) before initiating plans. The rest of the region, however, has not showed any interest on nuclear energy production.

MENA has experienced high-level of political conflicts and major security issues. It is worth mentioning that the lack of trust of the global community towards the misuse of nuclear resources by the countries of the region acts as one of the major obstacles to the development of nuclear energy technology in the region, as has been witnessed in the case of Iran. On the other hand, the associated public perception of the safety risks (which has been exacerbated following Fukushima's nuclear accident in 2011), combined with the management issue of nuclear waste and decommissioning, represent the main drawbacks of this energy alternative (World Nuclear Association, 2018b). Thus, in addition to overcoming the technical and socio-political barriers to the implementation of nuclear energy, the MENA countries must pay serious attention to safety risks and public perception issues should they decide to develop this type of energy.

The relatively high cost of offshore wind and PV compared to other non-renewable alternatives in the region lowers their desirability for the oil-/gas-rich MENA countries. Onshore wind performs better due to its lower economic burden. Whilst offshore wind's need for supporting foundation, submarine cables, vessels and equipment increases its cost in comparison to that on land (Bilgili et al., 2011). In a country where cost is strongly weighted, onshore wind is a more desirable option. However, issue of feasibility is not considered here. For a country like South Sudan offshore wind has medium desirability (Fig. 5) but it is not feasible due to lack of access to sea or ocean.

Wind's other major obstacle is its significant land footprint (Table 1). However, researchers have argued that wind's large land footprint is a false assumption, and in fact wind has one of the lowest land disturbances amongst renewable energies. Typically 98% of wind farms lands are left undisturbed, and free to be used for other purposes such as farming or ranching (AWEA, 2019). Others argue that its adverse impacts is not just restricted to land use, habitats for wildlife, fish and plants can potentially be degraded, while collision with the turbines threaten flying wildlife such as bats or birds (U.S. Department of Energy, 2019). In addition, wind energy can be responsible for noise pollution (in particularly associated with land), and to a minor extent visual interference (Saidur et al., 2011). It is argued that offshore wind can be more advantageous due to mitigation of the noise and obstruction by the distance away from land, higher wind speeds across open water because of lower surface roughness of water compared to land, and lower turbulence which increases energy efficiency (Bilgili et al., 2011). This highlights the need to study and consider local characteristics and conditions before the implementation of wind into national portfolios.

When land limitations are the main concern, PV becomes a more attractive alternative in comparison to wind. Solar energy has an enormous potential in the MENA region, yet this source is hardly exploited. PV's main drawback is its cost, which can be reduced further through research and development of this technology (Al-Saqlawi et al., 2018). On the other hand, CSP's desirability varies across the region due to resource availability variations. CSP's relatively high costs combined with its medium water footprint affect the desirability of this energy option. Since most of the region suffers from water scarcity, CSP is one of the least desirable renewable alternatives. The CSP industry is still in its initial commercialisation revelation in most countries (Yang et al., 2018). Further investment in CSP's technology advancement can lower its life-cycle costs, making it more desirable in MENA where the presence of cloud or haze is not continuous and the solar energy generation potential is high (Stauffer, 2015; Tsikalakis et al., 2011).

Geothermal is highly desirable across MENA but it is not widely deployed except for in the Palestinian territories with an installed capacity of 0.023 MW (Bryden et al., 2013). Iran's first unit of turbine (5 MW) is currently under installation with plans to bring it online very soon (Noorollahi et al., 2019). The MENA region has an estimated annual generation potential of 232.8 TWh of electricity, with the highest potentials in Algeria, Egypt, Iran, Morocco, Saudi Arabia, Tunisia, and Yemen (Farhani, 2013). Resource availability limits do not justify this low rate of deployment. Thus, in countries where this energy alternative is feasible, to make this source commercially available, energy policies would need to foster geological knowledge as well as regulatory and political support (El-Husseini et al., 2010).

Coal and oil both suffer from high carbon emissions and medium water footprint, the two most heavily weighted criteria of the region. Thus, these energy sources must be theoretically undesirable from the sustainability standpoint. This is not the case in practice, however, due to the lower cost of fossil resources, which is still the main driver of energy policies in the region. Whilst coal is more sensitive to water, oil has a higher land footprint and costs. The only countries currently integrating coal in their energy mix include Morocco, Israel and Iran, with 55%, 36% and 0.17% shares in their portfolios respectively (IEA, 2018). Generally coal has a lower capacity in comparison to oil and natural gas (EIA, 2018b). Except for Qatar, all other countries across MENA have oil implemented into their energy mix, with the highest individual shares coming from South Sudan, Lebanon, and Iraq, with 99%, 98% and 70%, respectively (IEA, 2018). Oil is amongst the most undesirable energy alternatives across the region (Fig. 5), which illustrate the need for careful assessment and consideration for future shares of this alternative if a more sustainable outcome is to be achieved.

The reason behind the popularity of fossil fuel resources across MENA, particularly in case of oil, is their abundance. Approximately 52% of the global proven oil reserves is accommodated by the MENA region. Saudi Arabia, Iraq and Iran, contain 16%, 9% and 9% of the global oil reserves respectively. In 2016, MENA was responsible for around 38% of the global oil production. Regardless of the oil supply disruptions experienced due to political issues, such as the Arab uprising in 2010 and sanctions on Iran, crude oil production has experienced uninterrupted growth. Thus, the abundance of oil, its lower water use in comparison to some renewables such as biomass, CSP and large-scale hydropower, and its lower associated costs, make this energy highly enviable and popular across the region.

Natural gas represents the most desirable fossil energy option, making it even more attractive than some renewable energies. Since MENA can rely on existing abundant and reliant fossil fuel infrastructures (Bridle et al., 2014), natural gas can represent an interesting alternative during the transition to a low-carbon future. It could replace coal and oil in the short-term to reduce emissions, contrary to wind and solar, which may require further research and development for an improved performance and competing costs. Given the high rate of GHG emissions in the region and the continued interest in using fossil resources, carbon capture and storage is an option to consider with the potential to increase the desirability of conventional energy sources such as oil, coal, and natural gas by reducing their emissions rate.

Large scale hydropower has a general low desirability across the region and the leading factor for this is its significant land and water footprints, combined with the severe water scarcity issue of the region (Bryden et al., 2013). However, currently, hydropower dominates MENA's renewable energy generation (81%) in the region (IEA, 2018). The popularity of this water-/land-intensive alternative is ironic given the geopolitical issues of water management in MENA. The low economic burden of hydroelectricity together with the general interest of the region in dam building in the last decades have made this option quite popular. While some MENA countries aim to further develop hydropower as a 'clean energy' option, the results here show that hydropower is not a desirable and 'green' option in this region. Recent studies also show that GHG emissions from hydropower reservoirs can be larger than previously anticipated. This challenges the common belief that hydropower is a low carbon technology (Barros et al., 2011; Beaulieu et al., 2014; Deemer et al., 2016; Graham-Rowe, 2005; Magill, 2014; Räsänen et al., 2018; Scherer and Pfister, 2016), making this energy option less desirable in a region with an already high rate of carbon emissions. Given that some of the countries with the highest emissions per capita are located in MENA, hydropower's desirability significantly drops across the region.

It is important to note that this study only considers large-scale hydropower due to lack of data on small-scale hydropower. This could have a significant impact on the results. Small-scale hydropower may be more reliable and environmentally friendly due to lower evaporation rates and land use. One must also note that large reservoirs used for hydroelectricity generation normally provide other services such as water storage and flood control. Such services are normally not properly considered in calculating the footprints of hydropower which consider reservoirs only as hydropower generation facilities.

Some technologies (geothermal, biomass and oil) have a stable high/low desirability all over the region. Biomass is unattractive everywhere mainly due to its large land and water footprints. It competes with the agriculture sector, affects the surrounding environment, and can emit more carbon than anticipated (El-Husseini et al., 2010). Although biomass only represents 0.38% of renewable technologies in MENA, several rural areas still depend on this source of energy. Algeria, Jordan, Qatar, and the UAE plan to deploy small-scale biomass electricity plants (Bryden et al., 2013). Based on the results, biomass is ranked as the ultimate worst (strictly dominated) alternative (RAF = 100) for 7 out of the 22 MENA countries, and is highly undesirable in all 22 countries (RAF $\geq$88). Given the fact that fossil fuels outperform biomass in MENA, further expansion of the share of biomass across the region should be properly investigated to limit its undesirable impacts. Nonetheless, second generation bioenergy demonstrate lower footprints for the sustainability indicators considered and could be a suitable alternative for decarbonisation pathways (Mathioudakis et al., 2017).

Overall, the analysis results demonstrate that the current energy mix of MENA is not in line with the desirability patterns portrayed in Figs. 4 and 5. Currently, hydropower dominates MENA's renewable energy generation (81.4%) followed by wind and solar PV, CSP, biofuel and other sources which constitute only 11.3%, 5.8%, 1.2%, 0.26% and 0.04% of MENA's renewable portfolio, respectively. The most desirable technologies such as geothermal, nuclear, and onshore wind are underrepresented in the region whilst conventional resources and large-scale hydropower, some of the most undesirable technologies with the highest emissions and water intensity, are amongst the popular options.

4. Conclusions

The current energy portfolio of MENA is heavily dependent on fossil fuels. This highly contributes to its GHG emissions while worsening the effects of climate change and extending the impacts of conventional energy generation on natural resources and the environment. The shift to renewable technologies has been slow in the region due to abundance of fossil fuels and the relatively low weight of environmental considerations in the public policy making agenda in the region. Although the need to transition to low-carbon technologies has been recognised, ambiguity remains around the sustainability of various renewable and low-carbon energy alternatives. The current energy mix of the region not only fails to contribute or address climate change mitigation, but also fails to consider its impact on other natural resources.

This model underlined the fact that it is fundamental to consider the complex relationship of the energy system with other systems such as land, water, climate, and economy. The study demonstrated the benefit of using the RAF index in developing a robust assessment that satisfies varying notions of optimality in multiple criteria assessment. Through consideration of technology performance uncertainty and local availabilities of resources, the adopted analysis approach provided a multi-dimensional appraisal framework to determine the desirability of various energy alternatives across MENA. The study results can be used to draw provisional conclusions on the desirability of energy alternative based on additional burden exerted on natural resources and the economy. This approach can facilitate the development of sustainable energy pathways to address the rapidly growing energy demand and alarming issue of energy security in MENA with minimum impacts on valuable natural resources. The applied model simply aims to draw attention to the need to consider the involvement of numerous systems that impact and are impacted by energy production through a multi-criteria life-cycle appraisal framework, highlighting its potential contribution to sustainable energy planning. This model does not provide a conclusive decarbonisation pathway to a more sustainable future or the best energy mix for each country. The model is merely an input framework for policymakers and only attempts to draw attention at the early stages of decision making to the possible unintended consequences of energy selection.

The study demonstrates that based on a multi-dimensional lifecycle perspective, some energy sources such as large-scale hydropower and biomass that have been perceived as 'clean' options are not desirable in the MENA region. Because of their intensive land and water footprint, which have been largely disregarded by the decision makers in the region, these energy options are outperformed by conventional fossil fuels such as coal, oil, and natural gas. The performance variance among technologies when resource availabilities were considered, reflected the need for careful local energy supply development planning and decision making that considers regional targets and limitations.

Like any other modelling exercise, this study has certain limitations that must be considered when interpreting its results. Nevertheless, these limitations do not undermine the need for more holistic and sustainable assessment of electricity technologies with respect to trade-offs and uncertainties as was done in this study. In general, this study did not consider the technological, physical, legal, operational, and institutional feasibility of different energy options in the region, neither did it consider the issues of security, regulation, social acceptance, and supply-demand gap which can jeopardize the implementation of different energy technologies. A wider range of indicators can be implemented into the analysis model to include such factors. This would develop a more reliable assessment of the sustainability and practicality of various energy technologies at national or sub-national scales. While the most recent data on technology performance was used, this data was selected from a global performance range, thus, failing to include the local conditions that could impact the variability of energy technology performances under different criteria in each country. The study did not consider the possible changes in technology performances over time through means such as learning effects, technologic improvements, or increased capacity of deployment.

Appendix 1. A brief overview of the energy sector in MENA countries.

Country	Renewable energy share target	By	Selected renewable technologies	Reference	Additional information	Specified strategies, actions and targets (Carbon Brief, 2015; UNFCCC, 2015a)	Ratified the Paris Agreement, Year of rectification (Climate Analytics, 2018; United Nations, 2019)	Global ranking based on CO_2 emissions per year (2017) (Global Carbon Atlas, 2017)	Global ranking based on CO_2 emissions per capita per year (2017) (Global Carbon Atlas, 2017)
Algeria	27% renewable electricity production	2030	• Photovoltaic • Wind • Thermal solar energy • Combination of biomass, geothermal and cogeneration	(Ross and Damassa, 2015)	–	• Cut down GHG emissions by 7–22% relative to a Business As Usual (BAU) scenario by 2030	Yes, 2016	35	96
Bahrain	5% renewable electricity generation	2020		(Erroukhi et al., 2016; Griffiths, 2017)	–	• Subsidize "low GHG emission development", diversify the economy and reduce share of fossil fuels • Expand renewables: 5MW Photovoltaic (PV) and 5MW solar/wind grid-connected plant	Yes, 2016	76	7
Djibouti	Reach 60% electrification across the country 100% renewable electricity 87%–100% of renewable energy	2015 2020 2035	• Geothermal • wind • solar • Interconnecting with the Ethiopian grid, which is based on hydropower	(IEA, 2016a; IRENA, 2015a)	• Around 55% of population do not have access to electricity • Approximately 65% of electricity demand is delivered by the Ethiopian grid (IRENA, 2015b)	• Cut down GHG by 40% relative to a BAU scenario by 2030 • Conditional pledge to cut down emission by additional 20%	Yes, 2016	168	161
Egypt	20% renewable electricity 42% of renewable electricity mix	2022 2035	• Solar • Wind • Biomass	(IRENA, 2018)	• Potential to source 53% of its electricity mix from renewables by 2030. This can be achieved by focusing on solar and wind and exploring the potential of biomass energy (IRENA, 2018)	• Cut down GHG emissions of the electricity sector by improving energy efficiency and implementation of nuclear and renewable sources for power generation • Phase out energy subsidies within 3-5 years • Seeking $73bn international support	Yes, 2017	27	120
Iran	Instalment of 5 GW renewable capacity Additional capacity of 2.5 GW 10% of the country's energy demand	2020 2030 2021	Unspecified renewable source	(CMS, 2016)	–	• Cut down GHG by 4% relative to a BAU scenario by 2030, conditional based on ending sanctions • 12% conditional reduction based on $35bn of international support and end to sanctions • Implement renewables, nuclear, and combined cycle power plants • Increase energy efficiency, substitute carbon-intensive fuels with natural gas • Economic diversification	No	7	43
Iraq	*	*	*		• No data was found on the country's renewable targets and specified resources in its Intended Nationally Determined Contributions (INDC).	Cut down GHG by 15% relative to a BAU scenario by 2035, of which 2% will be conditional, the remaining 13% can be obtained by unconditional targets (CTCN, 2015)**.	No	32	75
Israel	10% renewable energy 13% renewable electricity generation 17% renewable electricity generation	2020 2025 2030	Unspecified renewable source	(UNFCCC, 2015b) (Israeli Ministry of Energy, 2018) (Israeli Ministry of Energy, 2018;	• The exact sources and shares of renewables are not clear for this country.	• Cut down GHG emission per capita to 7.7 tCO2e (26% below 2005 levels) by 2030 • Interim reduction target of 8.8 tCO2e emission per capita by 2025	Yes, 2016	50	48

A brief overview of the energy sector in MENA countries. (*continued*)

Country	Renewable energy share target	By	Selected renewable technologies	Reference	Additional information	Specified strategies, actions and targets (Carbon Brief, 2015; UNFCCC, 2015a)	Ratified the Paris Agreement, Year of rectification (Climate Analytics, 2018; United Nations, 2019)	Global ranking based on CO_2 emissions per year (2017) (Global Carbon Atlas, 2017)	Global ranking based on CO_2 emissions per capita per year (2017) (Global Carbon Atlas, 2017)
				UNFCCC, 2015b)	• Solar, wind and biomass energies are among the popular candidates (Israeli Ministry of Energy, 2018).	• Increase energy efficiency by decreasing 17% of electricity consumption compared to BAU by 2030 • 17% of renewable electricity			
Jordan	Increase renewable energy to 10% 11% of renewable energy share in the total energy mix	2020 2025	Unspecified renewable source	(UNFCCC, 2015c)	• Jordan has one of the highest dependencies on imported energy sources. • 97% of its energy are delivered by foreign sources. • The country has not specified its focus in terms of renewable resources (Abu Dyak et al., 2017). • It has existing projects focusing on wind and solar for year 2020 (RCREEE, 2013).	• Cut down GHG emission by 14% relative to BAU by 2030, where 1.5% is conditional and the remining 12.5% is dependent on international support of approximately $5bn • Improve energy efficiency to 20% by 2020"	Yes, 2016	83	121
Kuwait	5% renewable energy 15% electricity generation	2020 2030	Unspecified renewable source • 5.7 GW of CPS • 4.6 GW of Solar Photovoltaic • 700 GW of wind energy	(Erroukhi et al., 2016) (Erroukhi et al., 2016; Griffiths, 2017)	–	• Avoid an increase in GHG emission above BAU by 2035 conditioned on international support • Transition to a low-carbon economy	Yes, 2018	40	4
Lebanon	12% of energy demand	2020	• 2.06% of wind • 4.20% of PV, CPS and solar water heaters • 3.24% of hydropower • 2.50% of biomass	(IEA, 2016b; MoE and UNDP, 2015)	–	• Cut down GHG by 15% relative to BAU by 2030 (unconditional) • Conditional reduction of 30% GHG • 15% of power and heat is produced by renewables by 2030 (20% with international support) • Improve energy efficiency to achieve 3% decrease in power demand in 2030 relative to BAU	No	88	103
Libya	7% of renewable electricity 10% of renewable electricity	2020 2025	• 0.6 GW of wind, • 0.15 GW of CSP • 0.3 GW of solar PV • 0.25 GW of solar water heating • 1 GW of wind, • 0.4 GW of CSP • 0.8 GW of solar PV • 0.45 GW solar water heat	(IEA, 2013)	–	Intended Nationally Determined Contributions (INDC) not submitted	No	58	40
Morocco	42 % of the installed electrical power from renewable sources (UNFCCC, 2015a) 52% of installed electricity production capacity by renewables	2020 2030	• Solar (14%) • Wind (14%) • Hydraulic (14%) • Solar • Wind • Hydropower	(Wiseman, 2016)	–	• Cut down GHG by 13% relative to BAU (unconditional) by 2030 • Cut down GHG by 32% (conditional) by 2030 through financial support • Over 50% installed electricity capacity by 2025 from renewables • Cut down 15% of energy consumption by 2030 • Additional capacity of combined Cycle (3.9 GW) that uses natural gas	Yes, 2016	54	135

(*continued on next page*)

A brief overview of the energy sector in MENA countries. (*continued*)

Country	Renewable energy share target	By	Selected renewable technologies	Reference	Additional information	Specified strategies, actions and targets (Carbon Brief, 2015; UNFCCC, 2015a)	Ratified the Paris Agreement, Year of rectification (Climate Analytics, 2018; United Nations, 2019)	Global ranking based on CO_2 emissions per year (2017) (Global Carbon Atlas, 2017)	Global ranking based on CO_2 emissions per capita per year (2017) (Global Carbon Atlas, 2017)
Oman	10% renewable electricity generation	2025	• Solar, • Wind • Waste-to-Energy	(Oman Power and Water Procurement, 2018)	–	• Maintain the projected GHG emissions increase by 2% from 2020 – 2030 • Decrease in gas flaring • Increase share of renewables • Increase the energy efficiency	No	51	17
Palestine (West Bank and Gaza Strip)	10% renewable electricity generation	2020	Unspecified renewable source	(Juaidi et al., 2016).	• Palestine (West Bank and Gaza) imports 100% and 87% of its fossil fuel and electricity (Juaidi et al., 2016).	*	Yes, 2016	149	178
Qatar	2% electricity generation 20% (1.8 GW) of generation	2020 2030	Unspecified renewable source Solar PV	(Griffiths, 2017) (Erroukhi et al., 2016; Griffiths, 2017)	–	• Economic diversification • Utilize clean energy and renewable sources such as solar and wind power to bring down emissions (no target for reduction of emission is set)	Yes, 2017	36	1
Saudi Arabia	4% of its energy demand 9.5 GW 54 GW of its installed capacity	2020 2023 2040	Unspecified Renewable Energy • 41 GW of solar energy • 9 GW of Wind • 3 GW from waste • 1 GW from Geothermal	(Borgmann, 2016; Griffiths, 2017) (Borgmann, 2016; Griffiths, 2017) (Erroukhi et al., 2016)	• In 2013, Saudi Arabia announced a target of making its energy supply mix 100% renewable in the coming decades (Creed and Kordvani, 2013). This target was then modified (Borgmann, 2016) to what is illustrated by this table.	• Increase investment in renewables • Economic diversification • Improve energy efficiency and implement carbon capture • Saving 130 million tonnes of CO_2 by 2030 relative to BAU	Yes, 2016	8	9
South Sudan	*	*	*		• South Sudan is one of the least electrified countries in the world. • Reliable information on this newly established country's renewable targets were unavailable (Mozersky and Kammen, 2018).	• Increase share of clean energy • Increase hydropower, solar and wind • Increase biomass efficiency • Increase efficiency of electricity use • Plant 20 million trees • Pledge on \$50bn of international support	No	153	200
Sudan	20% renewable energy in the power system	2030	• Wind energy: 1 GW • Solar PV energy: 1 GW • Solar CSP technology: 0.1 GW • Waste to Energy: 0.08 GW • Biomass Potential: 0.08 GW • Geothermal Potential: 0.3 GW • Small Hydro Plants: 0.05 GW	(UNFCCC, 2015d)	–	• Increase share of renewable by 20% in the power sector • Increase forest area by 25% by 2030 • Pledge on international support	Yes, 2017	90	179
Syria	4.3% of primary energy demand	2030	Unspecified renewable source	(RCREEE, 2019)	–	INDC not submitted	Yes, 2017	79	140

A brief overview of the energy sector in MENA countries. (*continued*)

Country	Renewable energy share target	By	Selected renewable technologies	Reference	Additional information	Specified strategies, actions and targets (Carbon Brief, 2015; UNFCCC, 2015a)	Ratified the Paris Agreement, Year of rectification (Climate Analytics, 2018; United Nations, 2019)	Global ranking based on CO_2 emissions per year (2017) (Global Carbon Atlas, 2017)	Global ranking based on CO_2 emissions per capita per year (2017) (Global Carbon Atlas, 2017)
Tunisia	14% renewable electricity production 30% renewable electricity	2020 2030	Installed renewable energy capacity of 3.815 GW in 2030 • 1.755 GW for wind power • 1.610 GWfor PV • 0.450 GW for (CSP)	(Climate Policy Observer, 2015)	–	• Cut down 41% of its GHG emission across all sectors by 2030 to decrease carbon intensity compared to 2010 levels • 13% of this reduction is unconditional while the rest depends on international support (approximately $20bn)	Yes, 2017	78	113
United Arab Emirates	24% clean energy	2021	Unspecified renewable source	(Erroukhi et al., 2016)	• The information on the country's national targets for electricity generation from renewable resources is unclear.	• Limit emissions • Expand clean energy to 24% by 2021 • No national targets have been set for electricity generation	Yes, 2016	26	5
	44% of its power generation capacity from renewable resource	2050	Unspecified renewable source	(Griffiths, 2017)					
	Abu Dhabi 7% of electricity generation	2020	Unspecified renewable source	(Erroukhi et al., 2016)					
	Dubai 7% of electricity generation	2020	Unspecified renewable source	(Erroukhi et al., 2016)					
	Dubai 25% of electricity generation	2030	5 GW: Solar	(Erroukhi et al., 2016)					
	Dubai 75% of electricity generation	2050	Unspecified Renewable Energy	(Griffiths, 2017)					
Yemen	15% of grid large-scale electricity generation mix (2600 GWh)	2025	• 0.4 GW from wind farms • 0.160 GW from geothermal power stations • 0.006 GW from power stations using landfill gas	(UNFCCC, 2015e)	–	• Unconditional reduction of GHG emission of 1% by 2030 relative to BAU projections • Conditional reduction of 14% of GHG by 2030 based on international support • Conditional pledge can lead to 15% increase in renewables by 2025 in the power sector	No	89	162

*No reliable data was found.
**Information is obtained from source different from to the rest of the column.

It is important to note that this analysis was limited to electricity generation and did not include the issues associated with operations such as the intermittence availability of wind and solar energies (Gaudard and Madani, 2019; Guittet et al., 2016). In addition, the inclusion of a wider energy systems and grid models, as well as the scale and portfolio reliability consideration of technologies could provide useful practical energy planning insights. This study is limited in the number and type of energy alternative it has considered. For example, alternative such as biomass and solar PV can be further distinguished into different types of available technologies. However, lack of data availability led to selection of technologies which are broadly classified as popular alternatives and extensively considered across the literature. Addressing these limitations in future studies will improve the desirability assessment of each energy alternative with respect to deployment capacity (Clack et al., 2017).

This study concludes that there is no one technology that can be considered as the ultimate solution to climate change in all countries. The sustainable answer to issues of climate change and energy security cannot be one technology but rather a mix of technologies. Ignoring local conditions could lead to the endorsement and implementation of unsuitable technologies that will lead to unintended consequences for the region. As MENA possesses a large potential of unexploited renewable energy (OECD, 2013), decision makers can diversify their energy supplies while limiting the secondary impacts (Hadian and Madani, 2014). Not only can this secure a sustainable energy supply but it would also minimize the risk of energy insecurity through a diversified energy portfolio that spreads the risk across a range of energy sources. This was not implemented in this study, but future studies can include portfolio assessments to determine the optimal energy mix of a region by considering its resource availability. Future research can also develop recommendations and policies for adoption of appropriate pathways for each country in accordance to their national decarbonisation agenda or climate target.

Declaration of Competing Interest

The authors have no conflict of interest to declare in relation to this publication

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